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INVESTIGATIONS RELATING TO CIRRUS CLOUD

By D. G. JAMES, Ph.D.

Summary.—Some 200 reports by aircraft observers on the presence or absence of cirrus cloud have been analysed. Some statistical relationships between the occurrence or non-occurrence of cirrus cloud and synoptic variables are shown to be significant, in particular a large proportion of the reports of extensive cirrus sheets is associated with advection of cyclonic vorticity at 300 mb. About 30 observations were of cirrus cloud in the stratosphere.

Introduction.—This paper analyses cirrus cloud observations which were made by Royal Air Force aircraft between August 1952 and December 1954. Reports were also obtained from aircraft of the Meteorological Research Flight based at Farnborough, and were made during their routine high-level ascents. It was hoped that any ascent to cirrus levels by aircraft from these stations would yield a report of "cirrus observed" or "no cirrus observed", but in the early stages of the investigation a certain reluctance was shown to make a report of the latter type.

In order to facilitate simple analysis of the reports, the reporting stations were issued with forms which were so designed that an observer was only required to tick whether cirrus cloud had been observed, and if so to give the distribution and type of the cloud, and the heights and temperatures of bases and tops. Amplifying remarks were also invited.

Altogether about 220 reports for 180 separate days were available for analysis. The majority of these cases were reports of the presence or absence of cirrus cloud at a particular place, though several were reports made on long-distance flights, sometimes as far as North Africa. There were approximately twice as many reports of cirrus observed as no cirrus observed, but it was thought that sufficient observations had been obtained to permit a statistical examination of the reports.

Although a request was made that visibility in and through cirrus cloud should be reported, very few such estimates were made, and no statistical analysis was possible.

Analysis of observations.—Murgatroyd and Goldsmith[1] made an analysis of cirrus cloud observations obtained from routine high-level ascents by aircraft of the Meteorological Research Flight, and also from several selected synoptic reporting stations. With the greater number of observations available for the present investigation, it was thought worth while re-working some of the histograms presented in the earlier paper.

Fig. 1 shows the distribution of observations of the tops of cirrus cloud relative to the tropopause. It can been seen that a maximum occurs between 2,000 ft. and 4,000 ft. below the tropopause, and that rather more than 50 per cent. of the observations of cirrus tops occur from the tropopause down to 6,000 ft. below. Altogether 29 observations were made of cloud in the stratosphere. Of these latter, 10 were more than 6,000 ft. above the tropopause, the greatest reported height (estimated) being 20,000 ft. above. The occurrence of a maximum just below the tropopause is consistent with the results presented by Murgatroyd and Goldsmith, although a peak of more than 50 per cent. was found by those authors to be from 0 to 2,000 ft. below the tropopause.

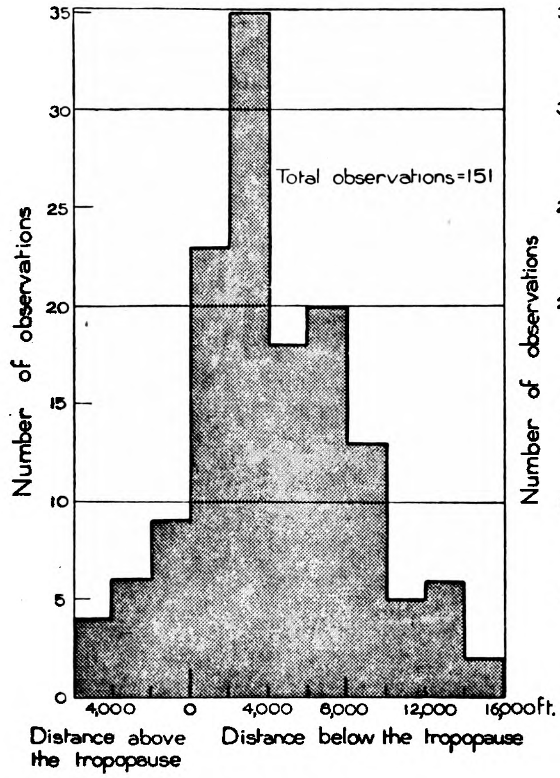


FIG. 1—DISTRIBUTION OF CIRRUS TOPS RELATIVE TO THE TROPOPAUSE

10 observations were from 6,000 to 20,000 ft.

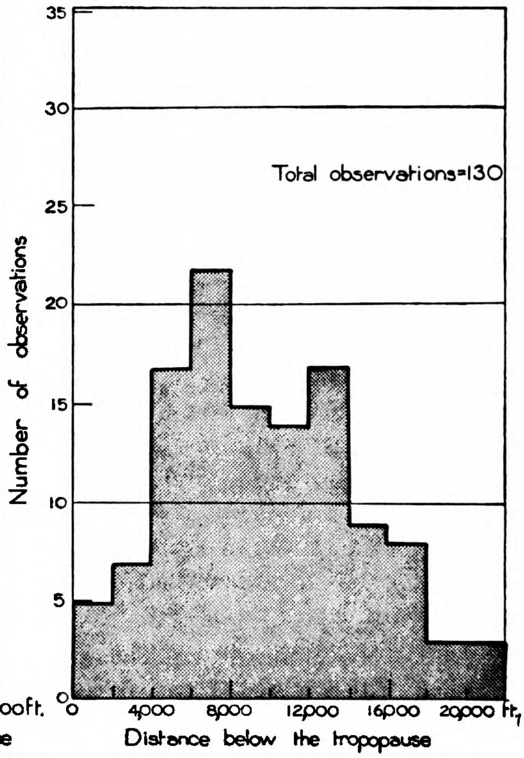


FIG. 2—DISTRIBUTION OF CIRRUS BASES RELATIVE TO THE TROPOPAUSE

10 observations were above the tropopause

Fig. 2 presents a histogram of the frequency distribution of the distance of bases of the cirrus clouds below the tropopause. No well marked peak is evident, but more than 50 per cent. of the observations give a cloud base between 4,000 ft. and 12,000 ft. below the tropopause.

The frequency distribution of the heights of cirrus cloud bases is shown in Fig. 3, where maxima are evident at about 20,000 ft., 25,000 ft. and 30,000 ft. It was thought that these maxima may well be due to a preference for estimating and reporting heights to the nearest 5,000 ft., though a maximum was also obtained by Murgatroyd and Goldsmith between 25,000 and 30,000 ft. Ten cases were reported when the base of the observed cirrus was above 40,000 ft.

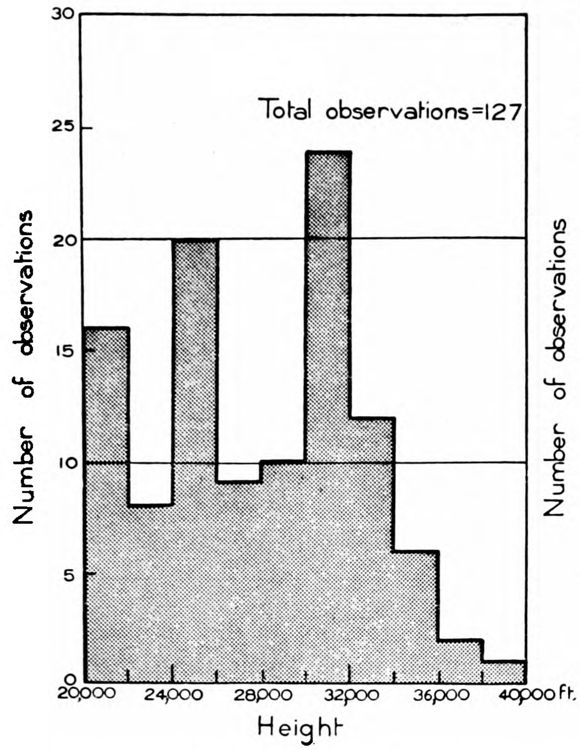


FIG. 3—DISTRIBUTION OF HEIGHTS OF CIRRUS BASES

9 observations were < 20,000 ft.
10 observations were > 40,000 ft.

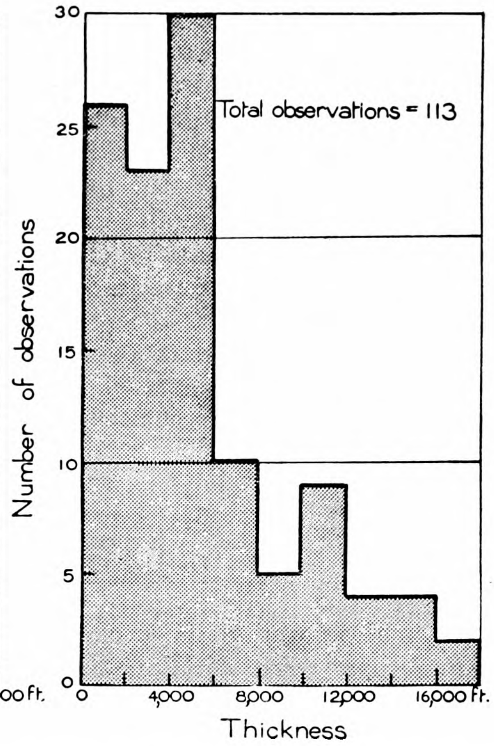


FIG. 4—DISTRIBUTION OF CLOUD THICKNESS

Fig. 4 presents the frequency distribution of the thicknesses of cirrus cloud. About 70 per cent. of the cirrus reported had thicknesses in the range from a few hundred feet to 6,000 ft., though thicknesses of up to 17,000 ft. were reported.

Analysis of surface charts.—It is well known that cirrus cloud is frequently observed in association with a frontal boundary between air masses. However, it is equally apparent from analysis of surface synoptic charts that extensive cirrus cloud is observed in situations other than those exhibiting surface frontal features. Examination of the distances of points of observation of the cirrus cloud from surface fronts showed that about half of the cirrus reports lay from 0 to 200 miles ahead of a surface front, while less than a tenth of the no cirrus reports lay in this range. However, there were more than one quarter of the cirrus reports which could not be associated with any well marked surface front.

Similarly, analysis of the distances of the points of observation from surface-pressure maxima and minima indicated that rather more than half of the no cirrus reports, and rather less than a third of the cirrus reports, occurred in association with a ridge or high-pressure centre.

Although the above analysis seems to indicate that extensive cirrus cloud is more commonly found in association with well marked fronts and isobaric troughs than elsewhere, this is already common knowledge among forecasters, and makes no additional contribution to the cirrus-forecasting problem.

Analysis of upper air soundings.—The occurrence of cirrus cloud is undoubtedly associated with moist air in the upper troposphere. Since humidity observations are not normally available at these heights, an examination was made of the dew-point depressions at 500, 450 and 400 mb. in the hope that a significant increase in humidity might be apparent below the usual cirrus levels. Table I presents the mean depressions of the dew-point at 500, 450 and 400 mb. and the significance levels of the differences between the means for occasions of cirrus and no cirrus. It can be seen that at all three levels the differences between the means of dew-point depression are highly significant.

TABLE I—DRYNESS OF AIR IN ASSOCIATION WITH REPORTS OF CIRRUS AND NO CIRRUS

	500 mb.			450 mb.			400 mb.		
	Dew-point depression	No. of obs.	Significance	Dew-point depression	No. of obs.	Significance	Dew-point depression	No. of obs.	Significance
	°F.			°F.			°F.		
Cirrus	18	164	Better than 0·1%	18	152	Better than 0·1%	17	156	Better than 0·1%
No cirrus	26	80		26	74		25	72	

An analysis was made of cases when the depressions of dew points below temperatures were simultaneously lower at all three levels than the mean depressions for cirrus reports at these levels, and also when the depressions were simultaneously greater at all three levels than the means obtained for no cirrus reports. This included rather more than half of the total cases. The results are presented in Table II from which it is seen that if these criteria had been used as a basis for forecasting, the "useful effort" (Crossley[2]) and forecast accuracy for forecasts of cirrus cloud would have been 84 per cent. and 80 per cent. respectively. This would undoubtedly be of some assistance to a forecaster in assessing the distribution of cirrus cloud from radio-sonde observations.

TABLE II—CIRRUS AND NO CIRRUS WHEN THE DEPRESSIONS OF DEW-POINTS AT 500, 450 AND 400 MB. WERE SIMULTANEOUSLY (i) LESS THAN THE MEANS FOR CIRRUS REPORTS (HUMIDITY FAVOURABLE) AND (ii) GREATER THAN THE MEANS FOR NO CIRRUS REPORTS (HUMIDITY UNFAVOURABLE)

	Cirrus	No cirrus	Total
		number of reports	
Humidity favourable	70	18	88
Humidity unfavourable	13	32	45
Total	83	50	133

Kimachi[3] suggests that cirrus cloud over Japan is observed only when the temperature at 500 mb. falls within discrete limits and has a maximum frequency of occurrence between temperatures from 0° to −20°F. Analysis of observations in the present investigation showed that the temperatures at 500 mb. when cirrus cloud is reported range from +20° to −30°F. with a flat maximum between +10° and −15°F. Furthermore, no significant difference was found between the distributions of temperatures at 500 mb. for reports of cirrus and no cirrus.

Kimachi also suggests that the lapse rate of temperature with height may well be important in the cirrus-forecasting problem. This is consistent with the work of Bannon, Frith and Shellard[4] who obtained a correlation coefficient of 0·80 between the temperature at 500 mb. and the frost point at 300 mb. as measured from aircraft of the Meteorological Research Flight engaged on high-level ascents.

Table III presents the means of the temperature lapse rates at 100-mb. intervals from 500 mb. at times of reports of cirrus and no cirrus. The means at each interval are not significantly different, and are of little use for assessing the presence or absence of cirrus cloud.

TABLE III—MEANS OF TEMPERATURE LAPSE RATE

	500–400 mb.	400–300 mb.	300–200 mb.
		degrees Farenheit per thousand feet	
Cirrus	3·90	4·06	2·07
No cirrus	4·02	4·02	1·47
"Student's" *t*	1·86	0·06	1·00

Murgatroyd and Goldsmith[1] suggest that cirrus cloud is most frequent when the wind at 300 mb. is in the south-west to west sector, and least when the wind is in the east sector. No significant differences were found between the means of the wind strengths at any level up to 200 mb. for reports of cirrus and no cirrus. Table IV presents the frequencies of the winds in various sectors at levels from 500 mb. to 200 mb. for observations of cirrus and no cirrus. Considerable variation is observed in the distribution of the winds for these two classes of reports at all levels up to 200 mb., and application of the χ^2 test indicates that the differences are most significant at 400 mb. It can be seen that the large values of χ^2 at most levels result from an excess of no cirrus reports in the east–south sector and an excess of cirrus reports in the south-west to west sector. These results are in good agreement with those of Murgatroyd and Goldsmith[1].

TABLE IV—DISTRIBUTION OF WIND DIRECTIONS AT VARIOUS PRESSURE LEVELS FOR REPORTS OF CIRRUS AND NO CIRRUS

Pressure		N.-NE.	NE.-E.	E.-SE.	SE.-S.	S.-SW.	SW.-W.	W.-NW.	NW.-N.	Total	χ^2	Significance
mb.												%
200	Cirrus	13	17	0	5	11	39	34	29	148	36·1	<0·1
	No cirrus	9	4	2	3	9	8	16	12	63		
300	Cirrus	17	13	2	7	14	35	29	26	143	24·0	0·1
	No cirrus	7	6	4	4	11	11	10	14	67		
400	Cirrus	15	13	3	4	22	31	36	22	146	45·7	<0·1
	No cirrus	8	4	7	5	11	6	12	13	66		
500	Cirrus	17	11	6	5	19	30	40	19	147	23·3	0·3
	No cirrus	11	5	7	2	8	8	13	12	66		

It has further been suggested by these authors that warm-air advection at cirrus levels is frequently observed when cirrus cloud is reported. This is supported by a report issued by the Washington Air Weather Service[5], where it is claimed that warm-air advection between 700 mb. and 300 mb. may be used for forecasting cirrus cloud. Table V presents frequencies with which warm-air or cold-air advection are found at times of reports of cirrus and no cirrus at intervals from 500 mb.

TABLE V—CIRRUS ASSOCIATED WITH ADVECTION OF WARM OR COLD AIR

mb.		Warm advection	Cold advection	Neither	χ^2	Significance
		number of cases				%
300–200	Cirrus	50	42	42	15·46	0·1
	No cirrus	16	30	18		
400–300	Cirrus	53	31	48	13·67	0·1
	No cirrus	20	26	21		
500–400	Cirrus	52	41	42	3·92	20
	No cirrus	20	23	22		
500–300	Cirrus	70	37	35	21·40	0·1
	No cirrus	23	30	14		

These frequencies were obtained by examining the winds reported from routine upper air soundings at the times and in the neighbourhoods of the reports. A veering wind with height was taken to indicate warm-air advection between the two levels considered, and conversely. In numerous cases the change in direction was slight within the height interval, and all instances where this change was less than 5 degrees were classified as "neither". Also under this classification were reports of wind strengths less than 5 kt. The distributions of frequencies in these classes were significantly different for reports of cirrus and no cirrus at the 0·1-per-cent. level or better for all intervals considered except 500–400 mb. Reports of clouds in the stratosphere were not included in these analyses. The association between the occurrence of cirrus cloud and warm-air advection in the upper troposphere is thus confirmed.

Analysis of 1000–500-mb. thickness charts.—Although time differences of up to six hours occurred between the times of observation and the times of the thickness chart used in this analysis, for the purpose of comparison with the thickness charts it was thought justifiable to neglect the changes in the thermal pattern in this interval. In fact, most of the reports were made on afternoon flights and the average time interval was probably of the order of one to two hours. No significant difference was found between the means of the thickness value for the two classes, cirrus observed and no cirrus observed, though significant differences were evident in the means of the thickness gradients. This is shown in Table VI, where the means of the thermal winds are given for cases of cirrus and no cirrus. The means are 21 kt. and 16 kt. respectively, and application of "Student's" t test indicates that they are significantly different at the 0·5-per-cent. level.

TABLE VI—ASSOCIATION OF CIRRUS WITH THE THERMAL WIND SPEED

	Cirrus	No cirrus
Mean thermal wind (kt.)	21	16
No. of observations	174	79
Standard deviation	11·4	12·3
Standard error of mean	0·9	1·4

An attempt was made to relate the point from which an observation was made to a trough–ridge pattern in the 1000–500-mb. thickness field. To allow simple classification, an idealized wave-length was divided into six equal parts along its axis, and the frequencies obtained for each class of reports of cirrus or no cirrus. Only about half the observations allowed of a reasonable degree of confidence in this classification. Fig. 5 presents the ratios of the frequency of observations of cirrus to no cirrus in each section of the ideal wave-length. It is clear that this ratio is greatest in and near a thermal ridge and least near a thermal trough, and is consistent with surface observations of the association of cirrus cloud with warm fronts.

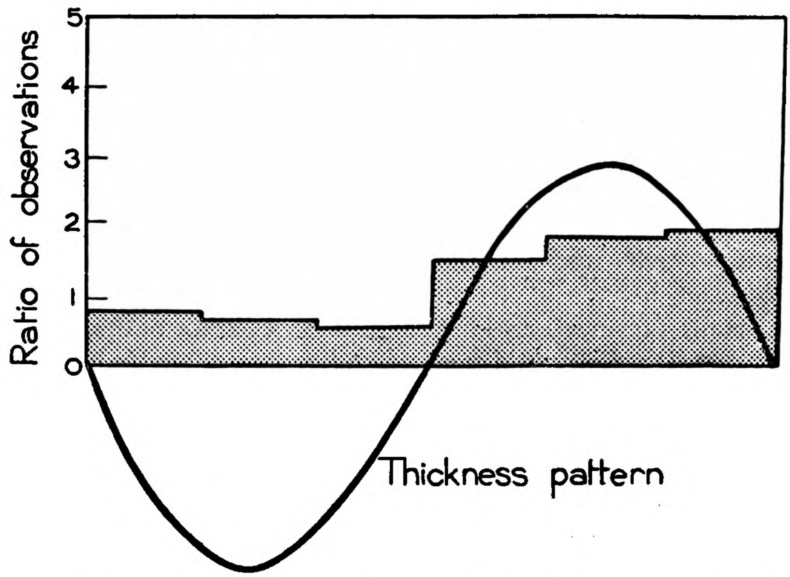


FIG. 5—RATIOS OF THE NUMBER OF OBSERVATIONS OF CIRRUS TO NO CIRRUS IN RELATION TO AN ASSUMED WAVE-FORM IN THE TOTAL THICKNESS PATTERN

Since only about half the observations were used in the above analysis, an attempt was made to classify types of thickness pattern over the area from which reports were obtained, in terms of the curvature of the thickness lines. The thickness patterns were labelled as cyclonic or anticyclonic according to the sign of the curvature of the thickness lines. If these were straight, or the gradients very weak, the observation was assumed to belong to a third class, neither cyclonic nor anticyclonic. Table VII presents the frequencies of these observations in these three classes.

TABLE VII—ASSOCIATION OF CIRRUS WITH CURVATURE OF THICKNESS LINES

	Cyclonic	Anticyclonic	Neither	Totals
	number of cases			
Cirrus	59	54	49	162
No cirrus	31	15	35	81

A χ^2 test applied to the distributions showed that they were significantly different at a level which was better than 0·1 per cent., and the individual χ^2 values indicate that there is a tendency for cirrus cloud to be most frequent when the curvature of the isotherms is anticyclonic.

Cirrus cloud and vorticity advection at 300 mb.—French and Johannessen[6] attempted to relate the presence of extensive layers of cirrus cloud to patterns on the 300-mb. contour chart. For their analysis observations were obtained from high-flying aircraft engaged on routine navigation flights over extensive areas of the United States. Their observations were classified according to the sign of the advection of cyclonic vorticity at 300 mb.

Theoretical considerations indicated that if the vertical motion at the tropopause was zero or very small compared with the vertical motions at lower levels, then the sign of the vorticity advection at 300 mb. gave the direction of the mean vertical motion through a layer which had its top at the tropopause and its base somewhere below 300 mb.

The authors found that 86 per cent. of the mileage flown through extensive cirrus by the aircraft corresponded with a positive sign of the vorticity advection at 300 mb. at the same time implying, on the above assumption, upward vertical motion at 300 mb. Further, cirrus cloud sheets were always to be found when the absolute vorticity at 300 mb. was negative.

Using a finite difference approximation to the geostrophic wind it is possible to express the vorticity and also the advection of vorticity at a point in terms of known contour heights at a set of points on a grid centred on the given point, the Coriolis parameter and the magnification factor of the grid. Although the preparation of vorticity and vorticity advection charts is possible by hand computation, with a large number of cases considerable time and labour is saved by using an electronic computer.

A grid of 12 by 11 points was adopted covering an area bounded approximately by longitudes 40°N. and 60°N. and latitudes 15°E. and 35°W. To conform with the limited capacity of the machine—the MEG computer at Manchester University was used—mean values along a line of latitude of the Coriolis parameter and magnification grid were used. These were shown to be justifiable approximations by comparison of several charts analysed fully by hand with and without these limitations. A total of 180 charts was subjected to analysis by the computer, and the field of vorticity advection at 300 mb. obtained for the times of the charts. The distribution of absolute vorticity at the same level was also evaluated for some 40 charts.

Sixteen charts were analysed for occasions when reporting aircraft were engaged on long-distance flights generally at altitudes in excess of 40,000 ft. On two of these flights the cirrus cloud was reported as being well above the aircraft and consequently well into the lower stratosphere. These were not included in the statistical analysis at this stage.

TABLE VIII—ASSOCIATION OF CIRRUS WITH SIGN OF VORTICITY ADVECTION AT 300 MB. FOR POINTS AT 100-MILE INTERVALS ALONG AIRCRAFT TRACK

Cirrus	Sign of advection +	−	0	Total
	number of cases			
Thick	23	7	0	30
Patchy	18	16	0	34
Nil	19	39	3	61

Considering first these observations made during long-distance flights, points were taken every 100 miles of the aircraft track, and Table VIII presents the frequencies of the sign of the vorticity advection at 300 mb. for cases of cirrus and no cirrus. The cirrus observations have been further divided into two classes, namely thick and patchy. The former includes all observations of cloud sheets thicker than 1,000 ft., whilst the latter includes all observations of wisps, bands and tufts, generally believed to be 3–6 oktas. Reports of anvil cirrus alone were not included. Table VIII shows that 77 per cent. of all thick cirrus cloud reported on long-range flights were in areas where the vorticity advection at 300 mb. was positive, indicating upward vertical motion in the upper troposphere.

Table IX presents corresponding figures obtained from the remaining 164 cases, namely point observations, the cases of cirrus cloud in the stratosphere again being excluded. Several observations were made independently on individual days, and all have been included in Table IX.

TABLE IX—ASSOCIATION OF CIRRUS WITH SIGN OF VORTICITY ADVECTION AT 300 MB. FOR SPOT REPORTS

Cirrus	Sign of advection +	−	0	Total
	number of cases			
Thick	69	19	3	91
Patchy	27	28	5	60
Nil	18	40	2	60

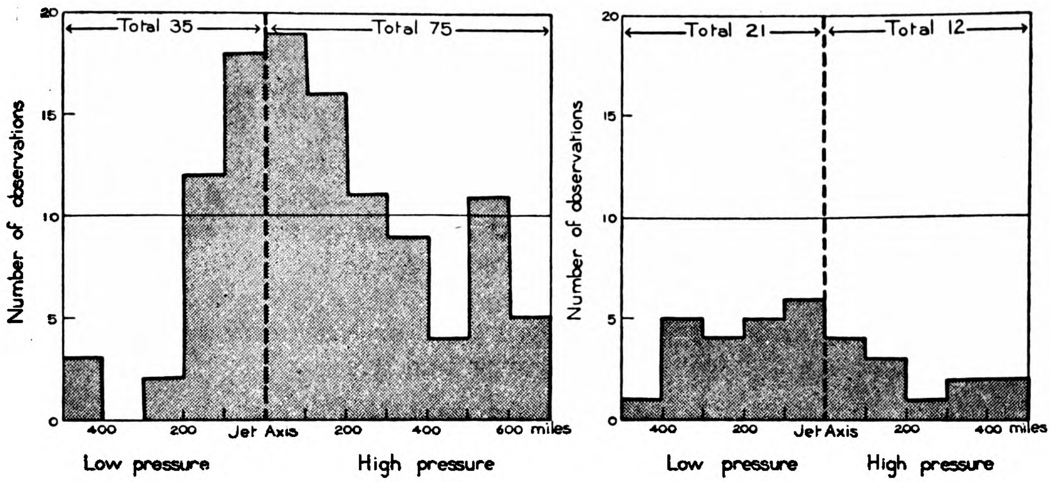
Table X is obtained by combining Tables VIII and IX, i.e. assuming that an observation every 100 miles of aircraft track is equivalent to a spot observation. Thus 76 per cent. of the observations of thick cirrus cloud were found in areas where the advection of cyclonic vorticity at 300 mb. was positive, whilst 66 per cent. of the cases of no cirrus were found in areas where the term was negative.

TABLE X—SIGN OF VORTICITY ADVECTION AT 300 MB. COMBINING TABLES VIII AND IX

Cirrus	Sign of advection +	−	0	Total
	number of cases			
Thick	92	26	3	121
Patchy	45	44	5	94
Nil	37	79	5	121

Little difference was found between the means of the absolute vorticities for the two classes cirrus and no cirrus, although the number of cases available for analysis was not sufficient to give any statistical accuracy. French and Johannessen[6] state that extensive sheets of cirrus cloud were found in areas where the absolute vorticity at 300 mb. is negative. Since this implies dynamical instability at 300 mb., a phenomenon which is thought to be rare and in any case confined to small areas only, it is not surprising that no cases were found in the charts analysed when the absolute vorticity was negative. Hence no additional evidence is available for comparison with the claims of the above authors.

Analysis of 300-mb. contour charts.—Sawyer and Illett[7] described an investigation into the frequency distribution of type and amount of cirrus cloud in relation to the jet stream at 300 mb. Later, Murray[8] in an analysis of flights through jet streams made by aircraft of the Meteorological Research Flight drew similar conclusions concerning the distribution of high and medium layer cloud with respect to the jet stream. Fig. 6 (*a*) shows the frequency distribution of cirrus reports of the present series with distance from the jet-



(*a*) Cirrus (*b*) No cirrus

FIG. 6—RELATION BETWEEN FREQUENCY OF REPORTS AND DISTANCES FROM JET-STREAM AXIS AT 300 MB.

stream axis at 300 mb. In spite of the difficulty in placing the jet axis to within ±100 miles it is clearly seen that the majority of cirrus reports lie on the high-pressure side of the axis, very few being more than 200 miles on the low-pressure side. The division of reports of no cirrus shown at Fig. 6 (*b*) is not so well marked, but even so about two thirds of the reports occur on the low-pressure side. These figures show good agreement with the conclusions of the above authors, although many reports of cirrus or no cirrus were rejected as having no apparent association with a jet stream at 300 mb.

It has been shown above that there is a significant connexion between the presence of cirrus cloud in the upper troposphere and the sign of the vorticity

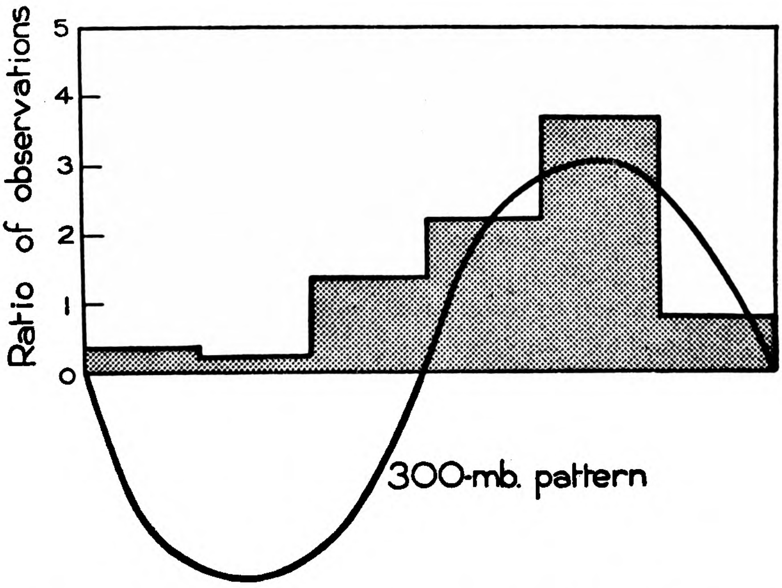


FIG. 7—RATIOS OF THE NUMBER OF OBSERVATIONS OF CIRRUS TO NO CIRRUS IN RELATION TO AN ASSUMED WAVE-FORM IN THE 300-MB. CONTOUR PATTERN

advection at 300 mb. Considering only the curvature of the contours, the advection term $(V'\partial\zeta/\partial s)_{300}$ is positive to the rear of a ridge and forward of a trough in the contour pattern. Fig. 7 shows the ratios of the percentages of observations of cirrus to no cirrus in relation to an idealized wave pattern in the 300-mb. flow. It is clearly seen that this ratio is a maximum in and to the rear of a ridge and a minimum in and to the rear of a trough. At first sight this does not appear fully consistent with the conclusion above, since we should expect upward vertical motion in the layer immediately below the tropopause to be taking place through the region forward of the trough line and to the rear of the ridge line at 300 mb. However, it is thought that although the air may commence to ascend immediately forward of the trough, some little time must elapse before the rising air becomes saturated, and hence before the appearance of cirrus clouds. Thus it is not surprising that the maximum frequency of reports should occur just in and to the rear of the ridge, as shown in Fig. 7.

Cirrus clouds in the stratosphere.—Some 30 cases were reported when the bases or tops of cirrus cloud were above the tropopause obtained from analysis of neighbouring upper air ascents. In eight of these cases, the clouds had been definitely below the tropopause reported from neighbouring stations, and extended upwards above the tropopause. These cases are not surprising since local variations in height of the tropopause could permit reported tops of cloud to extend above the tropopause height reported by the nearest radiosonde ascent.

Some of the remaining reports were discussed by Jacobs[9] who concluded that the extensive layer clouds observed over southern England on July 27–29, 1953 were in fact dust clouds which originated from a volcanic eruption in Alaska on July 9, 1953. The clouds reported in this case were estimated to be at heights in excess of 50,000 ft. at times. It seems highly improbable that the remaining 18 cases could be attributed to similar disturbances, and in all probability there were genuine ice-crystal clouds, at times as much as 10,000 ft. above the tropopause.

Little can be said concerning the existence of these very high clouds; the sample is too small to permit a statistical investigation, even if the relevant data were known at these heights. However, vorticity advection charts at 300 mb. were constructed for these occasions, and the results were remarkable in that for all cases of extensive cirrus sheets in the stratosphere, the sign of the advection of cyclonic vorticity at 300 mb. was negative (Table XI).

TABLE XI—SIGN OF VORTICITY ADVECTION AT 300 MB. FOR CIRRUS CLOUD IN THE STRATOSPHERE

Route flights and spot observations included

Cirrus	Sign of advection +	−	0	Total
	number of cases			
Thick	0	17	1	18
Patchy	3	5	0	8

The theory postulated by French and Johannessen associates upward vertical motion in the upper troposphere with a positive value of vorticity advection at 300 mb. assuming little or no vertical motion at the tropopause. A negative value of the vorticity advection would imply downward vertical motion below the tropopause, which would thus be a region of horizontal convergence. If this is so then it is possible that upward vertical motion was occurring in the lower stratosphere, and hence if the air were sufficiently moist at these levels the formation of cirrus cloud might result. Obviously, this is far from being anything but a tentative suggestion, and considerably more cases need to be reported of these high clouds which undoubtedly do exist in the stratosphere.

Conclusions.—

(i) The observations confirm the work of earlier writers on the association of cirrus cloud in the troposphere with the area ahead of surface fronts, the high-pressure side of the jet stream at 300 mb., and with thermal ridges. Considerable agreement is obtained with the statistical results presented by Murgatroyd and Goldsmith[1] regarding the distribution of bases and tops of cirrus cloud in relation to the tropopause.

(ii) A strong association is found between the presence of cirrus cloud and the humidities at 500, 450 and 400 mb. Some assistance to the forecaster is possible in assessing the distribution of cirrus cloud from radiosonde ascents if the humidities at all three levels are taken into consideration.

(iii) At all levels from 500 mb. to 300 mb. the winds between S. and W. were most frequently accompanied by cirrus cloud, and winds between S. and E. had the lowest frequency of cirrus reports.

(iv) Consideration of the winds at 500 and 300 mb. confirms that cirrus cloud is associated with warm-air advection at these levels. Also, cirrus cloud has an association with strong thermal contrasts as indicated by the 1000–500-mb. thickness pattern.

(v) Cirrus cloud in the troposphere is associated with positive values of the advection of cyclonic vorticity at 300 mb., implying upward vertical motion in the upper troposphere.

(vi) Reports of cirrus cloud in the stratosphere were comparatively few, but are sufficient to confirm that high clouds at these levels do exist.

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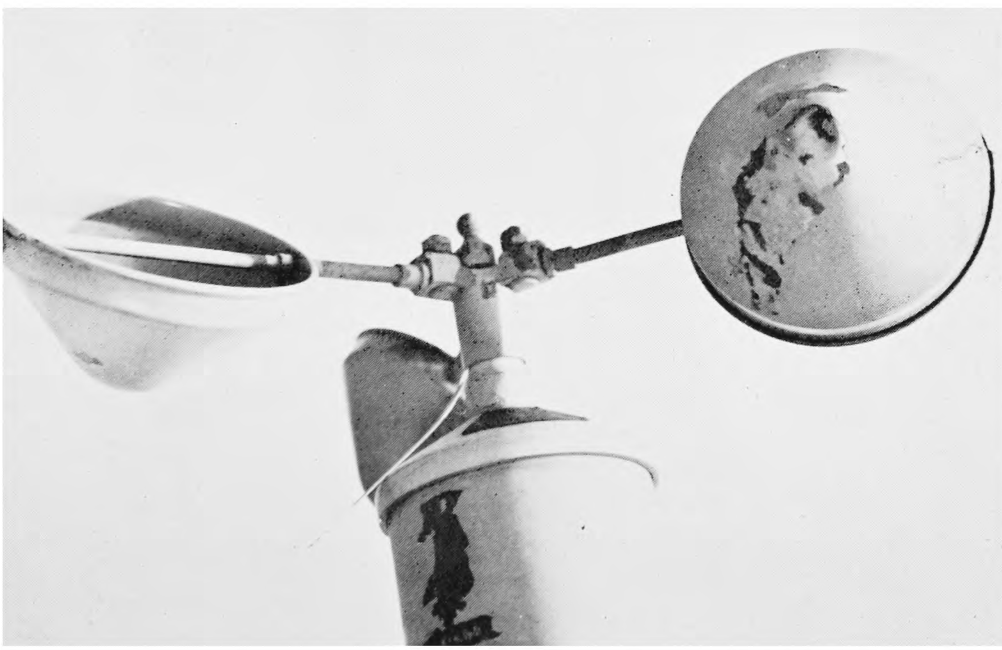
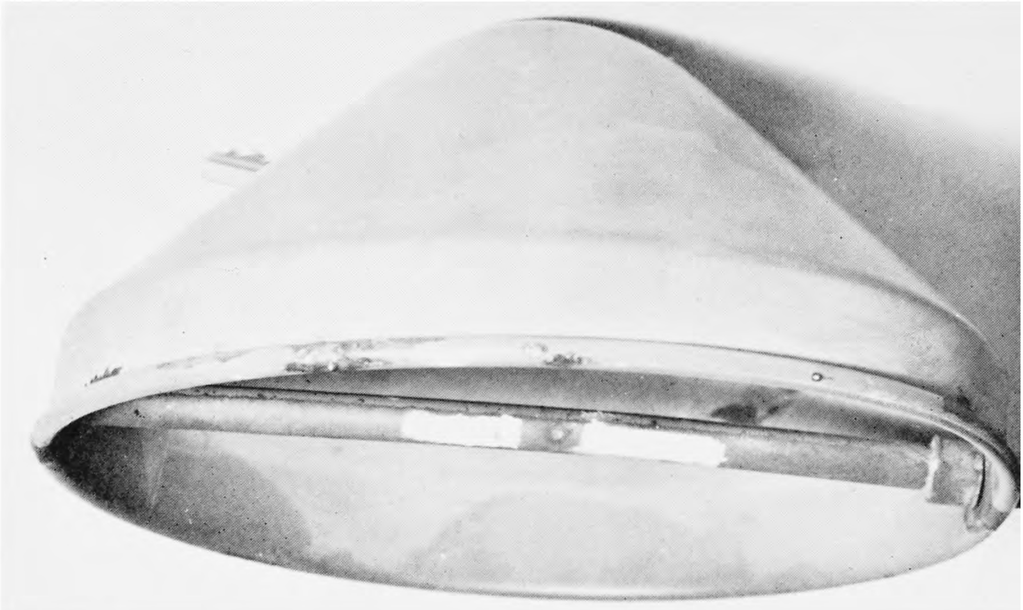
ERRATUM

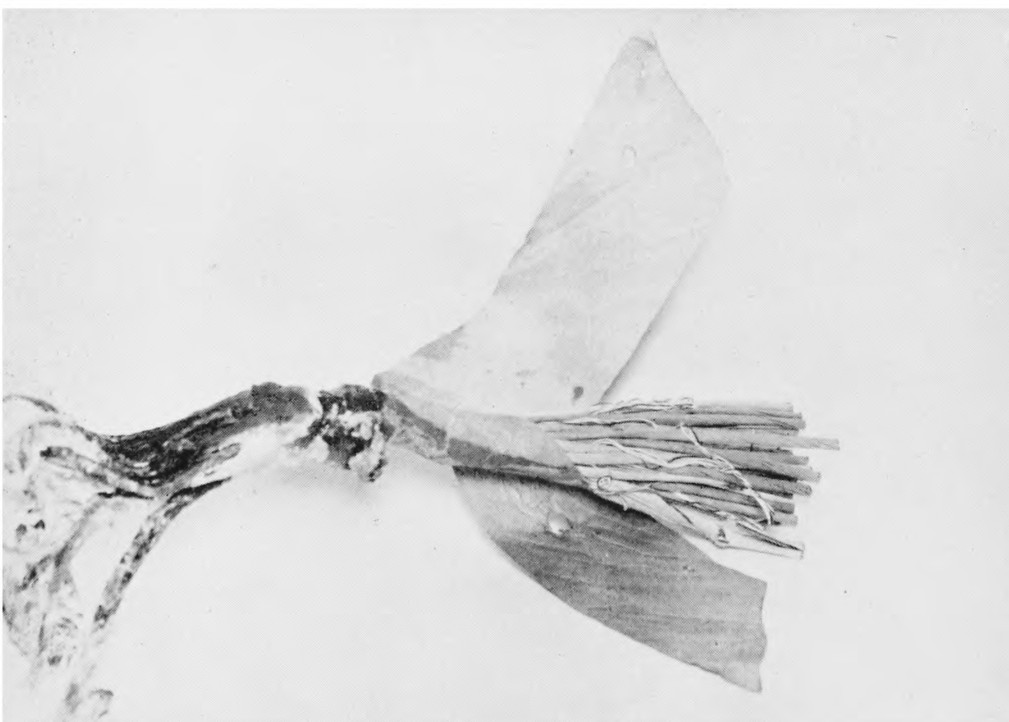
NOVEMBER, 1956, PAGE 352. Rainfall of September 1956, Station Compton, Compton Ho., Per cent. of Av.; *for* "49" *read* "169".



LIGHTNING DAMAGE TO ELECTRIC-CUP-GENERATOR ANEMOMETER

(See p. 25)





LIGHTNING DAMAGE TO ELECTRIC-CUP-GENERATOR ANEMOMETER AND INSTALLATION

(See p. 25)

HETEROGENEITY IN THE MEASUREMENTS OF HUMIDITY MADE BY THE RADIO-SONDE NETWORK OF EUROPE

By A. H. HOOPER

In the course of an investigation into variations in radio propagation at metre wave-lengths, the results of radio-sonde ascents over a large part of the European region were used to study the radio-refractive-index structure of the lower troposphere. In a well mixed atmosphere a steady lapse, i.e. a decrease, of radio-refractive index with height is developed, and propagation conditions are normal. The presence of thin but extensive layers in which the lapse is markedly greater than normal was found to be associated with extensions of radio range. Estimates were made on each occasion of the occurrence and intensity of these discontinuities in lapse, based on rules in which the moisture structure played a predominant part, for each of the upper air soundings made over Europe. While there was good general agreement over the region, it was found that the estimates for certain stations were not in accord with the results of the network as a whole, and could not easily be explained meteorologically. There are grounds, therefore, for suspecting instrumental causes, particularly in regard to the humidity observations of certain individual stations and of certain types of radio-sondes.

Limitations of data and method.—The method employed was to estimate from tephigrams, by examining primarily the hydro-lapse, the occurrence of discontinuities of radio-refractive index of various intensities. Search was made specifically for layers with a marked decrease of water vapour with height. As most radio-sondes sample the atmosphere discontinuously, an increased hydro-lapse must extend over several hundred feet to be detected, thereby implying considerable changes of water-vapour content. Changes of the required magnitude are usually associated with horizontal stratification of the subsidence type in which a large and rapid decrease with height of moisture content is maintained. Such structures tend to extend over considerable areas and to be observed simultaneously at several upper air stations.

A given temperature imposes an upper limit on the water-vapour content and hence imposes a corresponding limit on the maximum change in radio-refractive index due to a change from saturated to dry conditions. An additional limiting factor arises from the lag in response of the radio-sonde humidity sensing devices. With the slow response associated with low temperatures, a sharp discontinuity of sufficient magnitude may be reported in stages over several successive readings. In such circumstances the indicated change in hydro-lapse could be taken, wrongly, as being insignificant. Thus at low temperatures, humidity discontinuities are both restricted in magnitude and are less well recorded. A latitude effect is, therefore, to be expected.

A further limitation arises from the procedure used for compiling the messages containing the radio-sonde observations. As a sufficiently large hydro-lapse cannot be maintained over the height intervals between the International Standard Levels for which humidity is invariably reported, the reporting of these discontinuities is dependent upon adequate use of additional levels in the reported message. There was no reason, however, to attribute the discrepancies discussed below to any deficiency on this score. It is probable, therefore, that a radio-sonde which fails to indicate the full extent of a humidity change from wet to dry, or which has either a slow sampling rate or slow response, will introduce discrepancies between the observed radio effects of the atmosphere and the measured lapse rates for humidity and temperature.

From a daily scrutiny of tephigrams plotted from radio-sonde messages, the presence of any discontinuity in radio-refractive index lapse over the European region was assessed in the following steps:—

(i) an estimate by inspection of the Hemsby upper air sounding,

(ii) a computation of radio-refractive-index structure of the Hemsby sounding to check the validity of the estimates,

(iii) an estimate by inspection of all other available upper air observations.

The intensities of all discontinuities were assessed on a four-point scale from "Nil" to "Strong" and their heights noted. The degree of validity of 515 estimations of the incidence of "Strong" discontinuities for Hemsby, when compared with the subsequent computations, was found to be 96·1 per cent. Estimations for all other stations have been corrected on this performance. The broad conclusions of this report do not, however, depend upon this uncertainty, as the magnitude of the correction is too small.

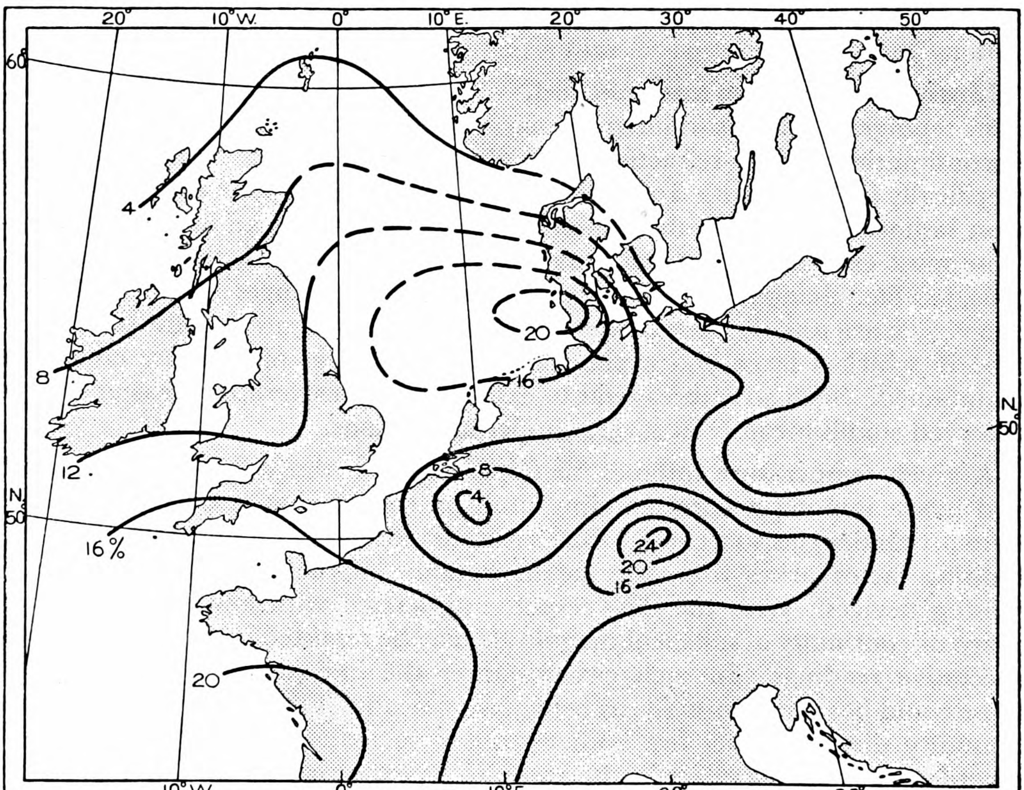


FIG. 1—OCCURRENCE OF STRONG RADIO-REFRACTIVE-INDEX DISCONTINUITIES MID JULY, 1953—MID OCTOBER, 1954

Surface to 10,000 ft.

Geographical and seasonal distribution of results.—Fig. 1 shows for each station the percentage frequency of occurrence of a strong radio-refractive-index discontinuity, assessed and corrected in the above way, during the 455 days commencing July 17, 1953.

In the western half of the chart the frequency is seen to decrease from south-east to north-west. In so far as the condition is mainly associated with subsidence and is limited by temperature this result could be attributed to the occasional north-eastward extension of the Azores anticyclone and to the general variation of temperature with latitude.

Four other features are apparent:

(i) a very low frequency over Belgium

(ii) a very low frequency over Scandinavia

(iii) a relatively high frequency over Flensburg

(iv) a relatively high frequency over Erlangen.

In case these features were real geographical variations arising from the modification of the lower layers of the troposphere by varying surface conditions, the figures were separated into successive 1,500-ft. intervals above ground level.

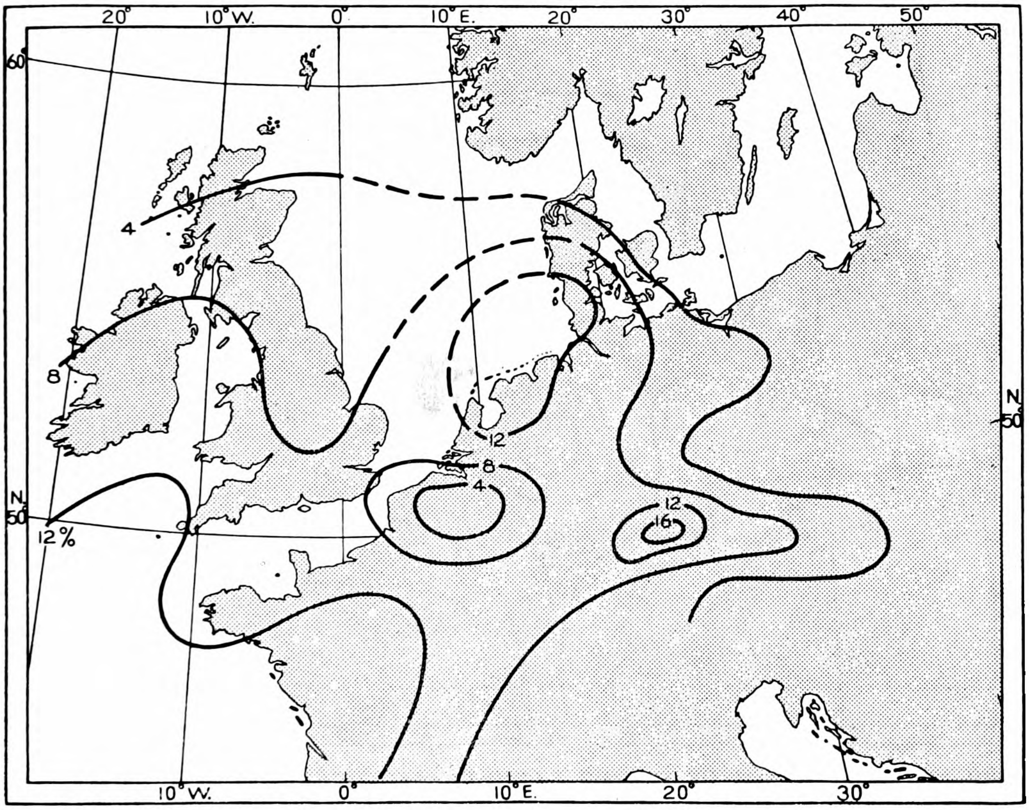


FIG. 2—OCCURRENCE OF STRONG RADIO-REFRACTIVE-INDEX DISCONTINUITIES
MID JULY, 1953—MID OCTOBER, 1954
3,000 ft. above ground to 10,000 ft.

It was found that in each layer the general pattern remained. Fig. 2 shows the percentage frequencies when the height-range surface—3,000 ft. is excluded and it is seen that the isopleths are substantially unchanged in pattern. The possibility remains, however, that geographical variations in surface conditions, while not causing variations in incidence at low levels, may affect the instrumental performance by governing the conditions of storage and preparation before use.

In winter, the limitation set by temperature on saturation-vapour-pressure results in radio-refractive-index discontinuity of the required magnitude being infrequent, despite the occurrence of extensive subsidence. The figures have been examined on a seasonal basis. It was found that during the three-month period mid-June to mid-September 1954 the frequency of occurrence was much higher than average at certain stations. These were the southern British, the French stations, Erlangen, Friedrichshaven and Payerne. This effect could possibly be due to the extension of the Azores anticyclone bringing warm moist air more frequently to these areas than to the remainder. Fig. 3 shows, therefore, the percentage frequency of discontinuity for the six months from mid-December 1953 immediately preceding the season of increase. It can be seen that while the last of the four peculiarities has been excluded the other three still remain to be explained. They occur in all the periods examined.

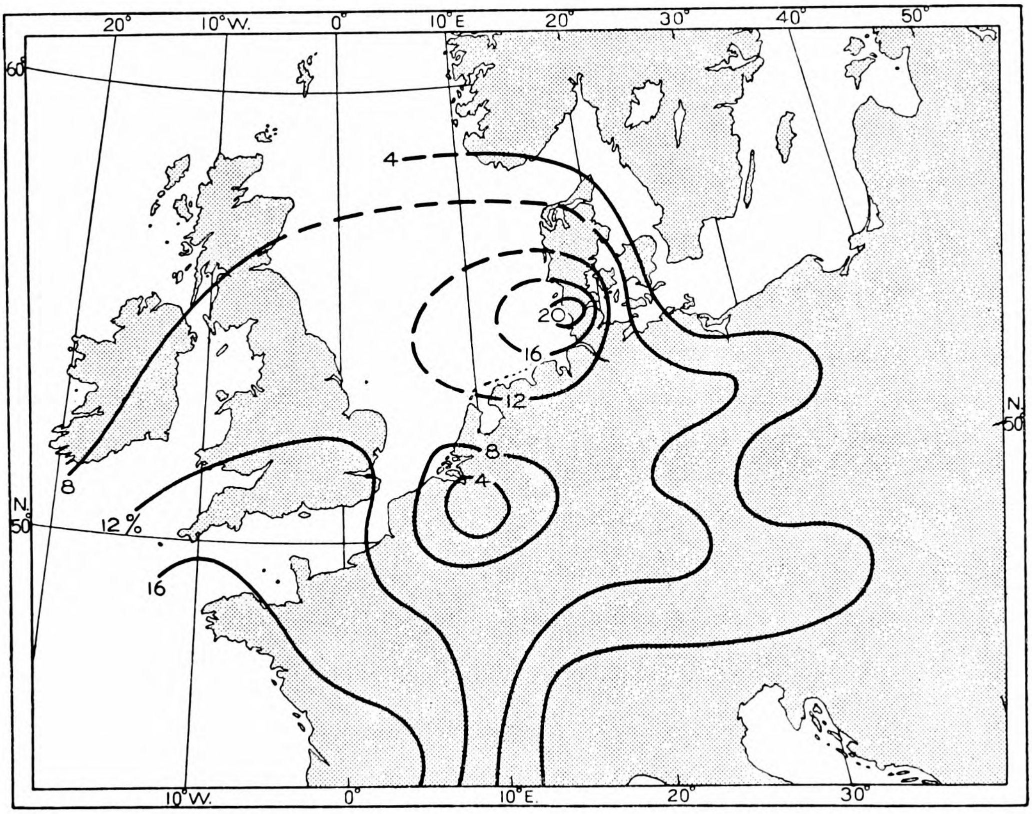


FIG. 3—OCCURRENCE OF STRONG RADIO-REFRACTIVE-INDEX DISCONTINUITIES MID DECEMBER 1953–MID JUNE 1954

Surface to 10,000 ft.

Examination of heterogeneities.—In the examination of the heterogeneities shown by this method no evidence is submitted as to the absolute accuracy of the various forms of radio-sonde humidity-measuring devices. The results as they are presented herein suggest that at certain radio-sonde stations a marked change in the vertical humidity-structure is observed with greater or less frequency than at other stations, to a degree which cannot be explained by meteorological considerations alone. The variation in the frequency with which this type of humidity structure is observed thus suggests a variation between stations in the accuracy of response to change of humidity, but external evidence, which might be obtained from observations of radio propagation, would be necessary to judge which response was the most accurate.

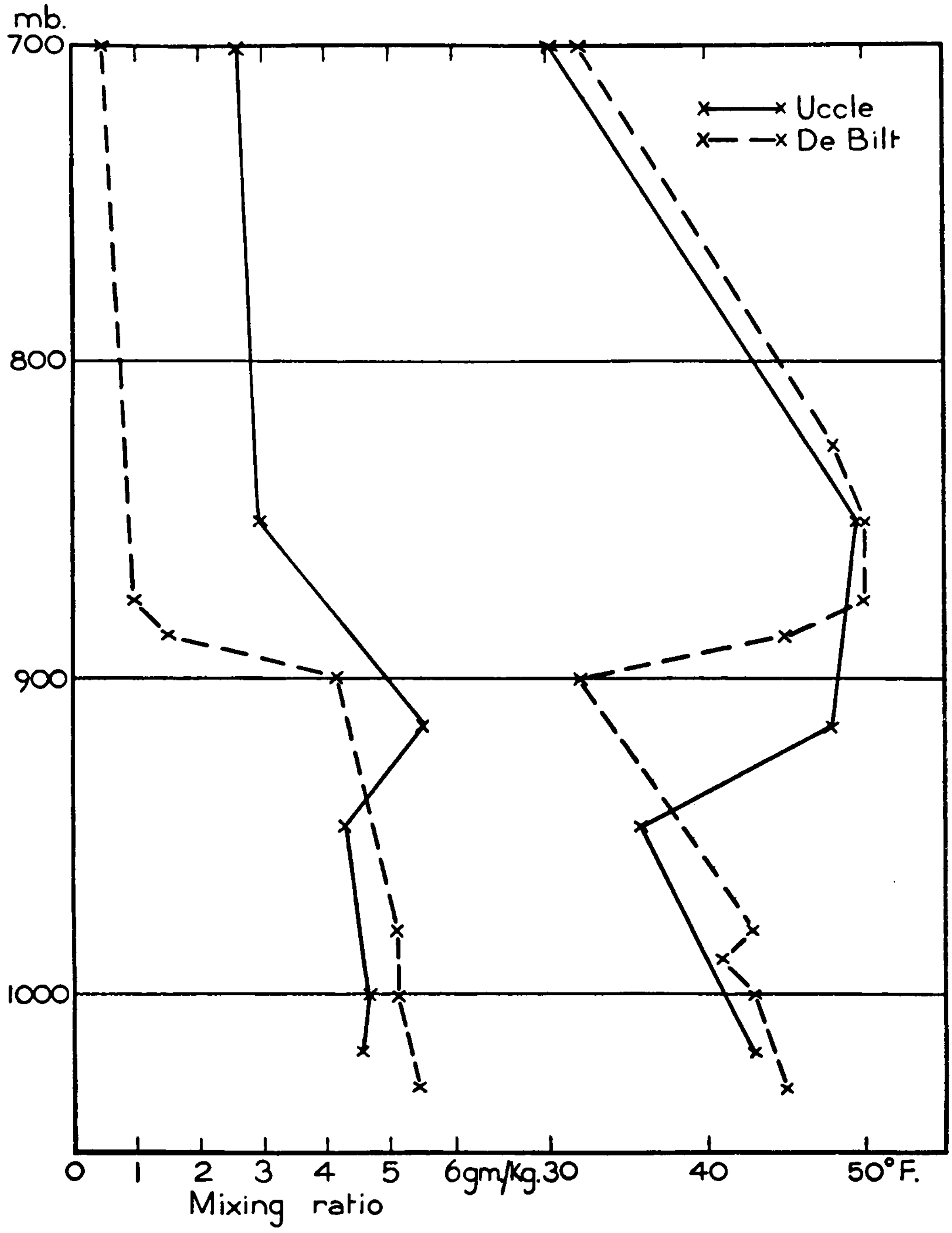


FIG. 4—RADIO-SONDE DATA FROM UCCLE AND DE BILT FOR AN OCCASION WHEN SURROUNDING STATIONS SHOWED SIMILAR SUBSIDENCE STRUCTURES

The radio-refractive-index discontinuity implied is "strong" at De Bilt but merely "average" at Uccle.

The first feature, the Brussels "low", depends upon the one station Uccle which is surrounded by stations experiencing frequencies of occurrence many times greater. This is especially curious in that the British radio-sonde is in use both there and at De Bilt and these, together with the British stations, should form a homogeneous network. Gold-beater's skin is used as the humidity-sensing element and it has been reported[1] that this material exhibits a hysteresis effect below about 70-per-cent. relative humidity. British practice is to expose the material to a near-saturated atmosphere for about 1 hr. immediately before use so that subsequent operation is largely over the curve given by calibration, from wet to dry. The sondes used at Uccle and De Bilt are supplied uncalibrated and it is suggested that calibration and/or subsequent treatment at Uccle differs in some way from British practice. The procedure at De Bilt yields results that are comparable with those of the United Kingdom in the respect examined. Again it is stressed that the results considered herein give little or no indication as to which procedure is the more reliable.

A search was made for specific occasions when the report from Uccle differed from those from surrounding stations, and there was reasonable assurance that the air mass was homogeneous. Fig. 4 shows the reports from Uccle and De Bilt on such an occasion while Fig. 5 shows their reports on an occasion of agreement. Specific occasions of reasonable assurance were, in fact, rare

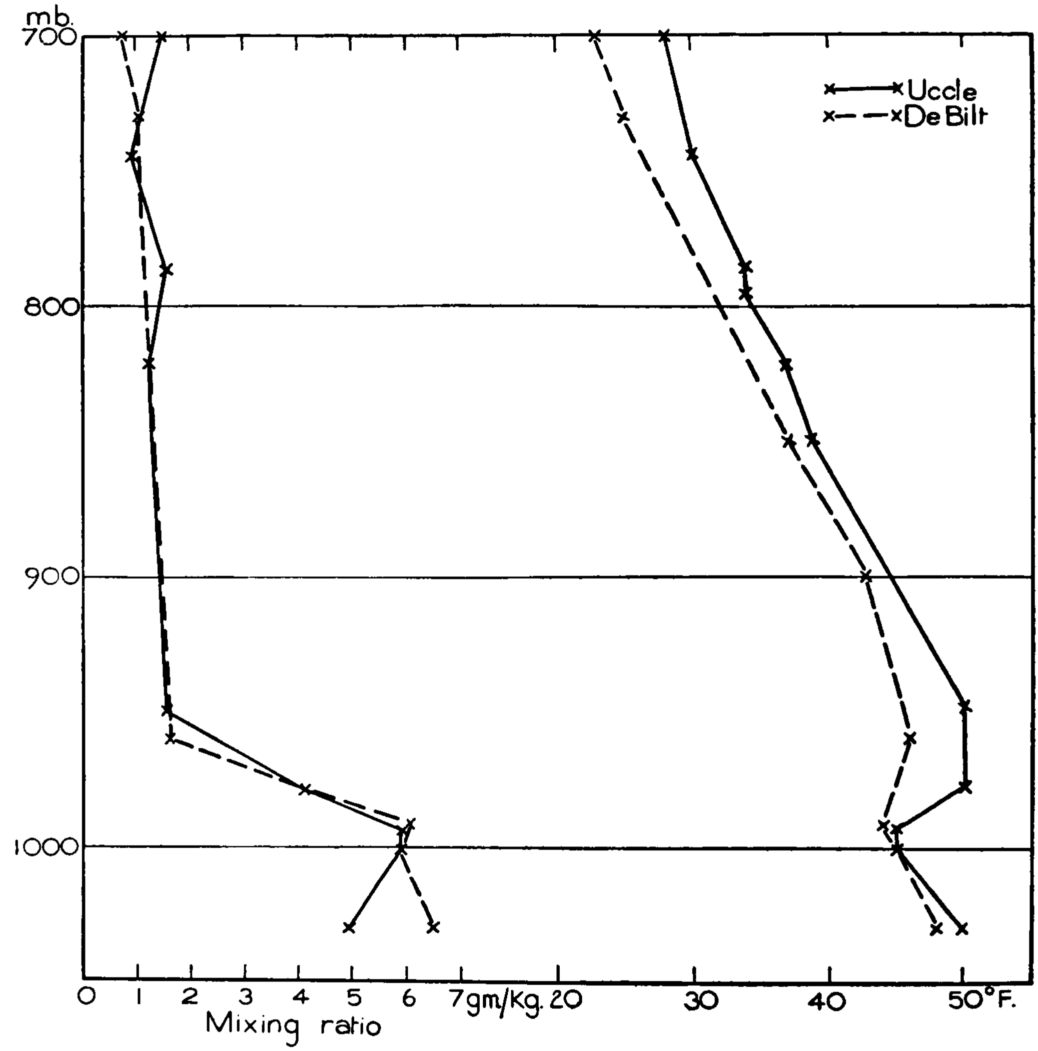


FIG. 5—RADIO-SONDE DATA FROM UCCLE AND DE BILT FOR AN OCCASION WHEN SUBSIDENCE WAS PRESENT

The humidity structure results in a "strong" radio-refractive-index discontinuity.

owing mainly to not all of the surrounding stations showing the required condition. As Fig. 1 shows, however, the surrounding stations agree closely as to long-term frequency of occurrence and it is on this result that the conclusion of network heterogeneity is based.

The second feature of very low incidence over Scandinavia arises from the results reported by stations using the Väisäla radio-sonde. While a gradual reduction northward in frequency is to be expected, as experienced 9 per cent. to 4 per cent. over the British Isles, the difference in frequency of occurrence between Flensburg and Copenhagen, for example, is very great. The sudden reduction from the high incidence at Flensburg and Emden to the very low incidence at Copenhagen, Gothenburg and Sola is most unlikely from climatological considerations. This, together with the fact that in this region the demarcation between stations with frequencies of more than 10 per cent. and stations with frequencies of 1 per cent. or less coincides exactly with the use of a particular type of radio-sonde, again suggests an instrumental origin.

The humidity-sensing element in the Väisäla sonde is of hair and is calibrated at each station several days before use, room humidity and 97 per cent. being used. It is then seasoned in a near-saturated atmosphere for 48 hr. It has since been reported[2] that in July 1954 the Swedish stations changed to the use of hair treated by the Frankenburger process, for which a greatly reduced lag is reported.

Table I shows the incidence of strong discontinuities at stations in this region for successive 3-month periods, ending mid-October 1954.

TABLE I—OCCASIONS OF STRONG DISCONTINUITIES

3-month period ending	Norway		Sweden		Denmark—Germany	
	Sola	Gardemoen	Torslanda	Stockholm	Copenhagen	Flensburg
Mid-January	0	1	1	1	1	15
Mid-April	1	0	2	0	0	15
Mid-July	1	0	2	2	1	14
Mid-October	0	4	1	6	2	11

In the last period examined, when "Frankenburger" hair was being used, the incidence at Stockholm suddenly increased, at a time when the general incidence at the north-west German stations decreased. Although several extraneous reasons can be advanced to explain the absence of a corresponding change at Torslanda, there is insufficient evidence to associate this increase with the introduction of "Frankenburger" hair.

The area of relatively high incidence over north-west Germany is due to reports from Flensburg, supported in part by the reports from Emden. While this geographical distribution is meteorologically plausible the impression was gained, during consideration of radio propagational effects observed in the area, that the increase in incidence is unreal. The radio-sonde in use at these two stations and at Hanover was the standard type H.50 using Frankenburger hygrometers. From the difference in incidence between these stations it appears that differences in treatment before use can modify the characteristics of "Frankenburger" hair.

The high incidence over southern Germany is due only to one station—Erlangen. This station, too, uses the type H.50 radio-sonde. It is at a relatively high level, 909 ft., however, and may well be subject to marked local effects which either modify the lower tropospheric structure or, as earlier envisaged, the radio-sonde performance. As during the six-month period shown on Fig. 3 the incidence was not exceptional, and the radio-propagation effects observed in the area were limited, it is not possible to suggest an explanation.

It is of interest to note that at Wiesbaden and Munich, American equipment with yet another humidity-sensing material, lithium chloride, was employed. The results from these stations are seen to fit in smoothly with those from neighbouring stations e.g. Payerne.

General Discussion.—Direct comparisons between many types of radio-sonde were carried out at Payerne in 1951. They comprised a series of ascents in which radio-sondes were carried aloft in pairs. The differences between each pair of sondes and the change of these differences with height has been examined. Comparing each radio-sonde type in turn with the average of the remainder, it is inferred that with a decrease of relative humidity with height between the pressure ranges 900–800 mb. and 600–500 mb., there is a slight tendency for the German and Finnish instruments to under-estimate the decrease while the French and British sondes give an over-estimate. The geographical distribution implied by this is not wholly in accord with that now found and it is concluded that the effect now described is not associated with the type of humidity performance observed at Payerne.

A study of radio-sonde observational homogeneity has just been published by the World Meteorological Organization[3]. In the method[4] adopted, changes with time of the observed thickness between various pressure surfaces are examined. Such thicknesses depend mainly on temperature, humidity playing only a small part. For example, the total contribution of water vapour in a pressure/height evaluation in the British Isles seldom exceeds 50 ft., and in conditions of marked subsidence a contribution of 20 ft. is usual. Changes of the type considered in the humidity structure of shallow layers would thus be unobservable as a change in thickness.

It can be seen from the relation customarily used[5] that for radio-refractive-index discontinuities the situation is reversed, and although temperature plays a part, it is the humidity contribution that predominates. It can be shown that no reasonable differences in the measurement of temperature between radio-sondes of different types could account for the features discussed here.

The discrepancies shown in this paper in regard to radio-sonde humidity observations are thus unlikely to be detected by any of the standard methods of radio-sonde comparison in use at present, or to affect the main meteorological purpose of radio-sonde ascents in providing temperature and height information. At the same time, accurate humidity observations have great importance in meteorology and other spheres and are among the most difficult of the required data to obtain reliably. It is probably true to say that no other meteorological measuring device is as sensitive to changes both of design and of handling technique as the radio-sonde hygrometer. This is instanced at Uccle, where by comparison with United Kingdom results, the British radio-sonde, possibly due to some difference in calibration or sounding technique, apparently causes a rapid moisture change from wet to dry either (i) to be incompletely observed, or (ii) to be observed with a large lag. Over-all, however, the upper air humidity data over western Europe are surprisingly homogeneous.

[To face p. 20

Photo by J. E. Gittens

Photo by J. E. Gittens

FENLAND "BLOW", JULY 5, 1956
(See p. 21)

To face p. 21]

Photo by J. E. Gittens

FENLAND "BLOW", JULY 5, 1956
(See p. 21)

With the attention being given at the present time to tropospheric humidity on a regional scale it is hoped that at future international trials closer study of humidity comparisons will be made and that ultimately the remaining differences will be eliminated.

Conclusions.—The homogeneity of the European upper air network has been indirectly examined in respect of magnitude and speed of response to low-level moisture discontinuities of large magnitude. It appears:

(i) that instrumental differences existed at the time of the comparison

(*a*) between the British radio-sonde as used in Great Britain and Holland and as used at Uccle, probably due to differences in technique.

(*b*) between the British, French, German, American and Swiss radio-sondes together and the Vaisala sonde with standard hygrometer, attributable to a large difference in properties between goldbeater's skin, "Frankenburger" hair, and lithium chloride on the one hand and "ordinary" hair on the other.

(ii) that smaller differences existed between certain stations using the H.50 radio-sonde, possibly due to variations of surface conditions.

(iii) that the British sonde, as normally used, and the French sonde gave directly comparable results, as regards the aspect of humidity examined, and that both agreed well with results from the American and Swiss instruments.

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[Prof. Dr. J. van Mieghem, President of the World Meteorological Organization Technical Commission for Aerology, who saw the above article before publication, has commented as follows:

L'étude de Mr. Hooper révèle incontestablement qu'il existe à la station d'Uccle une anomalie que l'on ne peut justifier par des arguments météorologiques. Je crois que l'étallonage est hors cause, et qu'il faut attribuer cette anomalie à une trop grande vitesse ascensionelle et peut-être aussi à ce que les prescriptions relatives à la preparation de l'hygromètre avant le lancer ne sont pas toujours scrupuleusement suivies.

Les travaux dans le genre du celui de Mr. Hooper sont fort utiles, car ils montrent les efforts que nous devons encore accomplir pour que le réseau aérologique ne représente plus que les seules phénomènes météorologiques.]

SOIL BLOWING IN THE FENS IN 1956

By M. T. SPENCE, B.Sc.

Storms which lift the top soil and fill the air with soil particles, reducing visibility to a few yards, occur in the Fens from time to time; they are known locally as "blows". Farmers suffered heavy losses of soil, seeds and fertilizers over a wide area in the severe "blow" of May 4–5, 1955, previously described in this Magazine[1].

In 1956, the "blows" were less severe and more localized. A small amount of surface drifting was seen in March 1956, but the first "blow" came on May 10. It was confined to particularly vulnerable areas, notably one of some 800 acres of black fen 8–10 miles north-east of Cambridge. Most of the stricken fields in this fen were re-sown with carrots though a small acreage was re-drilled with sugar beet. From May 11 to July 4, the wind was never strong enough to cause "blowing" but on July 5 and again on July 29–30, the mean hourly wind reached or slightly exceeded 25 kt.; the direction on both occasions was south-west to west. The maximum gust recorded on the 5th was 37 kt. and on the 29th–30th, 43 kt. It is unusual to have such strong winds in July and exceptional to have fields with bare soil exposed to the strong winds if they do occur. Normally fields are covered by vegetation at this time of the year and so are protected from loss of soil. However, in July 1956, those fields which had "blown" in May were still vulnerable and it was upon these fields that most of the damage occurred. Many acres of carrots and sugar beet were lost. The photographs facing pp. 20 and 21 were taken during the "blow" of July 5 and show how great the loss of soil can be. The low level of the top of cloud confirms that the storm is analogous to a sandstorm rather than a dust-storm—a view expressed previously in connexion with the storm of May 1955[1].

There is a tendency to regard drought as essential for soil erosion by wind. This is not borne out by conditions in the Fens in July 1956. Rain preceeded the "blow" of July 5; on the previous night 0·02 in. fell at Mildenhall and not long before that the ground had been thoroughly moistened (0·34 in. in the last week of June). Again, in the case of the "blow" of July 29–30, light rain had fallen continuously on the morning of the 29th (0·02 in.) and copious rain had fallen (0·32 in.) on the two previous days. It seems that the earth clods, when drying after rain, tend to break up into small particles thus increasing the liability to wind erosion.

I am indebted to Mr. N. J. Sneesby of the Agricultural Land Service, Eastern Province, for information about the areas affected by the "blows".

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NOTES AND NEWS

Universal Decimal Classification[1,2]

551.5 Meteorology

One of the most important tasks of the World Meteorological Organization's Commission for Bibliography and Publications is to keep the meteorology section of the Universal Decimal Classification up to date. Meteorology is more fortunate than some sciences as regards classification of the literature because of the existence of such an international body as the Commission for Bibliography and Publications.

The Commission held its first session in Paris during November and December 1953 and agreed on a number of revisions of 551.5. The revisions were later agreed by the Executive Committee and the International Federation for Documentation—the central governing body dealing with Universal

Decimal Classification—and are announced in "W.M.O. Technical Regulations Volume 1" as to come into force on January 1, 1957. Annexe V of Volume 1 gives the complete revised classification for meteorology.[3]

The major changes from the classification in force since January 1, 1950, are as follows:—

551.501.6 : 551.511.1 *Thermodynamical diagrams.* New number added under 551.501.6 *graphical methods of representation—isopleths.*

551.508.765 *Instruments for measuring ice accretion.* New number added under 551.508 *meteorological instrumentation.*

551.509.313 *Dynamics (hydrodynamics and thermodynamics) applied to forecasting.* New number added under 551.509 *weather forecasting, artificial action on weather.* This new number will be used for literature on numerical methods of forecasting.

551.509.314 *Statistical methods of forecasting.* New number added.

551.509.32 *Forecasting of specific elements and phenomena.* New number added. This number is sub-divided to cover individual elements (e.g. 551.509.325 covers *forecasting of visibility.*)

551.510.522 *Layer in contact with the Earth's surface.* New number added under 551.510.52 *troposphere.* This new number will be used for papers on the general meteorology of the atmosphere at breathing level and heights accessible by fixed instruments.

551.510.528 *Tropopause.* New number added. Previously there was no number for the tropopause as such and the device of using 551.510.52/551.510.53 i.e. *troposphere/stratosphere* had been used in the Meteorological Office Library.

551.510.53 *Atmosphere above the tropopause (highest tropopause if there is a multiple arrangement).* The title of this number was changed from *stratosphere in general* in recognition of the increase in complexity of the known structure of the higher atmosphere.

551.511 *Mechanics and thermodynamics of the atmosphere in general.* This number is used for papers dealing with the mechanical and thermodynamical processes in air, regarded from the theoretical or physical point of view, without reference to the place of the air in any specific circulation, such as a depression. There is another number, 551.515, with suitable sub-divisions for classifying papers on the dynamics of depressions and anticyclones. It has for long been recognized that 551.511 needed sub-division to permit easier finding of papers on specific parts of theoretical dynamical meteorology and the first session of the Commission for Bibliography and Publications produced one as follows:

551.511.1 *Statics and quasi-statics.*

.12 *Hydrostatics. Standard atmospheres.*

.13 *Static and quasi-static thermodynamic states and processes. Thermal equilibrium.*

.2 *Kinematics*

.3 *Dynamics.*

.32 *Hydrodynamics.* This number will be used for theoretical papers on such subjects as the general equations of motion, variation of wind with height, geostrophic relation, and the conservation theorems of hydrodynamics.

.33 *Thermodynamics*. This number will be used only for papers on subjects in which variation in time plays an essential part.

.6 *Turbulence and diffusion*. This number will be used only for papers which are wholly or mainly theoretical. Papers which are wholly or partly observational will be given either 551.551 *turbulence, gustiness, turbulent diffusion* or both 551.551 and 551.511.6.

551.521.326 *Radiation from the night sky*. New number under 551.521.32 *terrestrial and atmospheric radiation* in place of 551.521.4 which has been deleted.

551.547.5 *Distribution in space (of upper air pressure), isohypses, isobars*. New number added under 551.547 *upper air pressure*.

551.551 *Turbulence, gustiness, micro-variations of wind, turbulent diffusion in the atmosphere* has been renamed from *wind structure, micro-variations, gustiness, turbulence*, and is sub-divided as follows

551.551.2 *Turbulence in the lower layers defined as the region accessible by instruments mounted on the ground, on masts, towers, and fixed balloon cables.*

.21 *Turbulence in the layers up to normal anemometer height.*

.25 *Turbulence in the lower layers above normal anemometer height.*

.5 *Turbulence in the free atmosphere.*

.8 *Turbulent diffusion of momentum, heat, water vapour and aerosols.*

551.556.6 *Wind pressure on buildings*. New number added under 551.556 effects of wind, in place of 551.556 : 69 which has been deleted.

551.556.81 *Effects of wind on water surfaces*. New number added.

551.557.5 *Specific large-scale winds (e.g., jet stream, anti-trades)*. New number added under 551.557 *upper air wind*.

551.589.6 *Quasi-periodic phenomena (e.g. Ice-Saints' Days)*. New number added under 551.589 *synoptic climatology*.

551.593.653 *Noctilucent clouds*. Name changed from luminous clouds.

The revised classification will be brought into use in the Meteorological Office library for classifying books and papers received on and after January 1, 1957.

This note is published with the agreement of the British Standards Institution, copyright holders of the Universal Decimal Classification in the United Kingdom. A list of the relevant B.S.I. publications is given[4, 5, 6].

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6. The Hague, The International Federation for Documentation. Extensions and corrections to the U.D.C. Issued half-yearly cumulative (annual subscription, 63*s*.).

Royal Society International Geophysical Year Expedition to Antarctica

Since early January 1956 the advance party of the British International Geophysical Year Expedition[1] has been established at a site a mile and a half inland on the ice shelf in Coats Land on the eastern side of the Weddell Sea. The base is known as the Royal Society Base, Halley Bay. The revised co-ordinates are 75° 31'S., 26° 36'W. The main party of the International Geophysical Year Expedition and that of the Trans-Antarctic Expedition sailed from London on November 15, 1956 in the M.S. *Magga Dan* (2,000 tons). The Trans-Antarctic Expedition base is at Shackleton, 77° 57'S, 37° 16'W, about 250 miles south-westward of Halley Bay.

The Expedition's main party of 20 under the leadership of Col. R. A. Smart, R.A.M.C., includes 11 scientific members who will be responsible for the observational programme of the aurora, geomagnetism, glaciology, the ionosphere, meteorology, radio-astronomy and seismology until the end of 1958. The component for work in meteorology, geomagnetism, glaciology and seismology consists of the following members of the Meteorological Office, Messrs. J. MacDowall, A. Blackie, J. M. C. Burton, D. T. Tribble and D. G. Ward; all of whom, along with several other of their Office colleagues, volunteered for this enterprise more than a year ago. They will be joined, for 1957, by another colleague, Mr. P. H. Jeffries, who has been with the Trans-Antarctic Expedition advance party at Shackleton throughout 1956. Having accomplished their indispensable mission during 1956 of establishing the base at Halley Bay, instituting preliminary scientific observations and carrying out other essential pioneer work, the advance party, which includes Mr. D. W. S. Limbert of the Meteorological Office, will return to the United Kingdom early in 1957.

An immediate preoccupation of the new arrivals at Halley Bay will be to erect, on the ice shelf, the instrument and observation huts (including those for the geomagnetic instruments and for filling radio-sonde balloons) and additional aerial arrays, and to install equipment with minimum delay so that everything shall be fully operational well before the beginning of the International Geophysical Year, July 1, 1957.

The general nature of the work in meteorology and geomagnetism, to be undertaken at Halley Bay in 1957–8, has been outlined previously[1]. One of the important features will be upper air soundings twice daily. For the measurement of upper winds to 80,000–100,000 ft., it is hoped 3-cm. radar equipment very recently developed by Decca Radar Ltd is to be used. A three-component Willmore-seismograph assembly is to be used for recording earthquakes which may occur at moderate distances from the base.

Our best wishes for complete success go to the whole party at Halley Bay, and to the several other similar parties in the far South, in their endeavours to achieve significant contributions to the general International Geophysical Year programme for Antarctica.

REFERENCE

1. ABSALOM, H. W. L.: International Geophysical Year. *Met. Mag., London,* **85,** 1956, p. 33.

Lightning damage to an electric-cup-generator anemometer

The electric-cup-generator anemometer at the R.A.F. station at Wyton, Huntingdonshire was struck by lightning at 1546 G.M.T. on July 18, 1956 during a severe thunderstorm. Some of the damage to the anemometer and installation is shown in the four photographs facing pp. 12 and 13.

The lightning struck the revolving-cup assembly. The top photograph facing p. 11 shows the assembly with twisted cups, the lower photograph an indentation at the apex of one of the cups and the upper photograph, facing p. 13, beads on the rim of a cup, produced by local fusing of the metal. This local fusing effect was produced on the rims of two of the three cups. This photograph also shows a mark on the supporting arm of the cup, due apparently to sparking between rim and arm. Finally, the lower photograph facing p. 13 shows the fusing in the 14-pair cable leading out of the mains terminal box. The cable was fused to the inside of the terminal box and the insulation wax melted off the cable wires. The outer wrapping of the cable shows perforations caused by fusing points on individual wires.

S. F. COLEMAN

BOOK RECEIVED

Indian Journal of Meteorology and Geophysics. 7, 1956, No. 4, India Meteorological Department. 9½ in. × 7¼ in., pp. ii + 414 + vi. Manager of Publications, Delhi, 1956. Price: *Rs.* 3/- or 5*s.*

REVIEWS

Equatorial weather with particular reference to Southeast Asia. By I. E. M. Watts. 8½ in. × 5½ in., pp. xvi + 224, *Illus.*, University of London Press Ltd, London, 1955, Price: 25*s.*

This is a brief and elementary outline of the theory and practice of synoptic meteorology in equatorial regions together with the essential background of climatology and physical principles. After reading it the enthusiastic amateur and the not too advanced student will feel that they have acquired some worthwhile knowledge of the subject, but the expert in tropical meteorology will find much to criticize. However it is evident that the book was not written for the expert and it would be improper to judge it entirely from his standpoint.

Little fault can be found with the scope of the book, but considered as a whole the work does not hang well together. The order of treatment is somewhat confusing and the standard of knowledge assumed for the reader varies greatly from one section to another. It begins with a brief and somewhat facile account of the general circulation of the atmosphere with special reference to low latitudes. There follows a rather digressionary chapter dealing with the differences between tropical and temperate latitudes as regards meteorological observations and their interpretation. The following chapter on the vertical distribution of temperature is of very patchy quality; for example the terms "lapse rate" and "adiabatic" are introduced without explanation, neither is any inkling given of why a rising parcel of air cools. In the brief theoretical explanation of the tephigram it is by no means evident that temperatures used in formulae are on the absolute scale. On the other hand the explanation given of stability and instability is a most elementary one.

There are next three descriptive chapters on the formation of fog and cloud, precipitation and other phenomena associated with strong convection, and the seasonal and geographical distribution of rainfall in Southeast Asia. The last is a useful and well written summary, illustrated by clear diagrams. However the statement on p. 67 that the maximum frequency of precipitation over the sea normally occurs in the early morning will not pass without question; this is known to be true only for coastal waters.

The kinematics and kinetics of air movements near the equator are dealt with in the next block of four chapters. The treatment is mostly descriptive though now and again there are appeals to the minimum of mathematical background, for example the Rossby long-wave formula and the Petterssen kinematic formulae for the motion of pressure systems. The basic physics and dynamics are skimmed over rather lightly. The restrictive conditions under which the Rossby formula applies are not mentioned, while on p. 86 there is a statement implying that movement of air along the isotherms contributes to its changes of temperature. Frequent reference is made to convergence as an active factor in producing weather but it seems that confluence in the flow patterns is too easily accepted as an indicator of convergence. If shortcomings of this kind occurred only here and there they could be tolerated but similar, though perhaps less glaring ones, characterize much of the book.

The remaining chapters deal for the most part with the practical aspects of weather analysis in Southeast Asia. Inevitably there are the usual comparisons with temperate latitudes (one wonders how synoptic meteorology would have developed in low latitudes alone) and emphasis is rightly laid on air streams and their boundaries. Some practical examples are given. These chapters are the best in the book and make a useful introduction for the forecaster going to the tropics for the first time.

A. G. FORSDYKE.

The atmosphere. By N. C. Gerson. *Air Force Surv. Geophy. Cambridge Mass.* No. 73. 10⅜ in. × 8¼ in., xii + 76, *Illus.*, Air Force Cambridge Research Center, Cambridge Mass., 1955.

It is still probably true to say that for the ordinary synoptic meteorologist the atmosphere ends just above the tropopause. The aurora, ionised layers, meteors and other upper atmospheric phenomena are considered the province of workers in other scientific fields, if not as mere physical curiosities. The pace of development in aviation, both service and civil, suggests, however, that meteorologists may soon be called on for information and advice on conditions in the ozonosphere, and eventually in the ionosphere.

This survey, prompted by the approaching International Geophysical Year programme, is intended to provide for the meteorologist a brief review of the properties of the 5 per cent. of the atmosphere lying beyond 20 Km. The author lists four fields of research from which information has been obtained: auroral physics, ionospheric physics, geomagnetism and cosmic rays. He gives a concise and readable account of the contributions each of these can make, with a note on their historical development.

Mr. Gerson deals then with the structure and composition of the higher atmosphere, following with a brief discussion of atmospheric motions. The remaining sections are concerned with the ionic layers, air glow and auroral statistics, and terrestrial magnetism. Despite the simplification and condensation required by a short survey there are few statements with which one could quarrel. Some controversial points, such as the seasonal variations in ozone concentration, the validity of methods of wind measurement and connections between high- and low-level phenomena are touched upon, but not discussed.

Fully half of the survey is taken up by diagrams relating to a wide range of phenomena. They include: energy-level diagrams for oxygen and nitrogen, neutral and ionized; the local, vertical and latitudinal variations of ozone concentration, the geographical and diurnal variation of the ionic layers, with illustrations for individual locations; absorption wave-bands for various atmospheric gases, and emissions in the air-glow and auroral spectra; and charts of auroral frequency, and of geomagnetic intensity. Several of these are taken from other sources, but it is convenient to have them assembled in this fashion.

The question of nomenclature is one that will shortly require to be settled, if confusion is not to arise. The simplicity of referring to only three atmospheric layers, troposphere, stratosphere and ionosphere, will need to be weighed against the desirability of incorporating words such as mesosphere, chemosphere, thermosphere and exosphere into meteorological literature.

P. GRAYSTONE

OBITUARIES

Mr. Arthur John Lander, M.B.E. It is with deep regret that we record the sudden death of Mr. A. J. Lander, Head of M.O.4, on November 5, 1956, at the age of 57. He entered the Office in 1920 as a Technical Assistant and began his career at the Royal Aircraft Establishment, Farnborough. Rather less than a year later he was transferred to the newly formed Meteorological Department at the Chemical Warfare Experimental Station, Porton, where micrometeorological research was starting under N. K. Johnson. Lander remained at Porton for 15 years. During this period he developed a remarkable talent for designing and making intricate unconventional meteorological instruments, and the pioneer work at Porton owed much to his skilled hands. In 1936 he went to Kew, where he played a considerable part in making the radio-sonde a satisfactory instrument for routine use.

His practical knowledge of this new tool was of great value in 1939 when the setting up of a network of upper air stations became a matter of the highest importance. After visiting Finland and France to obtain first-hand knowledge of the Väisäla and Bureau systems, Lander gave his personal supervision to the task of setting up the radio-sonde stations including those as far afield as the Scilly Isles and Shetland. His efforts ensured the firm foundation of a good aerological service and they were followed by his assuming responsibility for the calibration of all the thousands of radio-sondes that were to be issued in the ensuing years. For this work he was awarded the M.B.E. in 1945.

From 1952 to 1954 Lander's earlier experience of micrometeorological work was put to good use when he collaborated with G. D. Robinson in research into the convective heat flux near the ground. The results of this work formed the subject of two valuable Meteorological Research Papers. In 1955 Lander was made head of the Branch (M.O.4) concerned with the supply and testing of instruments and was promoted to the grade of Chief Experimental Officer.

Lander was a born engineer, and he made no secret of the fact that he preferred the workshop bench to the desk. He will be missed, not only for his professional abilities, but also for his friendliness and good nature. Our deepest sympathies go to his widow and daughter.

O. G. SUTTON.

Mr. S. E. Ashmore, B.Sc., A.Inst.P., F.R.Met.Soc.—The news of the death on October 14, 1956, of Mr. Ashmore, Physics Master at Grove Park School, Wrexham, was received with deep regret.

Mr. Ashmore had maintained a climatological station at the school since 1943, submitting to the Meteorological Office unbroken records of the highest standard. Moreover, so infectious was his enthusiasm for meteorology and so ready his willingness to help and advise, that several others in the area were stimulated into making climatological or rainfall observations.

Nor was his interest limited to observing, but included the physical and geographical interpretation of meteorological phenomena and climatological data. Many of his articles and letters were published in the *Quarterly Journal* of the Royal Meteorological Society, the *Meteorological Magazine*, *British Rainfall*, and *Weather*. The subjects covered by them ranged from the geographical distribution of the annual variation of the diurnal range of temperature, the physics of meteorological optical phenomena, evaporation and percolation, to the semi-permanent snow beds of the British Isles. He was awarded the Darton Prize by the Royal Meteorological Society in 1955.

By his personal efforts and also his example and encouragement to others, Mr. Ashmore made a valuable contribution to the records from voluntary observers—records on which the study of climatology in this country so much depends. It is gratifying to learn that the station which he established at Grove Park School, in particular, is to be continued; there could be no more appropriate memorial to S. E. Ashmore.

Mr. Thomas Walton.—It is with deep regret we learn of the death, at the age of 36, of Mr. T. Walton, as a result of a road accident on the night of November 15, 1956. He joined the Office in May 1948 as a Meteorological Assistant after service in the Meteorological Branch of the Royal Air Force Volunteer Reserve from 1940 to 1948. He served successively at a number of aviation outstations, including a tour of duty in Malta and El Adem. He was promoted Assistant Experimental Officer in 1949 and Experimental Officer in 1954. At the time of his death he was serving at Bassingbourn.

He is survived by a widow and a daughter to whom the sympathy of all who knew him in the Office is extended.

AWARD

Prize of the International Meteorological Organization

The first recipient of the Prize of the International Meteorological Organization is Dr. H. T. Hesselberg, formerly Director of the Norwegian Meteorological Institute, who was President of I.M.O. from 1935 to 1946. The prize, which consists of a gold medal, a diploma and the sum of $1,200, was presented to him in Oslo on September 21, 1956 by M. André Viaut, President of the World Meteorological Organization. The Prize, created by the World Meteorological Organization to perpetuate the memory of its predecessor, is presented annually by the Executive Committee of W.M.O. for contributions to meteorological science combined with devotion to the cause of international meteorology.

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. A. J. Tabor, Senior Experimental Officer, retired on August 10, 1956, after 45 years' service. He joined the Office in December 1911 as a Boy Clerk in the Marine Division. In 1917 he was posted to the

Forecast Division and in April 1918 he joined the Royal Garrison Artillery as a gunner. On demobilization in February 1919 he returned to the Forecast Division. In April 1920 he was transferred to the Marine Division where he remained for 28 years. Since 1948, until his retirement, he worked in the Civil Aviation (Home) Branch on administrative duties.

Courses of training for climatological observers.—Two courses, each lasting four and a half days, were held in October 1956 at the Meteorological Office Training School, Stanmore, and 36 observers attended. Instruction and discussions covered the exposure and maintenance of instruments, the making of observations, and the completion of returns. Films and slides were shown, and talks given on some of the applications of climatological data. Special attention was paid to the work at Crop-Weather and Health-Resort Stations. Visits were made to the forecasting branch at the Air Ministry and to Harrow, where the work of the British Climatological Branch, the recording of data on punched cards in the Marine Branch, and the testing of instruments were seen and discussed. The courses are designed to help the observers with their specific work, to broaden their interests in meteorology, and to give them an insight into the ultimate purpose of the observations. It is hoped to arrange similar courses in October 1957.

WEATHER OF NOVEMBER 1956

The main cyclonic activity in the Atlantic was again north of its usual path and was probably unusually concentrated all month along the east coast of Greenland. This gave mean pressure values for the month 8 mb. below normal about Scoresby Sound in 70°N. Temperatures were 4° to 5°C. above normal from Iceland to Spitsbergen, and precipitation was very excessive on the windward southern slopes of Iceland and eastern slopes of north-east Greenland (excesses up to 600 per cent. of normal, these being unusually high figures for such a region).

As in October, the Azores anticyclone was shifted north, towards the British Isles, the monthly pressure anomaly reaching + 10 mb. near south-west Ireland.

The North-Pacific depressions appear also to have been north of normal, but not notably intense, whereas the north-east extension of the Pacific anticyclone over the central Rockies was remarkably intense and persistent. Mean pressure for the month was 8–10 mb. above normal over a wide area of western North America between 40° and 55°N., with peak values of 1030 mb.

The Siberian anticyclone was rather above normal intensity and its centre shifted somewhat north and north-east. The system had sufficiently increased extent to cover all central Asia in spite of the shift of centre.

Temperatures were slightly above normal in the broad south-westerly air stream from central Asia to the Arctic. Bigger excesses occurred in the south-westerly winds reaching the Canadian Rockies and in the Chinook region on the lee side, where anomalies reached +4°C. There was another region of temperatures 1° to 3°C. above normal between the Great Lakes and the Atlantic seaboard of the United States and Canada from 35° to 50°N.

The month was cold over most of Europe, except the British Isles; the anomaly pattern culminating with —6°C. over Finland was rather reminiscent of November 1955. There were also regions of negative anomaly

−1° to −3°C. over most of northern and central North America, over the central Rockies and in far-eastern Siberia. Locally over north Labrador, over Baffin Land, and north of Irkutsk, anomalies of −5°C. for November were reported.

In the British Isles this unusually dry November was dominated by anticyclones over north-west Europe or the eastern Atlantic.

The month opened with an intense anticyclone over Scotland with pressure at Benbecula 1044·5 mb., a new high November record of pressure in the British Isles. During most of the first week an anticyclone was situated to the west or north-west of the country and weather was cloudy with slight rain or drizzle and moderate north-westerly winds. As the anticyclone crossed southern England to the continent on the 6th and 7th, early morning frost and fog became widespread; at some places fog persisted most of the day but at others there were good sunny periods. On the 7th temperatures rose generally to the upper fifties as strong southerly winds spread into the western part of the country. The next four days were changeable with rain at times, and although some heavy falls occurred for short periods, rainfall was not substantial anywhere. A period of quiet, rather foggy weather followed with slight local rain, mainly in the north, and frost at night, as an anticyclone from the Azores moved north and then crossed England to the continent. On the 19th winds increased from the south-east ahead of an Atlantic trough; temperature began to fall steadily, and by the 21st cold continental air had spread over much of the British Isles. Frost was widespread; at Cardington a temperature of 18°F. was recorded in the screen on two successive nights. The cold spell was brought to an end by a frontal system which moved south-east into Scotland on the 24th, and as the associated warm front crossed the country the following day temperatures rose above 50°F. everywhere. Severe gales occurred in northern districts as very cold air again swept southwards over the British Isles on the 25th; wind rose in gusts to 70–90 kt. in Scotland. Strong, cold northerly winds persisted until the 29th and there were frequent snow showers in the north and scattered snow showers as far south as the Home Counties.

The main feature of the month was the low rainfall. Over the country as a whole it was the driest November since records began in 1869 apart from 1945 and also the driest month of 1956 so far. The mean temperature was only slightly below normal despite the severity of the two cold spells.

The mainly dry weather has enabled most farmers to catch up with their routine work and good progress has been made. The first general frost of the autumn was severe but later than usual so that its effect was not very great.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	63	17	−0·6	37	−5	99
Scotland	60	16	+1·2	62	−4	78
Northern Ireland ...	56	24	+1·4	70	−3	66

RAINFALL OF NOVEMBER 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	0·38	16	*Glam.*	Cardiff, Penylan ...	1·45	36
Kent	Dover	0·69	22	*Pemb.*	Tenby	1·33	31
,,	Edenbridge, Falconhurst	0·88	25	*Radnor*	Tyrmynydd	3·34	50
Sussex	Compton, Compton Ho.	1·01	27	*Mont.*	Lake Vyrnwy	2·83	49
,,	Worthing, Beach Ho. Pk.	0·69	22	*Mer.*	Blaenau Festiniog ...	4·47	42
Hants.	St. Catherine's L'thouse	0·94	30	,,	Aberdovey	2·69	59
,,	Southampton (East Pk.)	0·82	26	*Carn.*	Llandudno	1·43	49
,,	South Farnborough ...	0·72	27	*Angl.*	Llanerchymedd ...	1·71	41
Herts.	Harpenden, Rothamsted	0·80	30	*I. Man*	Douglas, Borough Cem.	1·48	31
Bucks.	Slough, Upton	0·41	18	*Wigtown*	Newton Stewart ...	2·17	44
Oxford	Oxford, Radcliffe ...	0·77	33	*Dumf.*	Dumfries, Crichton R.I.	1·02	28
N'hants.	Wellingboro' Swanspool	0·66	31	,,	Eskdalemuir Obsy. ...	2·81	48
Essex	Southend, W. W. ...	0·42	19	*Roxb.*	Crailing...	0·80	34
Suffolk	Felixstowe	0·55	27	*Peebles*	Stobo Castle	1·42	43
,,	Lowestoft Sec. School ...	1·13	48	*Berwick*	Marchmont House ...	0·89	30
,,	Bury St. Ed., Westley H.	0·72	31	*E. Loth.*	North Berwick Gas Wks.	0·61	28
Norfolk	Sandringham Ho. Gdns.	1·17	47	*Midl'n.*	Edinburgh, Blackf'd. H.	0·65	29
Wilts.	Aldbourne	0·93	30	*Lanark*	Hamilton W. W., T'nhill	1·23	34
Dorset	Creech Grange... ...	0·87	21	*Ayr*	Prestwick	1·30	40
,,	Beaminster, East St. ...	0·70	18	,,	Glen Afton, Ayr San. ...	3·34	61
Devon	Teignmouth, Den Gdns.	1·04	33	*Renfrew*	Greenock, Prospect Hill	2·65	44
,,	Ilfracombe	1·68	43	*Bute*	Rothesay, Ardencraig ...	...	...
,,	Princetown	5·11	58	*Argyll*	Morven, Drimnin ...	6·08	90
,,	Werrington Park ...	2·39	52	,,	Poltalloch	4·05	72
Cornwall	Penzance	2·38	52	,,	Inveraray Castle ...	5·29	63
,,	St. Austell	2·73	55	,,	Islay, Eallabus	3·68	68
,,	Scilly, Tresco Abbey ...	1·57	46	,,	Tiree	3·64	75
Somerset	Taunton	0·62	23	*Kinross*	Loch Leven Sluice ...	0·62	17
Glos.	Cirencester	0·81	26	*Fife*	Leuchars Airfield ...	0·76	33
Salop	Church Stretton ...	1·50	48	*Perth*	Loch Dhu	3·45	40
,,	Shrewsbury, Monkmore	0·76	34	,,	Crieff, Strathearn Hyd.	0·92	21
Worcs.	Malvern, Free Library...	0·68	27	,,	Pitlochry, Fincastle ...	1·30	35
Warwick	Birmingham, Edgbaston	0·87	33	*Angus*	Montrose, Hospital ...	0·90	34
Leics.	Thornton Reservoir ...	0·96	42	*Aberd.*	Braemar	1·22	32
Lincs.	Boston, Skirbeck ...	0·79	40	,,	Dyce, Craibstone ...	1·78	55
,,	Skegness, Marine Gdns.	1·01	47	,,	New Deer School House	2·78	82
Notts.	Mansfield, Carr Bank ...	1·02	42	*Moray*	Gordon Castle	1·82	63
Derby	Buxton, Terrace Slopes	1·85	40	*Nairn*	Nairn, Achareidh ...	1·45	64
Ches.	Bidston Observatory ...	1·39	56	*Inverness*	Loch Ness, Garthbeg ...	3·19	76
,,	Manchester, Ringway...	1·22	47	,,	Loch Hourn, Kinlochourn	9·85	83
Lancs.	Stonyhurst College ...	2·27	50	,,	Fort William, Teviot ...	7·96	97
,,	Squires Gate	1·26	38	,,	Skye, Broadford ...	7·27	85
Yorks.	Wakefield, Clarence Pk.	0·55	26	,,	Skye, Duntulm ...	5·58	93
,,	Hull, Pearson Park ...	0·73	33	*R. & C.*	Tain, Mayfield... ...	2·15	73
,,	Felixkirk, Mt. St. John...	1·63	67	,,	Inverbroom, Glackour...	...	...
,,	York Museum	0·65	31	,,	Achnashellach	11·74	136
,,	Scarborough	1·69	68	*Suth.*	Lochinver, Bank Ho. ...	5·42	107
,,	Middlesbrough... ...	0·98	46	*Caith.*	Wick Airfield	3·67	117
,,	Baldersdale, Hury Res.	1·41	39	*Shetland*	Lerwick Observatory ...	3·61	85
Norl'd.	Newcastle, Leazes Pk....	0·65	28	*Ferm.*	Crom Castle	2·26	65
,,	Bellingham, High Green	1·09	32	*Armagh*	Armagh Observatory ...	2·24	79
,,	Lilburn Tower Gdns. ...	0·68	20	*Down*	Seaforde	2·34	62
Cumb.	Geltsdale	2·30	70	*Antrim*	Aldergrove Airfield ...	1·30	40
,,	Keswick, High Hill ...	2·51	44	,,	Ballymena, Harryville...	2·39	59
,,	Ravenglass, The Grove	1·50	34	*L'derry*	Garvagh, Moneydig ...	3·16	80
Mon.	A'gavenny, Plâs Derwen	1·37	33	,,	Londonderry, Creggan	3·94	96
Glam.	Ystalyfera, Wern House	2·38	36	*Tyrone*	Omagh, Edenfel ...	2·88	78

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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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RADIO-SONDE TRIALS AT PAYERNE, 1956.

By A. H. HOOPER.

Payerne, a small country town lying away from the main tourist routes of Switzerland, is generally remembered for its white wine and for its "Abbatiale", the clock of which announces the passage of each hour with a double set of chimes. In the field of meteorology it is known, too, as the venue for the two international comparisons of radio-sondes conducted to date. The later of these events took place during May and June of 1956, delegates from 13 countries being present with 14 types of radio-sonde. From the results of this comparison, in the course of which about 370 radio-sondes were launched, it is expected to gain information, up to high levels, of the magnitude of instrumental differences. As nearly all types of the world's radio-sondes were represented, this information will be of considerable significance in the realm of routine upper air analysis and in the aerological programme of the International Geophysical Year.

The comparison, which was conducted by a working group of the World Meteorological Organization Commission for Instruments and Methods of Observation, can be divided into two main sections. In the first, radio-sondes were flown in groups of four, being suspended at standard intervals in a vertical train from a cluster of three balloons. The soundings were carried out by day and by night, the groups of radio-sondes and their positions in the trains following a statistical pattern proposed by Dr. A. Delver of the Netherlands. In the second section larger groups of radio-sondes were flown to obtain sufficient data for the direct comparison of any pair. Over the trials as a whole, ascents reached an average height of 22·1 Km. Although not coming within the main programme, four types of wind-finding equipment were compared in respect of elevation and azimuth measurements. One of them, the 3-cm. equipment by Decca, gives, in addition, a third and important parameter, range, enabling winds to be found without the need for an active balloon-borne transmitter; it also eliminates uncertainties which derive from the use of radio-sonde pressure-temperature data to give height. An attempt was made to overcome the effect of any instrumental damage incurred during launching by comparing each radio-sonde with the values given by a distant-recording meteorograph suspended at a known level from a kite-balloon. To this end the time of transit through the level was obtained from observations made by the Decca radar operated by a very willing team from the company.

For United Kingdom participation a mobile unit (see photographs facing p.48) was prepared, using a vehicle specially fitted as a radio-sonde operations room. Much interest was aroused by this unit, both during the journey and in operation. Despite the poor road surfaces experienced in travelling across Europe the equipment arrived at Payerne in excellent condition, the calibrations of the ground installation were virtually unchanged whilst those of the radio-sondes were altered to an extent smaller than that associated with delivery by rail.

Following the preparatory work of installation and testing, a number of trials were conducted in order to establish a technique for launching the trains of radio-sondes. After two practice launches and much good-humoured controversy, the problems of language and management were overcome and a launching "pattern" agreed for subsequent work.

It was an essential feature of the Delver programme that all radio-sondes in all soundings should yield information at all levels of comparison. In consequence the failure of any one radio-sonde in the course of ascent necessitated repetition by that particular group of radio-sondes. The expense of obtaining complete instrumental reliability is, of course, prohibitive, so that with any type of radio-sonde a small percentage of failures during ascent must be expected. With four radio-sondes in each train the probability of an ascent failure is considerably increased and despite the utmost precautions a number of repetitions were, in fact, necessary.

The second series of ascents began cautiously with a train of eight radio-sondes, later followed by two trains of nine. The photograph in the centre of the magazine shows the final stage of preparation of a train of eight radio-sondes; the last balloon is being tied up in the shelter, the sondes are being assembled down wind and two individuals can be seen running to help in letting up the eight balloons. Then followed the most memorable day of all, June 11, when in calm weather, a train of all 14 types of radio-sonde was assembled and, with some trepidation, attached to a cluster of 15 balloons. With a total lift of 56 Kg. the launch presented several problems. Would the balloon launching team, suitably augmented, be able to let up the balloons successively on their individual cords and retain control until the moment came for release? Would the initial acceleration due to such a great lift so increase the normal launching "snatch" that the earlier sondes of the train would be damaged? Would the 91-m. train of radio-sondes extending in a zigzag right across the launching area and into the neighbouring field so limit manoeuvrability that the later radio-sondes could not be launched clear of adjacent obstacles? In the event the launch was wholly successful. The balloons were restrained by three of the balloon team grasping the junction knot. Then, upon release, the radio-sonde team ran with their instruments first towards the balloon team for the earlier sondes to rise vertically, and then away from them for the later radio-sondes to rise without risk of swinging to the ground. Everyone then retired to their receiving equipment for an hour anxiously awaiting possible failure. With great luck, however, all radio-sondes, in their several ways, gave sounding data to the burst level of 35 mb. This ascent, it is believed, comprising an assembly extending over 200 m. from the uppermost balloon to the lowest radio-sonde, represents a notable achievement in the history of upper air exploration and was, for the fleeting hour of its life a symbol of whole-hearted international collaboration. Encouraged by its success and by the resulting saving in time, further attempts were made in various strengths of wind until, in all, eight such soundings had been completed. Inevitably, the number of radio-sonde failures during this period approached the average, emphasizing thereby the extraordinary luck attending the first attempt. The positions of the radio-sondes in the trains were unchanged over this period, all presenting especial difficulties, ranging from the first with a maximum of "snatch" to the last with a maximum of sprinting.

A small Secretariat was set up whose functions day by day were to duplicate and distribute the voluminous data compiled from each sounding, together with, in several languages, information sheets based upon decisions taken at daily Working Meetings. The commencement of 14-radio-sonde soundings so increased the work of the members of the Secretariat that they were active far into each night. It is to their great credit that the delegations were able to leave Payerne in possession of most of the data. As a result of this very considerable start it is hoped that the extensive tables summarizing the results of the trial will be produced by the Working Group by the Spring of 1957.

To ensure the use of a common time scale for all radio-sonde data a network of slave clocks was installed, a pair at each set of observing equipment, giving time in minutes and seconds. A loudspeaker at each position together with various public-address units gave both additional operational information and, during the stresses of launching, encouraging exhortations. What the neighbouring farmers made of the latter was never ascertained.

In striving for reliability continual attention is given, in radio-sonde work, to the different types of instrumental failure. In nearly all cases the disappearance of a transmission signal is assigned to valve or circuit failure of the radio-sonde. It is possible, however, that a small proportion of such failures can arise from damage by lightning. This occurrence, in routine conditions, cannot readily be proved. It is interesting to record, therefore, that on one occasion during trials the signals from all four of a train of radio-sondes ceased shortly after launching in thundery conditions. The simultaneous cessation of signals from radio-sondes of independent and widely different circuit arrangement is very strong evidence of an "external" cause. Having regard to the conditions prevailing it appears highly probable that the train was struck by lightning and the circuits damaged.

The balloons, upon which the success of the comparison depended, were contributed by several countries and were used in various combinations without noticeable difference in performance. Each balloon in a cluster was provided with a separate cord of unique length leading to a common knot from which hung the train of radio-sondes. Although before release the cords of the upper balloons chafed on the lower balloons it was found that in flight the balloons became widely separated and were at no time in danger of damaging each other. The photograph in the centre of the magazine shows a cluster of 15 balloons in flight. Despite the unusual angle their degree of separation is clear. The parachutes, radar reflector and upper radio-sondes of this particular sounding can just be seen, trailing away to the lower edge of the photograph.

The trials provided an unparalled opportunity of examining the detailed construction of the radio-sondes of the world and of observing them in action.

The main impression was of the great diversity of design and circuits; the fact that they represent 14 solutions to the single problem of measuring upper air conditions is a striking example of the independence of human invention. For pressure measurements all but one use an aneroid, the exception being an experimental radio-sonde of the Netherlands in which a hypsometer is employed. For temperature, bi-metallic strips of various sizes are in general use, but two instruments make use of thermistors. The Japanese sonde includes two mercury-in-glass thermometers to provide checks during ascent of the bi-metal calibration. The sensing materials for humidity are hair, gold-beater's skin and lithium chloride. The weights of complete radio-sondes range from a minimum of 300 gm. to a maximum of 2,200 gm. Naturally the appearances, too, of the radio-sondes vary widely. To one accustomed to handling the British type it was a distinct surprise to learn from a Swiss magazine that our own device was in other eyes, "à forme amusante".

Those of us privileged to participate in the trials will remember many things, the friendships, the amusements arising from diversity of language, the international team-spirit engendered by launchings and, above all, the generous and unfailing help of our Swiss hosts. To them must go the credit for a remarkable achievement of organization, which was so essential to the success of the trials.

ATMOSPHERIC SMOKE CONCENTRATION MEASUREMENTS AT ESKDALEMUIR

By D. H. McINTOSH, M.A., B.Sc.

Introduction.—The measurement of atmospheric smoke concentration has been made continuously at Eskdalemuir Observatory since late 1948 by means of equipment provided by the Director of Fuel Research, Department of

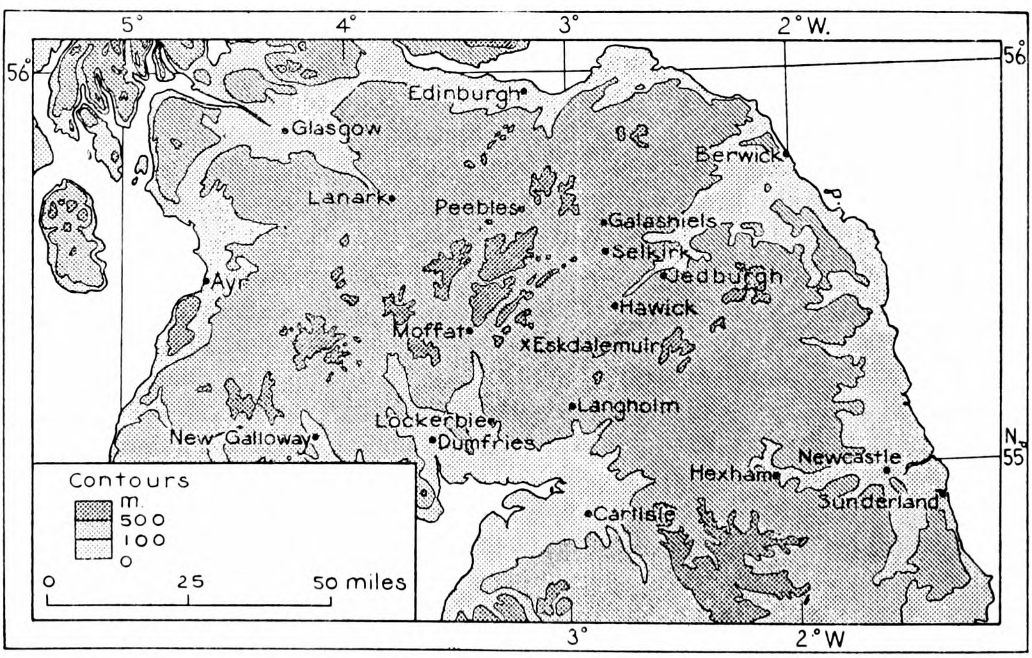


FIG. 1—MAP SHOWING POSITION OF ESKDALEMUIR IN RELATION TO CENTRES OF POPULATION AND INDUSTRY

Scientific and Industrial Research. As would be expected the smoke concentration at Eskdalemuir is relatively very low, but the unusually isolated location of the Observatory—18 miles from the nearest town and nearly three times as far from any major source of smoke (see Fig.1)—makes for rather special interest in the observations. The possible effects of changes in quite local sources of smoke is a factor which introduces an element of uncertainty into the assessment of most series of smoke measurements: those at Eskdalemuir are unusual in that they may with confidence be regarded as being free from such uncertainty.

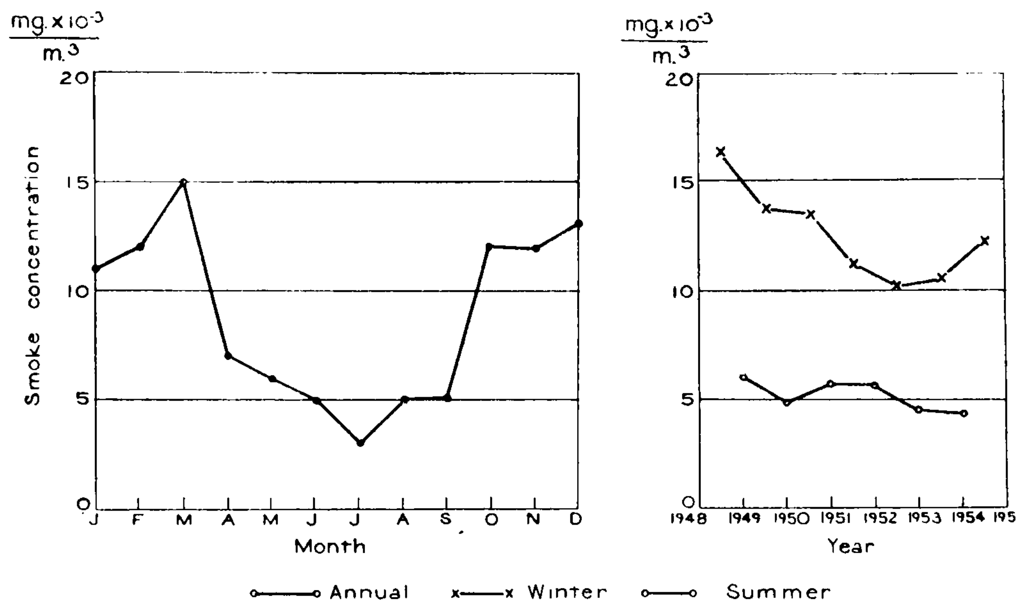
Here the results of nearly seven years' observations are used to investigate systematic weekly, annual and secular variations and the association of daily measured concentration with wind speed and direction.

Method of measurement.—The method of measurement is to draw, by means of an electric pump, a measured volume of air through a white filter paper in such a way that all the solid impurity in the air remains in the filter as a grey stain. The weight of the impurity caught is estimated at the Fuel Research Station by matching the stain with a scale of shades which has previously been calibrated by matching with weighed stains. Before June 1949 the stain values were obtained visually by the scale of shades: subsequently they have been determined by measuring the reflectance of the stains photoelectrically. A fresh stain is obtained at Eskdalemuir for each 24-hr. period beginning in the evening. The daily average smoke concentration was expressed over most of the period in the unit 10^{-3} mg./m.^{3} but recently the Fuel Research authorities have employed the unit 10^{-2} mg./m.^{3} as they no longer consider the accuracy implied in the smaller unit to be justified.

Magnitude of systematic variations.—The departures from monthly mean concentrations had already been evaluated in terms of the smaller unit of measurement when the change to the larger unit was made. It was decided to retain the smaller unit in looking for systematic effects since the additional figure would, at worst, occur as a random element. Subsequent detailed examination of the groupings of the departures, in terms of surface wind speed and direction, for example, strongly suggests that part of the additional implied accuracy is justified during the summer months when the smoke concentration is very low: this does not appear to be the case during the winter months when the average concentration is higher. The operation of the normal law of errors enables systematic, i.e. average, winter effects to be determined with an accuracy of about the discarded unit for individual measurement, while the accuracy in summer is slightly greater.

Weekly variation.—The individual daily smoke concentrations from October 1948 to June 1955 were examined for evidence of a systematic weekly variation: the results for the six "summer" months April to September, and six "winter" months October to March were considered separately. In both cases the minimum daily average concentration occurred on Sunday, the winter value for that day being 5 per cent., and the summer value 20 per cent., below the corresponding weekly average concentration. Examination of the "casual" errors involved shows that only the latter value is statistically significant. Since, however, the average concentrations on Saturday and Monday were in both seasons also below the weekly average, there is little doubt that a week-end decrease of smoke concentration was in both seasons a real feature of the observations. Local conditions provide no explanation for this feature which was therefore presumably caused by the lower week-end smoke output from distant factory chimneys.

Annual variation.—Average monthly smoke concentration over a period of nearly seven years is shown in Fig. 2. The graph shows the expected feature of winter maximum and summer minimum. From results to be discussed later it is probable that the winter maximum is delayed till March mainly because of a higher frequency of easterly winds in that month than in the earlier winter months. Another possible factor in the curve of the annual variation of smoke is the burning of moorland grass which is done in parts of the surrounding countryside in late winter or spring provided there is a suitable dry spell. While this may be an additional factor in the delay of maximum concentration till March it is unlikely to be an important factor because the moor burning is more frequently carried out in April and May, which had in every year appreciably lower average concentrations than March. It should perhaps be emphasized that throughout the series of measurements there was no day or succession of days which showed so large a smoke concentration as to indicate that an important local source of smoke was active.



1400 G.M.T., April 13, 1955 0200 G.M.T., March 16, 1955

FIG. 2—VARIATION OF SMOKE CONCENTRATION AT ESKDALEMUIR, 1948–55

Secular variation.—Fig. 2 also shows the year-to-year change of measured smoke concentration. A decrease over the period of some 30 per cent. in winter and 15–20 per cent. in summer is suggested by the curves, and statistical examination of the individual monthly values shows that the decrease is too large to be accounted for by chance fluctuations. The apparent decrease is however unreliable on two counts:

(*a*) photo-electric as opposed to visual measurement of the stains was introduced in May 1949, and may have caused a discontinuity in the computed smoke concentrations;

(*b*) because of the apparent secular change in the measurements, the gas meter of the ordinary domestic type employed in the measurements was in

September 1955 tested in series with a recently calibrated meter and found to have a positive error of about 7 per cent. Since the meter was accurate at the time of installation, about 7 per cent. of the apparent decrease of smoke concentration can reasonably be attributed to a subsequently developed fault in the meter.

The conclusion drawn from the series of Eskdalemuir measurements is that a decrease in average smoke concentration of some 10–15 per cent. has probably occurred during the period of measurement.

Variation with surface wind.—The smoke concentration on each day of the first three years of observation was expressed as a departure from the appropriate monthly mean, and these values were coupled with the corresponding prevailing surface wind direction and mean speed over the 24-hr. period, obtained from the hourly wind tabulations: on the many occasions on which no "prevailing" wind direction could be decided on, the wind was listed as "variable". The departures were grouped in 13 divisions according to wind direction, 12 each covering a range of 30° (350°–010°, 020°–040° etc.), the other being the "variable" winds: each of these groups was sub-divided five times according to mean wind speed, the lower limits being 0, 2, 4, 7 and 10 m./sec.

A cursory examination was enough to reveal system in the grouping of smoke concentration departures with respect to both surface wind speed and direction, and the period of three years was long enough to provide sufficiently reliable mean departures. The results for the six summer and six winter months were considered separately.

Variation of smoke concentration with surface-wind speed.—Apart from apparently casual influences the progression of the smoke-concentration departures was in all wind-direction groups in the same sense of decrease of smoke concentration with increase in wind speed, this effect being superimposed on another in which, broadly, easterly winds had positive departures and westerly winds negative. The process of condensing the original 13 groups into 5 groups, N.,

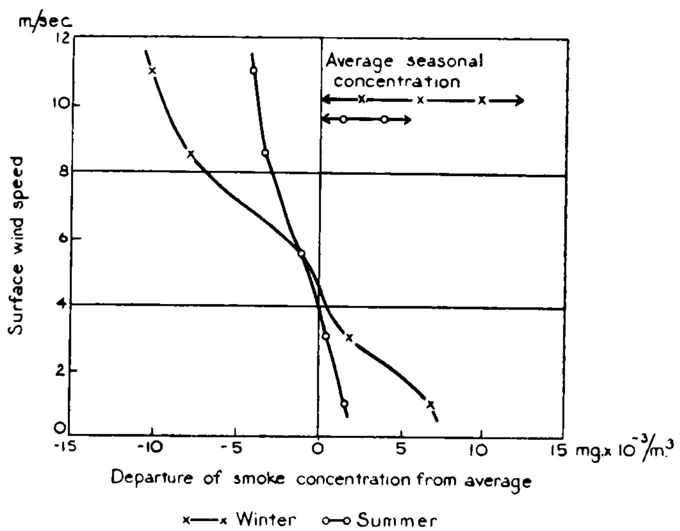
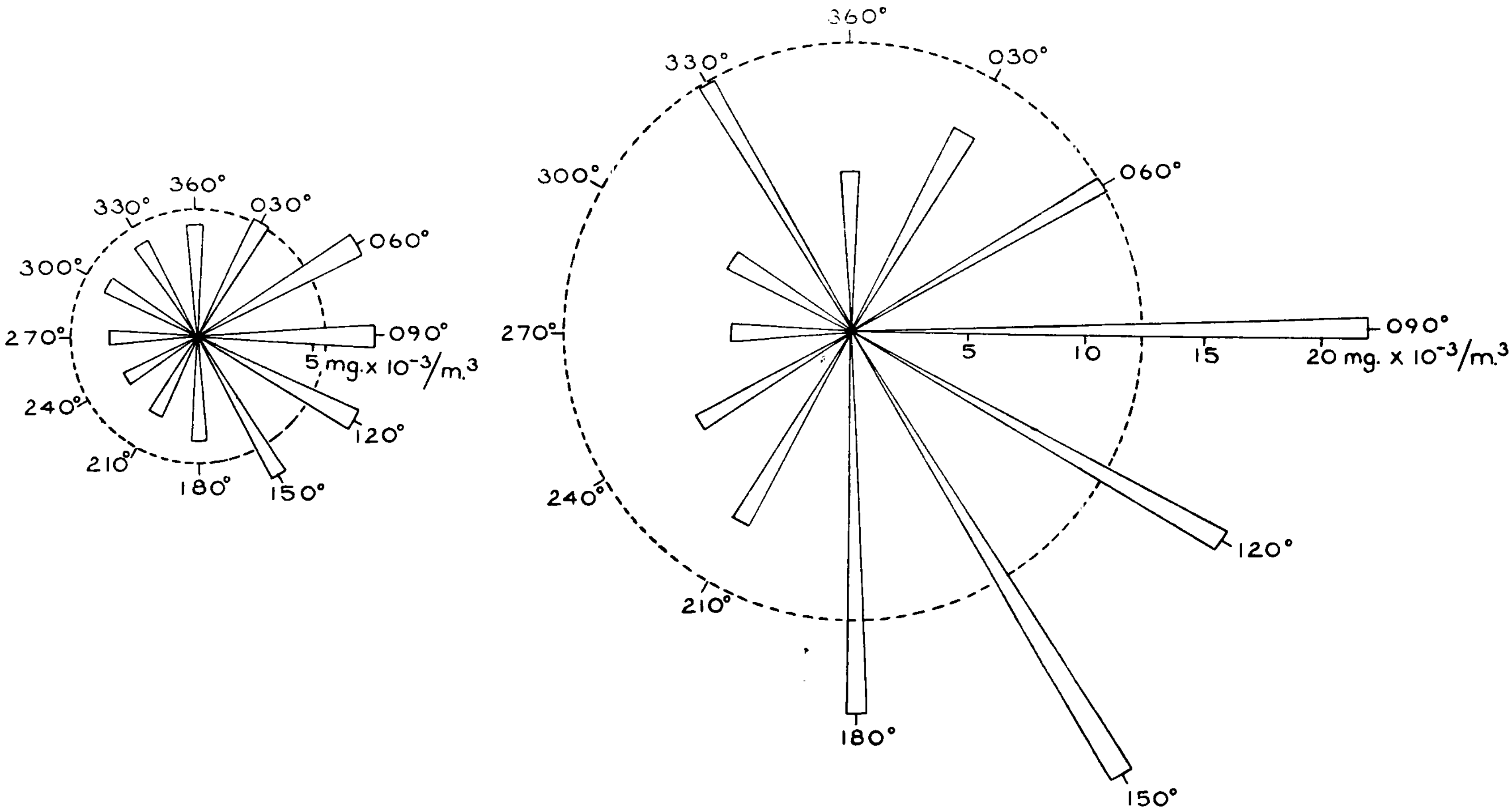


FIG. 3—VARIATION OF SMOKE CONCENTRATION WITH SURFACE WIND SPEED AT ESKDALEMUIR, 1948–51



Summer

Winter

FIG. 4—VARIATION OF SMOKE CONCENTRATION WITH SURFACE WIND DIRECTION AT ESKDALEMUIR, 1948–51

E., S., W. and variable, for better sampling revealed no significant difference in the way in which the smoke concentration varied with wind speed in these bigger groups. The individual mean departures in each wind-speed range of the 13 groups were therefore averaged, appropriate allowance being made for the fact that in some wind directions cases of high wind speed were lacking. The results are shown in Fig. 3 in which the mean departures appropriate to the middle points of the five wind speed-ranges, 11 m./sec. in the highest range, are plotted. These results apply to all wind directions and are freed, as far as possible, by the method adopted from the influence of varying frequency of winds of different direction. The curves cross the line of zero departure at points close to the seasonal mean wind speed, about 4 m./sec.

Variation of smoke concentration with surface-wind direction.—A procedure analogous to that described above was used to determine the variation of smoke concentration with wind direction, the influence of varying wind speed being removed. The results for summer and winter are shown in Fig. 4, the radius of the circle representing the seasonal average concentration of smoke and the lengths of the radii the concentrations corresponding to the wind directions considered. As with the wind-speed variation the effect of the varying frequency of winds in different directions has been removed from the results. The smoke concentration for the group of variable winds was found to differ insignificantly from the seasonal average covering all wind groups.

Precise determination of the standard error of the plotted means is made difficult by the day-to-day coherence of surface wind and of smoke concentration and also by the rather complicated procedure followed in trying to distinguish clearly the separate effects of surface wind speed and direction: approximate calculation shows, however, that all the main features that appear on the graphs are statistically reliable. These features are:

(i) There is in both seasons a decrease of smoke concentration with increase of surface wind speed throughout the range of wind speed observed. The data are not reliable enough to determine the exact nature of the curve in either case.

(ii) The smokiest wind direction at Eskdalemuir is centred on E. in summer and SE. in winter. The Newcastle area appears to be the main source of the smoke, although the relative stability of air masses associated with these surface winds is no doubt also important.

(iii) The relatively high concentration of smoke associated in winter with surface winds in the range 320°–340° appears to be a reliable feature in that season and is probably to be attributed to the Glasgow source in spite of its absence in summer.

Acknowledgment.—The observations were made as part of the co-operative scheme for measuring atmospheric pollution at a large number of places throughout the United Kingdom. The scheme is operated by the Fuel Research Station which also supplies the apparatus.

A STATISTICAL ANALYSIS OF VERTICAL VARIATION OF SUNSHINE OVER GERMANY

By G. A. TUNNELL, B.Sc.

In the course of collecting bright-sunshine data for Europe the vertical variation of the duration of sunshine in Germany (data from Deutsches meteorologisches Jahrbuch 1924–33) was examined as part of the preliminary work for mapping the data. This problem has been examined for numerous areas by continental meteorologists. The most systematic examination has been carried out for 90 stations in Austria by Conrad[1,2] who has expressed the seasonal variation at a number of levels by a Fourier series and has described the variation with height of average values and the amplitudes and phases of the first two terms.

The present analysis is concerned with the mean duration for each place for each month and examines simultaneously both the horizontal and vertical fields. Data for about 40 stations for each month of the year for a uniform

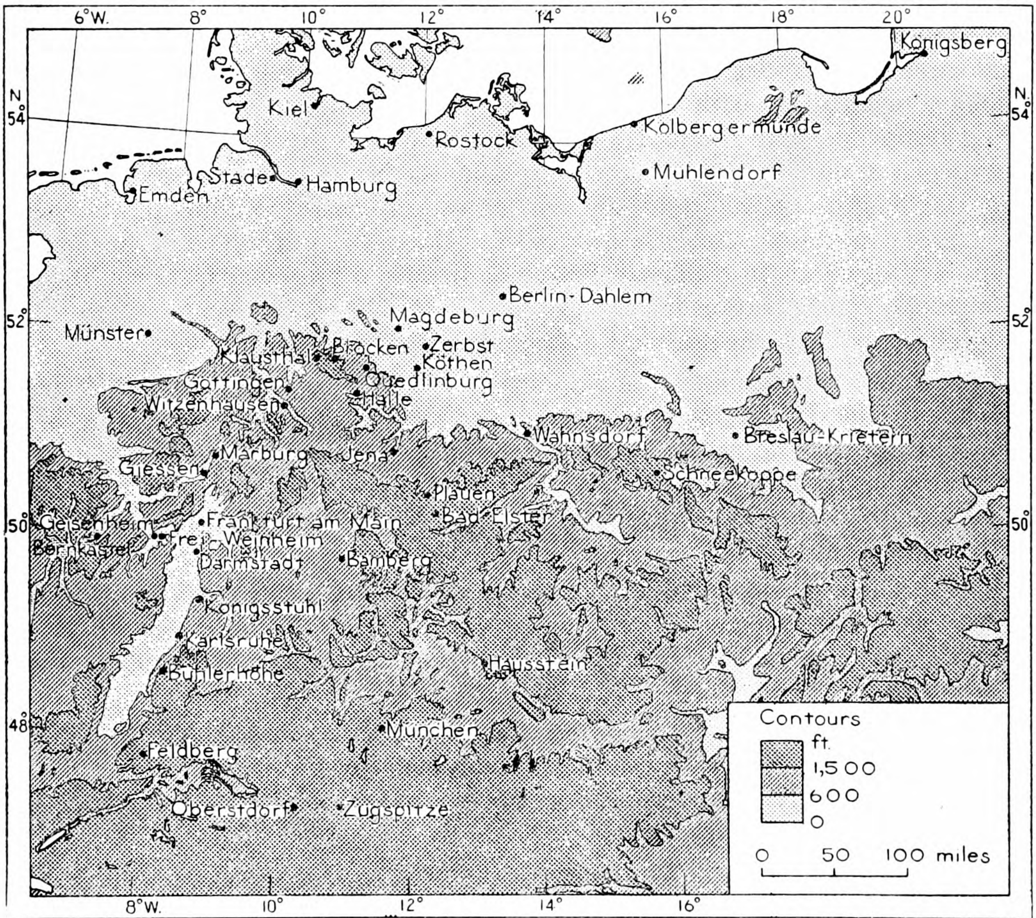


FIG. 1—DISTRIBUTION OF STATIONS IN GERMANY

Station heights in metres

Bad Elster	528	Göttingen	183	Muhlendorf	101
Bamberg	303	Halle	122	München	516
Berlin—Dahlem	58	Hamburg	53	Munster	60
Birnkastel	145	Hausstein	677	Oberstdorf	827
Breslau—Krietern	130	Jena	164	Plauen	401
Brocken	1157	Karlsruhe	136	Quedlingburg	143
Bühlerhöhe	785	Kiel	42	Rostock	45
Darmstadt	166	Klausthal	602	Schneekoppe	1618
Emden	3	Kolbergemünde	17	Stade	41
Feldberg	1471	Königsberg	32	Wahnsdorf	257
Frankfurt am Main	122	Konigstuhl	573	Witzenhausen	152
Frei—Weinheim	97	Köthen	107	Zerbst	73
Geisenheim	112	Magdeburg	88	Zugspitze	2972
Giessen	181	Marburg	251		

period 1924–33 have been analysed. Fig. 1 gives the distribution of stations with their respective heights. The values used are mean daily durations, expressed as a percentage of monthly mean possible sunshine in order to avoid effects due to purely astronomical causes. In the remainder of the paper percentage of possible sunshine is referred to simply as sunshine. The analysis is similar to that used in an earlier paper on the reduction of vapour pressure to sea level[3].

The data have been fitted by the method of least squares to an equation of the form

$$S = Ah + B\lambda + C\phi + D, \qquad \ldots\ldots (1)$$

where

S = Monthly average percentage of possible sunshine
h = Height of the meteorological observing station above sea level in metres
λ = The latitude of the station in degrees north
ϕ = The longitude of the station in degrees east of Greenwich
A, B, C and D are constants for any given month.

A is a constant of particular interest because it is the rate of change of sunshine with height i.e. $\partial S/\partial h$. There are 12 analyses, one for each month and the results have been put in Table I and Fig. 2.

There is a striking seasonal variation of A from a high positive value in December to a high negative value in May; this is the main concern of this paper. The goodness of fit of equation (1), as indicated by the coefficient of multiple correlation (R in Table I) is best when the magnitude of A is greatest. When the magnitude of A is low as in March and September the fit is poor.

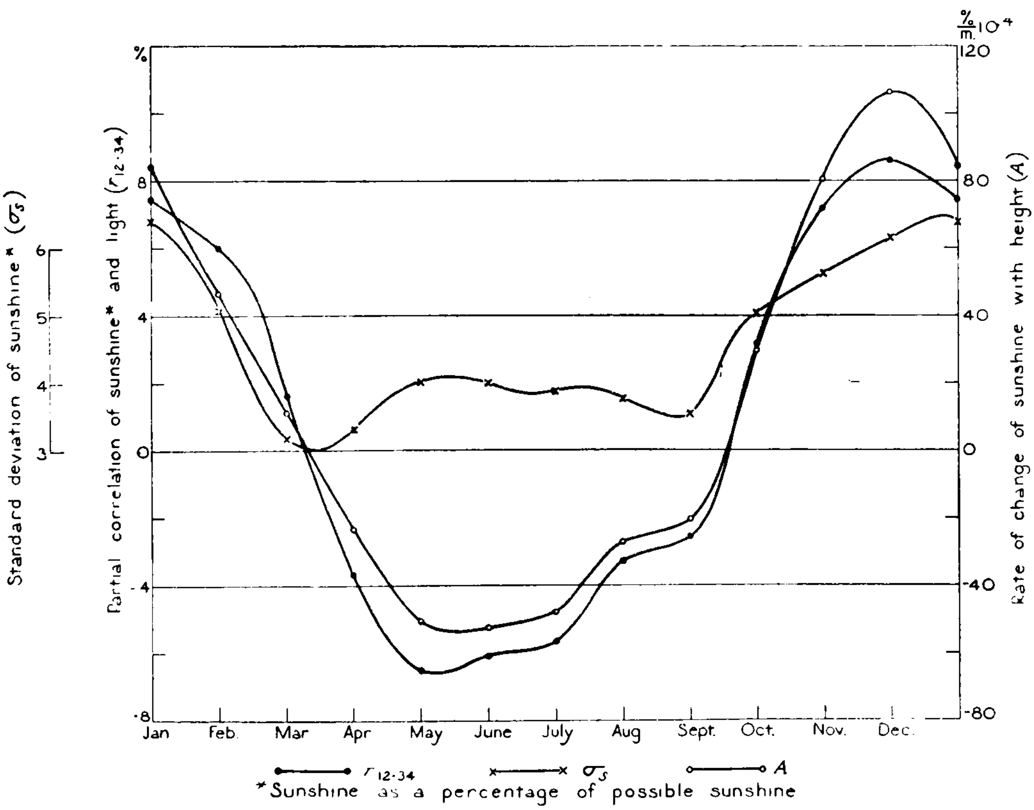


FIG. 2—MONTHLY VARIATION OF SUNSHINE

TABLE I—STATISTICAL ANALYSIS OF SUNSHINE DATA FOR GERMANY, 1924–33

No. of stations = 41

	Values of constants* A	B	C	D	Standard deviation† σ_s	Average value $\overline{S}$	Correlation coefficients r_{sh}	$r_{s\lambda}$	$r_{s\phi}$	$r_{sh\cdot\lambda\phi}$	R
	%.10²/m.	%/°N.	%/°E.	%	%	%					
January	+0·8417	−0·6159	+0·3589	+45·52	6·398	21·20	+0·84	−0·54	+0·09	+0·74	+0·85
February	+0·4600	−1·111	−0·2121	+86·18	5·079	28·83	+0·74	−0·74	−0·28	+0·60	+0·84
March	+0·1110	−0·1626	−0·2099	+48·17	3·181	37·98	+0·25	−0·28	−0·23	+0·16	+0·34
April	−0·2379	−0·1657	+0·5751	+38·79	3·319	35·76	−0·35	+0·32	+0·46	−0·36	+0·58
May	−0·5057	−0·0686	+0·4564	+43·22	4·024	42·83	−0·68	+0·49	+0·31	−0·64	+0·75
June	−0·5236	−0·3348	+0·1716	+61·68	4·001	44·49	−0·64	+0·30	+0·06	−0·61	+0·66
July	−0·4799	−0·8533	+0·5603	+82·65	3·889	43·41	−0·46	+0·13	+0·25	−0·56	+0·60
August	−0·2709	−0·3240	+0·3857	+57·69	3·773	44·37	−0·31	+0·18	+0·23	−0·33	+0·40
September	−0·2018	−0·6855	+0·3329	+71·26	3·531	39·15	−0·11	−0·08	+0·13	−0·26	+0·32
October	+0·2991	−0·9371	+0·6173	+71·04	5·036	31·10	+0·53	−0·40	+0·21	+0·32	+0·63
November	+0·8062	+0·2669	+0·4249	+ 0·1251	5·631	21·49	+0·75	−0·28	+0·25	+0·72	+0·79
December	+1·062	+0·4682	−0·0343	− 8·213	6·147	19·34	+0·88	−0·41	+0·04	+0·86	+0·89

	Sunshine	Value used every month Height	Latitude	Longitude	Correlation coefficient		Value used for every month
		m.	°	°			
Average	$\overline{S}$	$\bar{h} = 378·3$	$\bar{\lambda} = 51·08$	$\bar{\phi} = 11·01$	Simple	r_{sh}, $r_{s\lambda}$, $r_{s\phi}$	$r_{h\lambda} = -0·56$ $r_{h\phi} = -0·0019$ $r_{\lambda\phi} = +0·38$
Standard deviation	σ_s	$\sigma_h = 558·4$	$\sigma_\lambda = 1·886$	$\sigma_\phi = 2·847$	Partial	$r_{sh\cdot\lambda\phi}$	
					Multiple*	R	

* Associated with equation (1). † Standard deviation of average per cent. of possible sunshine.

It is of interest to note in Table I and Fig. 2 that when A is positive, i.e. in winter, the positional variability as indicated by σ_s is high but $\bar{S}$ the average sunshine is low. When A is negative, i.e. in summer, σ_s is low and $\bar{S}$ is high. A further point of interest is the negative correlation between latitude and height, $r_{\lambda h}$, which for some months causes the correlation between sunshine and latitude, $r_{s\lambda}$, to be of opposite sign to B, i.e. $\partial S/\partial \lambda$. The relationship between height and latitude produces a false correlation between sunshine and latitude.

Fig. 3 gives the values of average sunshine plotted as ordinates, with height above sea level as abscissae, for May, December and March. May is a month of negative partial correlation, December is one of positive, and March the only month when the partial correlation is not statistically significant as determined by the "t" test[4]. The straight lines on the diagrams correspond to equation (1) for the mean position $\bar{\lambda}$, $\bar{\phi}$. The diagrams show that the equation holds over a great thickness of atmosphere when the fit is good. For both May and December almost all the values are near or on the lines, including the high-level values for the Zugspitze. The causes of this annual cycle, illustrated in Fig. 2, are the seasonal changes over Germany which produce the control of sunshine mainly by low cloud in winter and by higher cloud, mainly above 3,000 m., in summer.

In winter Germany is on the edge of the North Atlantic cyclonic circulation and the Eurasian anticyclone and the mean air flow near the surface is fairly strong south-south-west, while the screen temperature falls from west to east

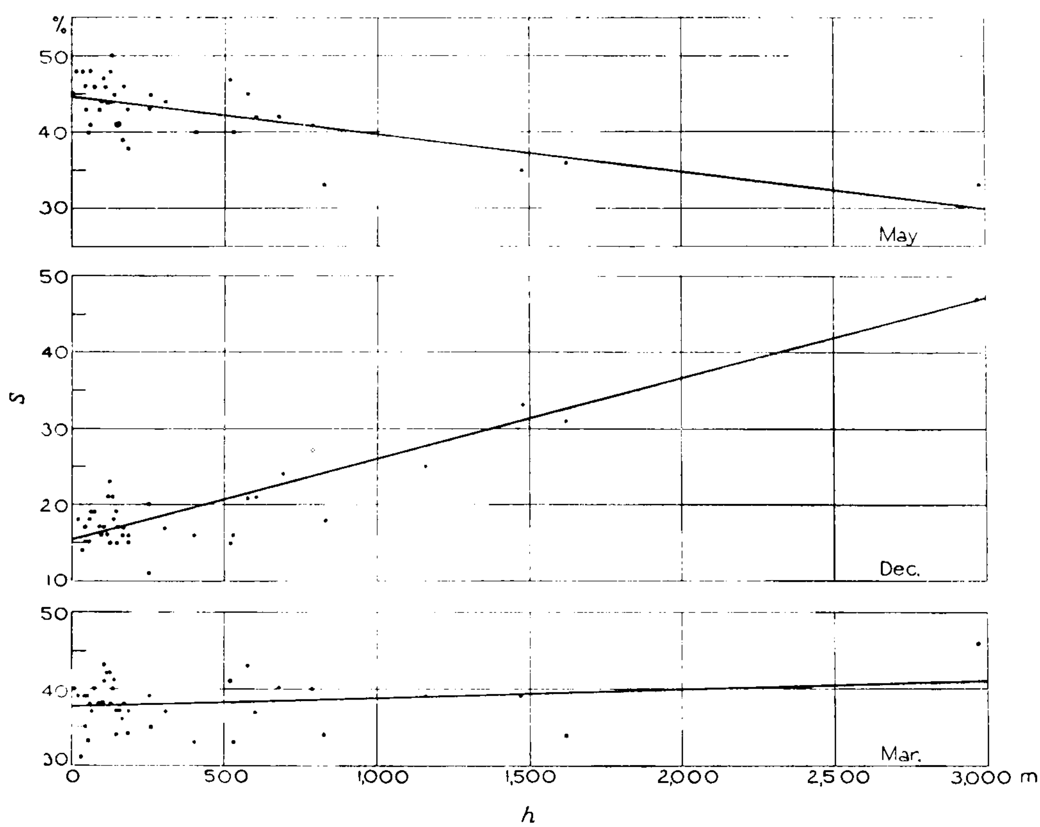


FIG 3—VARIATION OF S, MEAN SUNSHINE OVER GERMANY, WITH HEIGHT, h

and therefore the lower layers are on the average cooling along their trajectories[5,6]. The atmosphere during this time of the year is very stable up to 3,000 m. especially near the surface. Conditions are therefore favourable for the formation of layer cloud below 3,000 m. particularly near the surface. This cloud will vary with the local topography. In summer although Germany is affected by the fringe of the low-pressure region over north-west Europe and Asia, there is on the average a weak ridge with a light north-westerly surface air flow. Surface temperature increases from north to south and the lower layers are therefore warming along their trajectories. The atmosphere is drier but less stable in the lower layers than in winter. Conditions are therefore less favourable for the formation of cloud in these layers. These differences are confirmed by German cloud statistics[7] which show a general rise in cloud base and a decrease in low cloud from winter to summer.

There are two effects of cloud upon the vertical variation of sunshine. Firstly when cloud is above a station, the lower it is the greater the solid angle it subtends at the station. The higher the station above mean sea level the longer the time for which the sun's rays are cut off by cloud at any specific height above mean sea level. This is the cause of negative correlation between sunshine and height. Secondly, the duration of sunshine at a station cannot be influenced by cloud below it and therefore the higher the station the less cloud there is to cut off the sun's radiation. This effect causes positive correlation between sunshine and height. When these two effects cancel each other out there is little correlation and small variation of sunshine with height. This occurs in Germany in March and September. When one or other of these effects strongly predominates there is a large variation with height, a high correlation, and a good fit. In this example the first effect predominates in summer and the second effect in winter. However there is much low cloud in the lower layers in summer and the fit is less good and the variation with height smaller in magnitude than in winter. When there is a large amount of cloud in the lower layers, as in winter, there is associated with the positive partial correlation of sunshine with height a high positional variability, σ_s, because of the variability of topography. When higher cloud predominates there is negative correlation and low positional variability.

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WAVE CLOUDS OVER THE ISLE OF MAN

By W. H. KAVANAGH.

The Isle of Man is about 30 miles long and 10 miles wide at its widest point, tapering sharply at each end. In the southern half the hills form a long narrow

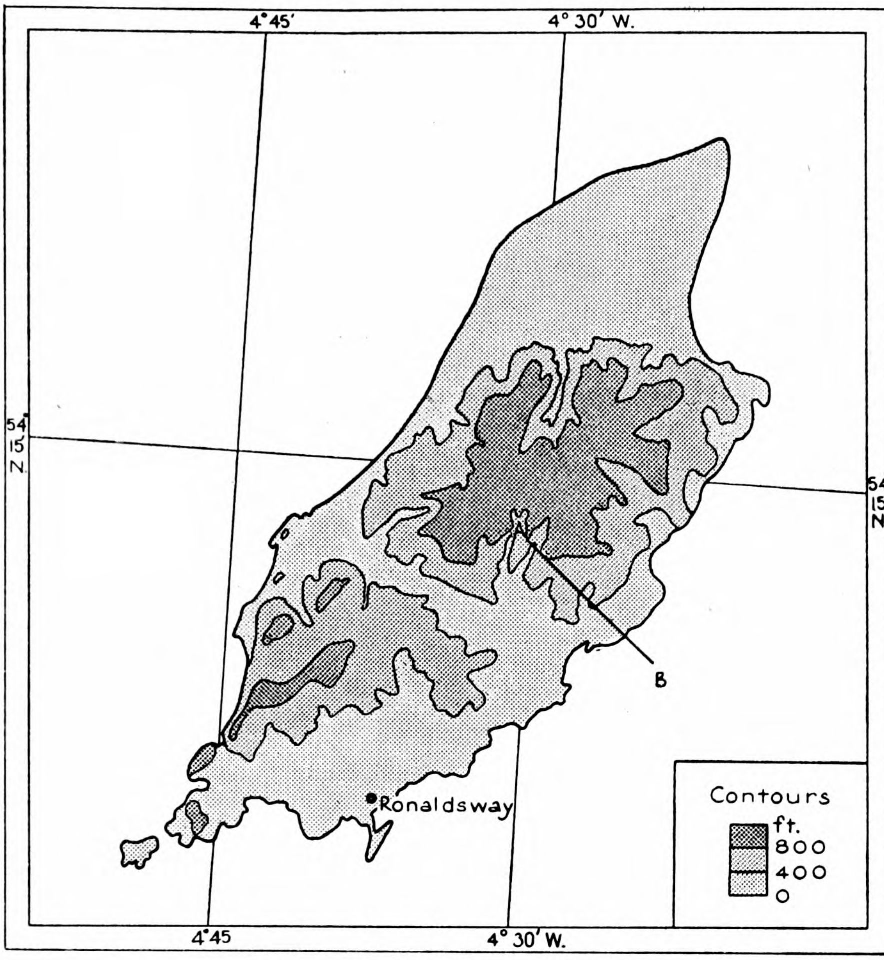


FIG. 1—ISLE OF MAN
A B is the line of cross-section shown in Fig. 4

ridge along the west coast, rising almost sheer from the sea to heights between 700 and 1,400 ft. In the northern part the hills form a rough square extending almost from coast to coast, rising generally to between 900 and 1,500 ft. and split into ridges by narrow steep-sided valleys running back into them. These features are illustrated in Fig. 1. Situated in the middle of the North Irish Sea the island is, in effect, an isolated hill ridge in an otherwise flat area. It is thus favourably placed for the formation and observation of orographic cloud.

During the past year observations have been made of clouds which remain stationary, or nearly so, in relation to the ground. They are believed to be due to the lifting effect over the hills or to orographic lee waves caused by the hills. They are usually lenticular and are often called wave clouds. No detailed analysis of the observations has yet been attempted but experience suggests that the most favourable conditions occur in a north-westerly air stream having a markedly stable layer or inversion in the first few thousand feet of the troposphere and a positive wind shear. Such a conclusion is consistent with the theory of mountain air flow put forward by Scorer[1] and discussed by Corby[2]. By way of example, two cases are briefly described below.

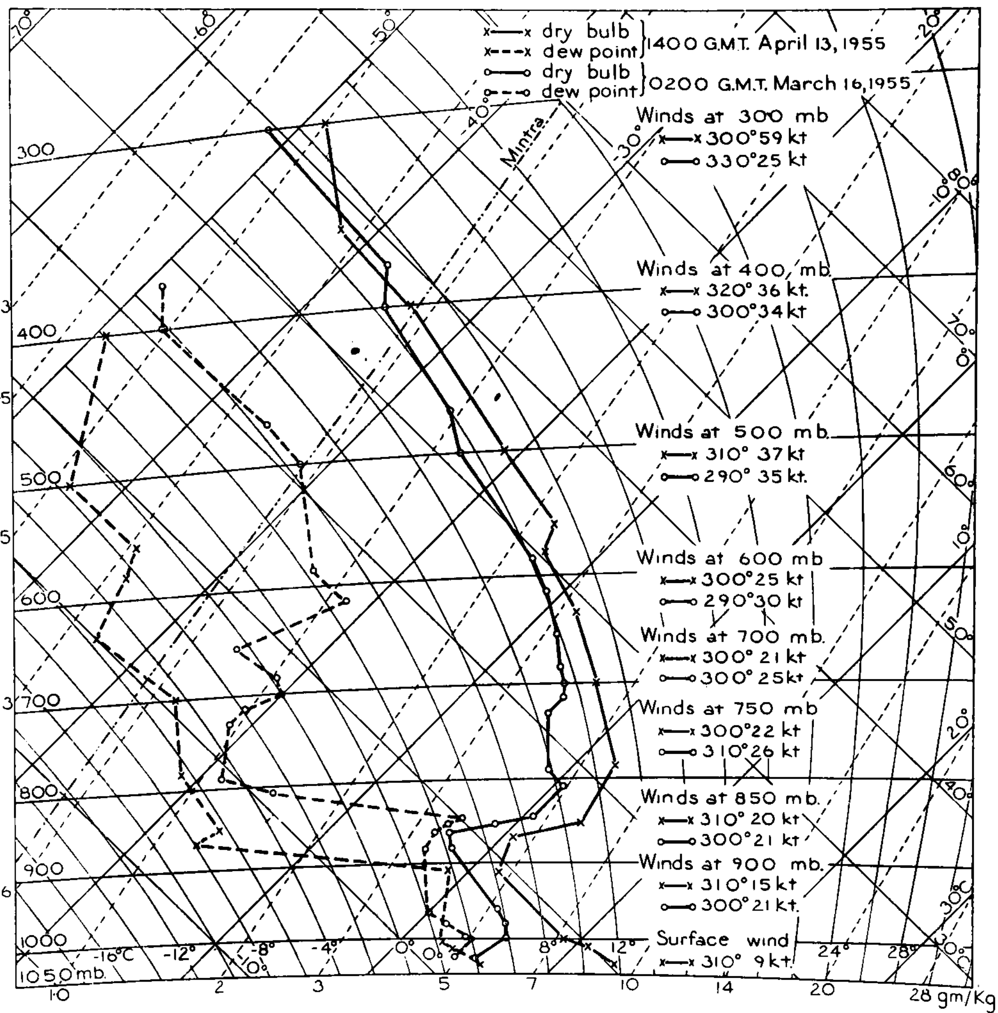
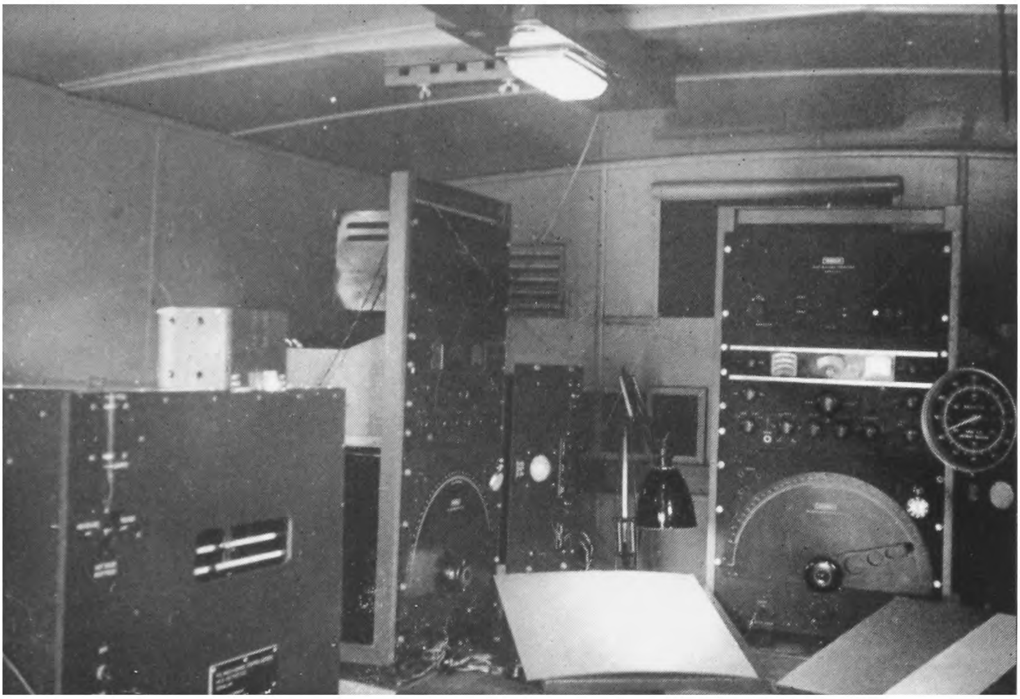


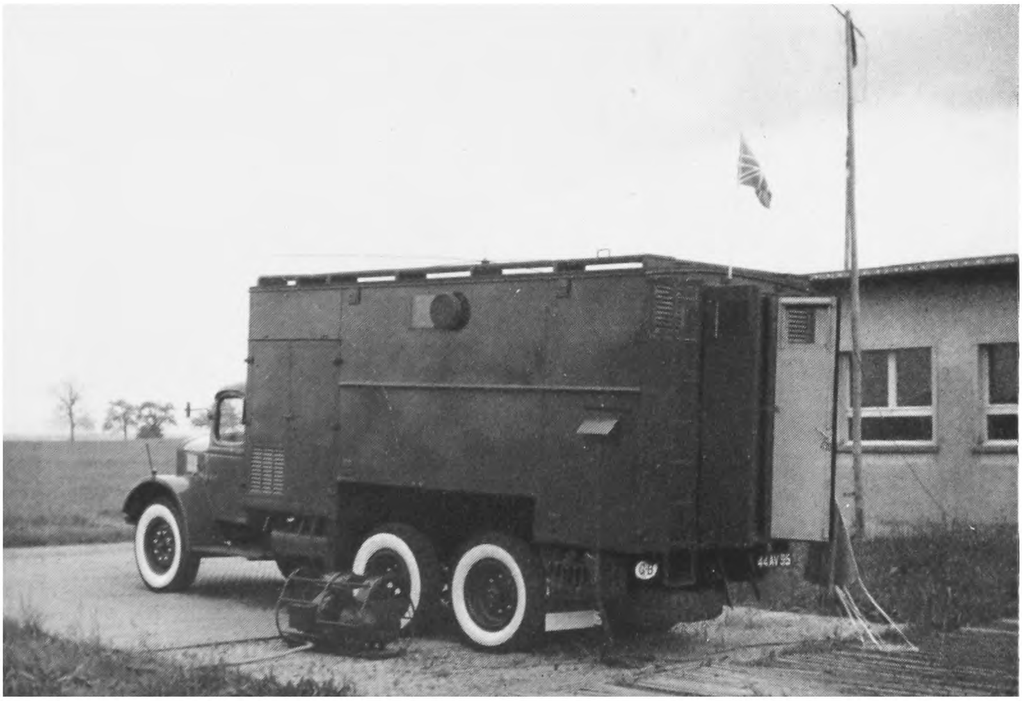
FIG. 2—TEPHIGRAM FOR ALDERGROVE ON MARCH 16 AND APRIL 13, 1955

On April 13, 1955 the air stream across the Isle of Man was north-westerly with little change in direction with height. The wind speed increased steadily from about 10 kt. at the surface to about 60 kt. at 30,000 ft. There was an unstable layer near the surface with marked stability between 900 and 800 mb. and an inversion about 850 mb. These characteristics can be seen in the 1400 G.M.T. Aldergrove sounding illustrated in Fig. 2 and we should expect them to favour the occurrence of lee waves. This is confirmed by the profile of the parameter l^2, which involves the stability and wind structure of the air stream, and has been shown by Scorer to be of fundamental importance in the problem of mountain air flow. The value of l^2 was calculated over 50-mb. layers, using the approximation $l^2 = g\beta/u^2$, and its variation with height is shown in Fig. 3. There is a pronounced maximum in the layer 900–850 mb. and a substantial decrease above that layer. The maximum is due mainly to the existence of the inversion. Scorer's theory thus leads us to expect lee waves.

At 1700 G.M.T. two stationary clouds were observed to the north-east of Ronaldsway Airport, obviously caused by the hills in the north of the island. An hour later there were five lenticular clouds and running through and connecting two of them in a wave pattern was a long grey trail. At 1820 G.M.T.



INTERIOR OF BRITISH MOBILE RADIO-SONDE UNIT USED AT PAYERNE



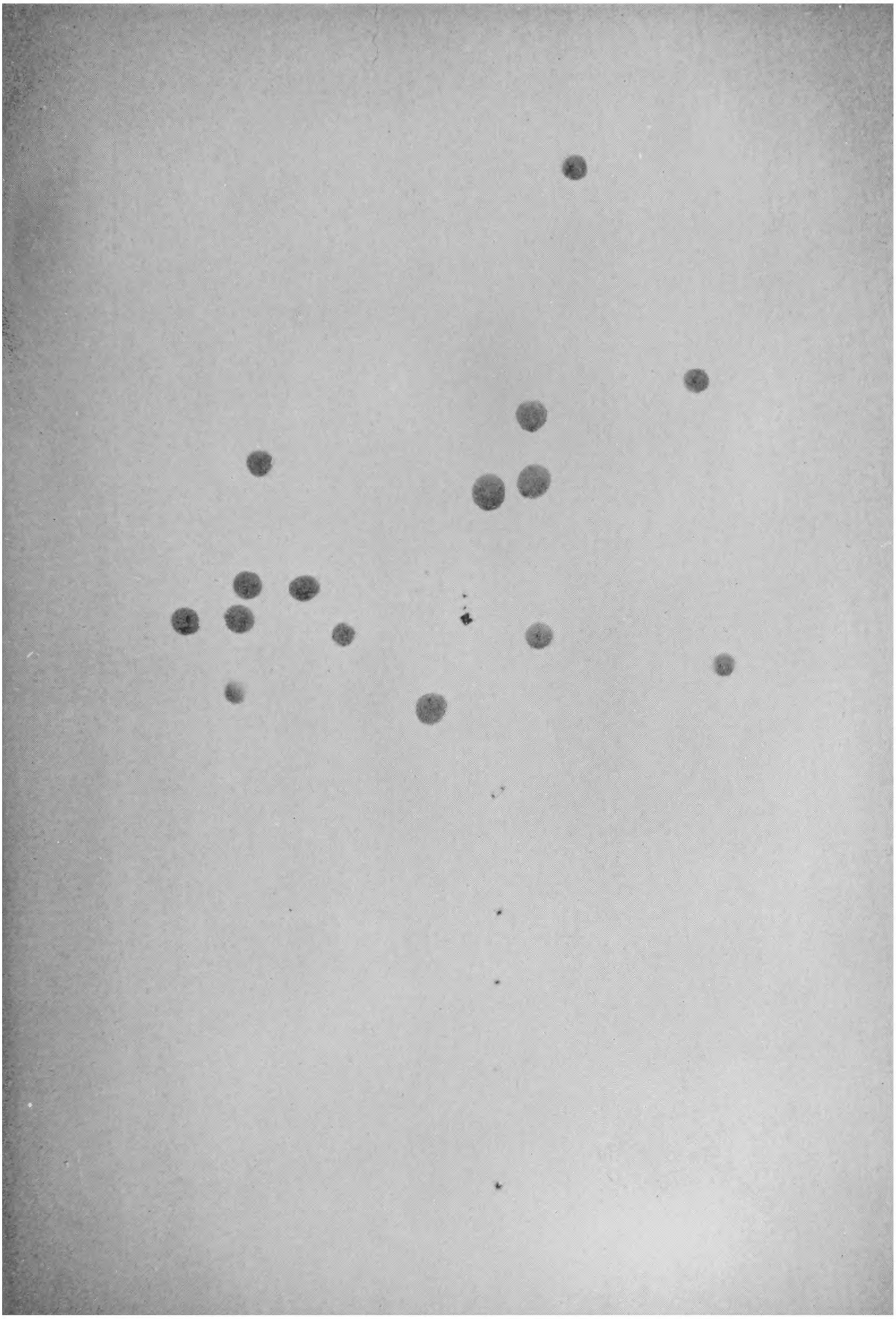
BRITISH MOBILE RADIO-SONDE UNIT USED AT PAYERNE

The generator alongside provides a safeguard against failure of the mains supply

(see p. 34)

PREPARATION FOR LAUNCHING A TRAIN OF EIGHT RADIO-SONDES

(see p. 34)

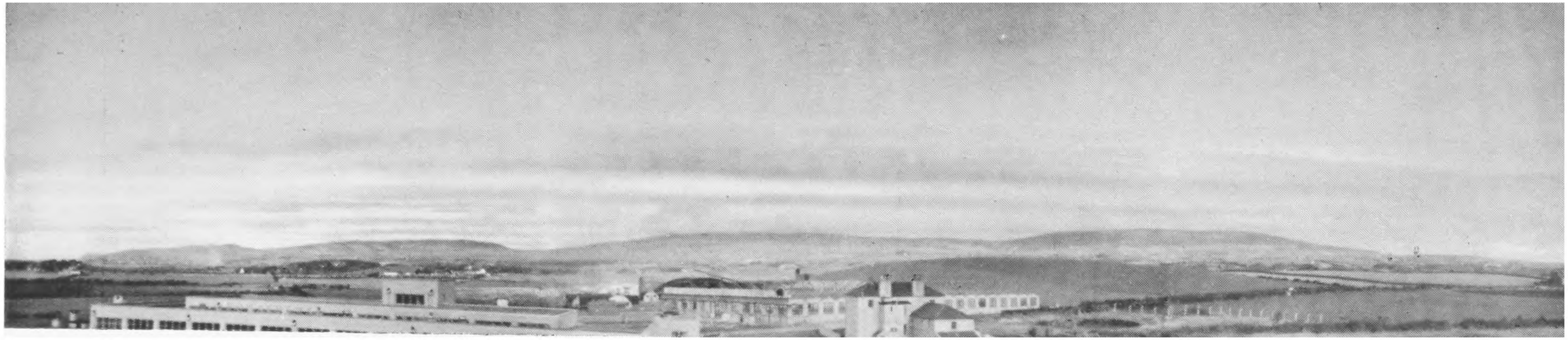


Reproduced by courtesy of W. Preston

GROUP OF FIFTEEN BALLOONS BEARING ALOFT THE FIRST TRAIN OF FOURTEEN RADIO-SONDES

The two parachutes and the target provided for location by Decca radar can be seen, together with the upper five radio-sondes.

(see p. 35)



Reproduced by courtesy of J. Connolly

View to the north-west

Reproduced by courtesy of J. Connolly

View to the south-east

WAVE CLOUD SEEN FROM RONALDSWAY MARCH 16, 1955

(see p. 50)

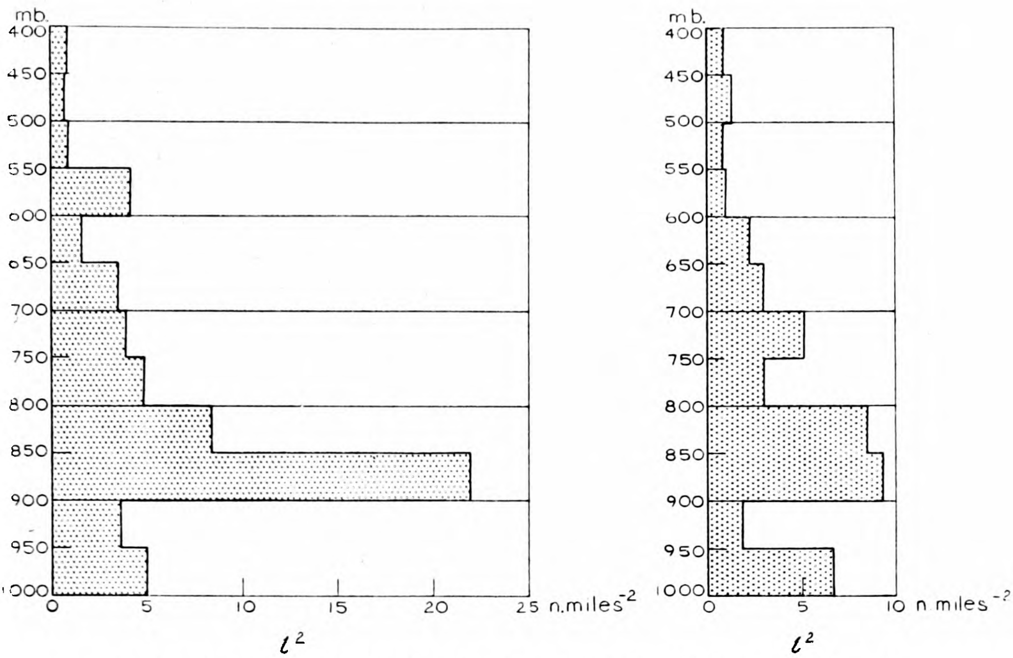


FIG. 3—PROFILE OF SCORER'S PARAMETER, l^2, AT ALDERGROVE

the azimuth and elevation of the crests and troughs of the waves were observed by theodolite. Two members of the meteorological staff, near Douglas at the time, also saw the wave. They took rough bearings and noted which ridge was causing this particular wave. This they were able to do because they could see that the trail joining the clouds was composed of smoke from burning heather on the hills to the north-west of the ridge. From the data thus assembled the positions of the troughs and crests were worked out and the heights calculated. The results are shown in Fig. 4. The cross-section is along the line AB in Fig. 1.

The appearance of the wave clouds during the evening, when they had not been observed earlier in the day, may well be an example of the diurnal variation referred to by Corby. The creation of low-level stability would have

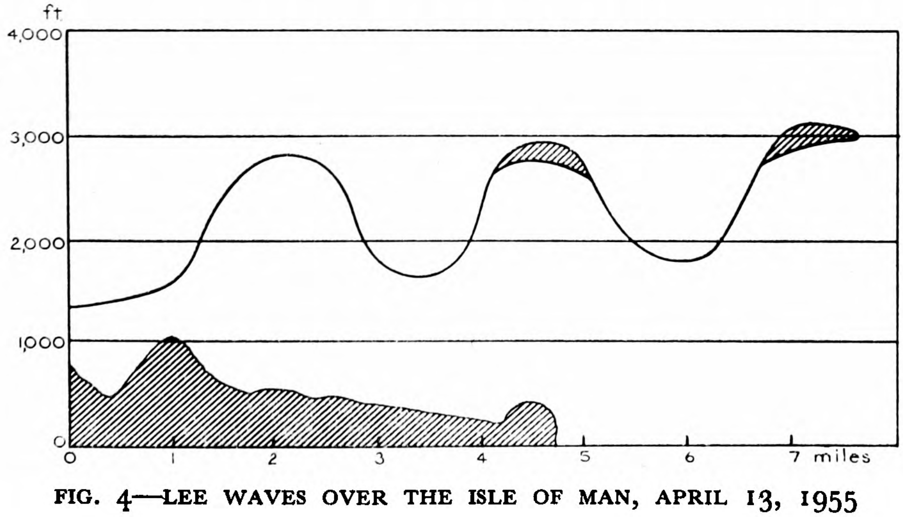


FIG. 4—LEE WAVES OVER THE ISLE OF MAN, APRIL 13, 1955

discouraged separation of the flow and encouraged the flow in these levels to hug the topography.

On the morning of March 16, 1955 an exceptionally good display of wave cloud was observed and photographed. The photographs are reproduced facing p. 49. The cloud was in two main groups which persisted from 0700 to 0930 G.M.T. The first consisted of a line of stratus along the hills, base about 1,200 ft., with a long bar of stratocumulus, base about 2,500 ft., above it. The second group was composed of three lenticular clouds one above the other just off the coast south-east of the airfield, with other lenticular cloud beyond.

The 0200 G.M.T. Aldergrove sounding and winds are shown in Fig. 2. The sounding closely resembles the shape of the 1400 G.M.T. sounding for April 13, 1955, with an inversion at 850 mb., and a stable layer between 860 and 810 mb. The wind was north-westerly increasing with height, though not to such a marked extent as in the previous case. The variation of l^2, using the approximation $l^2 = g\beta/u^2$, shown in Fig. 3, exhibits the same characteristics as that for Aldergrove at 1400 G.M.T., April 13, 1955.

Since the wave motion caused in the air stream in these conditions has at times a turbulent flow in the troughs and crests of the waves, in addition to the vertical currents, pilots often report moderate turbulence on the approaches to the airfield on these occasions. A reversal of surface wind at the airport control tower has also occurred at times, a previous north-westerly wind becoming easterly or varying rapidly. One instance of this has been described by Ward[3].

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METEOROLOGICAL OFFICE DISCUSSION

Some aspects of the microphysics of cloud

The Meteorological Office Discussion held at the Royal Society of Arts on Monday, October 22, 1956, on the physical processes occurring in natural clouds and the methods used by the Meteorological Research Flight to sample atmospheric aerosols was opened by Mr. W. G. Durbin. His statement covered a wide field ranging from an outline of the basic theory of the growth of cloud droplets to the results of recent investigations.

He began by remarking that although for most meteorological purposes the atmosphere was assumed to consist of water (in the vapour, liquid and solid phases) and air only, the cloud physicist had to take account of the nuclei in the atmosphere since without these nuclei clouds would not form at all. Those nuclei which are important in the formation of cloud particles have diameters which are usually between about 1/10 micron and 1 micron. By comparison, the diameters of cloud particles lie between about 1 micron and 100–150 microns. A small drizzle drop, a typical raindrop and a typical hailstone have diameters of about 100 microns, 1mm. and 1 cm. respectively.

Supersaturation leading to condensation occurs when saturated air is rapidly cooled as for example when it is moved rapidly upwards. A typical up-draught in a layered cloud and a strong up-draught in a cumulonimbus cloud have values of about 0·5 m./sec. and 10 m./sec. respectively. Even the latter value would be unlikely to give rise to a supersaturation of greater than 1 per cent. It has been shown theoretically and verified experimentally that a supersaturation of about 400 per cent. is necessary before drops of pure water will form spontaneously from the vapour and it is concluded that in the initial stages of cloud formation direct condensation from the vapour plays little or no part at all.

There must therefore be some agent in the atmosphere capable of allowing the growth of cloud droplets at supersaturations of 1 per cent. or less and this must take the form of a condensation nucleus around which the drop grows. During its growth molecules of water must move from the environment to the drop and for this to happen the vapour pressure at the surface of the drop must be less than that in the environment. Owing to curvature, however, the vapour pressure at the surface of a drop of pure water is higher than that in a saturated atmosphere at the same temperature and can be lower only if the environment is supersaturated. On the other hand the vapour pressure around a drop of solution is less than that around a drop of pure water of equal size and at the same temperature by an amount that depends on the nature and concentration of the dissolved substance. If the vapour pressure resulting from these two effects be less than or greater than that in the environment the drop will tend to grow or evaporate respectively. Moreover, before a droplet can grow to cloud-droplet size it will have to attain a certain critical size which in itself necessitates the existence of a minimum value of the supersaturation in the environment. For sizes of the droplet larger than this critical size the equilibrium value of the supersaturation diminishes so that the droplet can grow more easily the larger it becomes provided the ambient supersaturation is maintained. Theoretically it will continue to grow until it reaches a size which is in equilibrium with a relative humidity of 100 per cent. over a flat surface. In practice, as the drop grows, water vapour is extracted from the ambient air, the degree of supersaturation falls and the growth rate is slowed up.

Since a drop of solution will allow condensation to take place on it more readily than on a drop of pure water of equal size and, since the latter effect will not occur at all without the existence of a much higher degree of supersaturation than occurs naturally in the atmosphere, it appears likely that most cloud droplets originate as drops of solution. There is also the possibility that the nuclei of condensation which promote the formation of cloud droplets may be particles which are either insoluble and unwettable (non-hygroscopic) or insoluble and wettable. Since, however, even the latter type of particle, while being more favourable to condensation than the former, can at best behave only as a drop of pure water of equal size,this is unlikely. It would be possible only if the non-hygroscopic nuclei were appreciably larger than other atmospheric nuclei and there is no reason to believe that this might be so. Drops of solution can arise from particles which at low relative humidities, say less than 50 per cent., are surrounded by a thin film of adsorbed water but which dissolve in this water at higher humidities. Due to their high affinity for water they are said to be hygroscopic. When cloud droplets first form the nuclei activiated, i.e. able to grow larger than the critical size, will be the largest of those which, at the supersaturation available, can allow condensation to occur on them. In growing to cloud-droplet size these largest nuclei will remove water vapour, causing the supersaturation to fall and the smaller or less efficient nuclei will be prevented from becoming activated. This explains why the concentration of cloud droplets may be, and usually is, very much less than the total concentration of condensation nuclei.

The two most popular opinions regarding the nature of those hygroscopic nuclei which are believed to promote the growth of cloud droplets are that they are either salt particles or drops of acid. Salt particles float freely in the atmosphere[1] according to several reports. Their source is probably sea spray and they are carried upwards into the atmosphere by turbulence and convection.

Acids that have been identified in the atmosphere are sulphuric and nitrous acid. The former is a combustion nucleus formed from the combination of sulphur trioxide and water, the sulphur trioxide being formed as a result of the oxidation of sulphur dioxide which itself forms when substances containing sulphur, e.g. coal, are burned. Nitrous acid, on the other hand, forms from the combination of nitrogen, oxygen and water provided sufficient heat is supplied. Nitrogen and oxygen will combine at temperatures greater than 620°C. and it is thought that forest fires and lightning might provide the necessary heat. Nitrous oxide is believed to be a universal constituent of the atmosphere though not enough is known concerning its vertical distribution.

Instruments used to obtain counts of the numbers of nuclei in the atmosphere usually contain a chamber in which the air under test is subjected to sudden expansion. Condensation occurs on the nuclei present and an estimate is made of the concentration of droplets formed. This can be done by allowing the droplets to fall on to a plate and then counting them as in the Aitken instrument, attempting to count them in suspension as was done by Junge[2] or obtaining an estimate of their numbers by a photo-electric device as in the Pollak counter. Mr. Durbin then showed a slide on which was a photograph of the Pollak counter used in the Hastings aircraft of the Meteorological Research Flight. Results of this work are described by Day[3]. After describing the instrument he added that all instruments of this type produced supersaturations so large, from 200 to 300 per cent., that all nuclei down to ionic size acted as centres of condensation. It is not possible with these types of instrument to distinguish between those nuclei which promote the growth of cloud droplets and those which do not. The important nuclei may be salt particles, small drops of acid or it may even be that by far the largest atmospheric nuclei are non-hygroscopic. The real answer is not known.

The growth rate of a cloud droplet depends not only on hygroscopic and surface-tension forces but also on the processes of diffusion and thermal conduction which determine the rate of transfer of water vapour to and from the drop. Other important factors are the concentration and size distribution of the nuclei, the rate of ascent of the air and small-scale turbulence in the cloud.

The relative importance of these physical processes can be estimated theoretically but the crucial test of any theory is the accurate prediction of the drop-size spectrum[4]. Mr. Durbin then said that the most practical method to date of obtaining a cloud-droplet spectrum is the "impaction" method. In this the droplets are captured from an aeroplane on small slides coated with either an oil or a layer of magnesium oxide, photographed and counts made of the numbers of droplets having diameters lying between certain specified limits. Two slides were then shown on the first of which were two photographs giving examples of cloud-droplet samples obtained by both methods. The second slide showed graphically results obtained using the magnesium-oxide technique from the Hastings aircraft of the Meteorological Research Flight on ten flights through cumulus clouds in 1951[5]. The clouds varied in vertical depth from 750 ft. to about 7,000 ft. and each curve represented the mean for the samples taken on any particular flight. Common to all curves was a maximum concentration of droplets at about 8 microns diameter which suggests that having grown beyond the critical size most cloud droplets continue growing until they acquire a diameter of about 8 microns.

Average values of the water content in these clouds were between 0·5 and 1·0 gm./m.^{3} although a value of about 5·0 gm./m.^{3} occurred in one part of a cumulus cloud, 7,000 ft. thick, which was precipitating. Values as high as 10 gm./m.^{3} may occur locally in cumulonimbus clouds but such values have not yet been measured.

Mr. Durbin then discussed the ice phase in the atmosphere. Since snow-flakes and hailstones may originate from ice crystals it is important to consider how ice crystals arise in the atmosphere and to obtain information on their numbers, sizes and crystal habit.

There are two possible ways in which an ice crystal may form from the vapour. Either the water vapour molecules may unite directly to give ice or they may first of all form a drop of water which subsequently freezes. Researches into this problem have been carried out using cloud chambers and it has been found, using purified air in a cloud chamber in which the relative humidity was measured, that ice crystals first formed at relative humidities near to 100 per cent. with respect to water. This represents a considerable supersaturation with respect to ice and the implication is that ice crystals form from the freezing of water droplets rather than directly from the vapour. It has further been shown in these experiments that small water droplets usually change to ice crystals at temperatures between $-32°$ and $-41°$C. Researches into the problem of how far a drop of water can be supercooled before freezing have shown firstly that impure water will freeze at higher temperatures than pure water and secondly that the smaller the drop, the lower the temperature at which it freezes. Data on the results of these various researches have been discussed by Mason[6].

Using unpurified air in cloud chambers the temperatures at which ice crystals appear are appreciably higher than if purified air is used. This, and the fact that ice crystals occur naturally at temperatures appreciably higher than $-32°$C. suggest that in natural or impure air there are particles which promote the freezing of droplets at these higher temperatures. These particles are called "freezing nuclei". It has been suggested that these nuclei may be particles of salt or silicates but their real identity is unknown. From the numbers of crystals appearing at different temperatures in cloud chamber experiments, it appears that these nuclei are activated in minimum concentrations varying from about 1/m.^{3} at $-10°$C. to about 1/cm.^{3} at $-35°$C. but concentrations 100 times as great are sometimes observed.

An interesting hypothesis put forward by Bowen[7] regarding the origin of freezing nuclei is that one important source may be the debris of meteoric showers. An analysis of the rainfall intensity for the months of January and February for the years 1902–1944 revealed peaks of about twice the average value on January 13, 22, and 31. Bowen associated these peaks with meteoric showers which occur annually on December 13–14, 22, and January 3, the lag of 30 days being the time required for the particles to fall from about 100 Km. into the troposphere. Checks on Bowen's hypothesis have been made by flying an aircraft equipped with a cloud chamber throughout the month of January and finding out whether or not significant increases in the numbers of ice crystals appearing at different temperatures occurred on these dates. The evidence obtained does not support Bowen's hypothesis.

Mr. Durbin then briefly reviewed precipitation mechanisms. It is clear that a cloud droplet must grow considerably before it can gain a falling speed which enables it to fall out of the cloud, survive evaporation in the unsaturated air beneath and reach the ground as precipitation. From considerations of the amount of water available and the concentrations of cloud droplets found in natural clouds, of the order of a few hundred per cubic centimetre, it can be shown to be impossible to produce precipitation in the form of water drops, by continued condensation from the vapour, in a reasonable time. Ice crystals, on the other hand, are present in much smaller concentrations than cloud droplets, of the order of 10/cm.^{3}, and in the development of precipitation from ice crystals, continued condensation from the vapour is of great importance, particularly if the water content of the cloud is low.

Bergeron maintained that since within a cloud containing both ice crystals and water droplets the ice crystals are in an ice-supersaturated atmosphere they will grow by diffusion of vapour to their surfaces. The replacement of this vapour, which is necessary to maintain water saturation is effected by evaporation of the droplets so that this process effectively means growth of the ice crystals at the expense of the water drops. Bergeron thought that almost every raindrop originated as a snow-flake but this cannot always be true since a large proportion of the warm-sector rain in this country falls from clouds which contain no ice crystals and in many cases do not reach the freezing level. This type of rain is usually slight and is believed to occur as a result of coalescence between drops of different sizes due to their moving relative to each other with different vertical velocities. In tropical countries heavy rain has been observed to fall from vigorous convective clouds which do not reach the freezing level and a possible mechanism by which this rain can occur has been called by Langmuir[8] a "chain reaction of raindrop multiplication". When a drop grows by coalescence to a diameter of a few millimetres or so it becomes unstable and breaks up. If the up-draught in the cloud is strong enough to support the drop before it breaks up, then, when it does break up, all the drops it breaks into will be carried by the up-draught back into the body of the cloud and the process can repeat itself on each drop. All that is necessary for both this and the simpler coalescence process to occur is that initially there must be drops of different sizes in the cloud so that the process can start. It is worth noting that the possibility exists of the coalescence mechanism forestalling the Bergeron mechanism in clouds where both mechanisms are possible.

Mr. Durbin then described an instrument used at the Meteorological Research Flight for obtaining raindrop spectra in flight. The instrument contains a strip of aluminium foil which, when struck by a moving drop, receives a dent related to the size of the drop and the speed of impact. A typical vertical distribution of raindrop size obtained by this method was then illustrated.

Lastly Mr. Durbin referred to the artificial stimulation of precipitation. Clouds, part or all of which are supercooled yet do not precipitate, can contain very few ice crystals and this is possibly due to a deficit of efficient freezing nuclei. These clouds might be expected to precipitate if this deficiency can be remedied.

Two main methods of increasing the ice crystal content of a supercooled cloud have been tried. The first, which involves seeding a supercooled cloud with pellets of solid carbon dioxide from an aircraft, usually results in dissipation of the cloud. Mr. Durbin then illustrated with slides a seeding experiment of this type in which a large hole was made in a supercooled layer cloud.

The second method involves the generating of silver-iodide smoke on the ground and allowing the smoke to diffuse upwards into the cloud. Silver-iodide particles were found to behave as efficient freezing nuclei in cloud-chamber work. It is difficult to assess the success or failure of this type of experiment because it is not possible to distinguish between the rain which fell subsequent to the release of these particles and the rain that would have fallen if no particles had been released.

Mr. Durbin concluded by saying that evidence existed that the silver-iodide particles produced by ground generators possessed a different crystal structure from those found to act as efficient nuclei. Silver-iodide particles lose their nucleating ability when exposed to ultra-violet light. There is evidence also that these particles are unable to penetrate inversions and so may not be able always to reach those parts of a cloud where they may initiate freezing. Considered together these facts suggest that this method of inducing artificial precipitation is not likely to be very effective.

Dr. Stagg opened the subsequent discussion by remarking that although many problems associated with cloud physics had been solved there was still much to be learned. He wondered why there should be greater numbers of comparatively large cloud droplets near the tops in preference to other regions of the clouds. In reply, Mr. Durbin said that the aluminium foil instrument always showed this to be so and that it was noticeable how wet the wind-shield of an aircraft became on entering the tops of clouds. The droplets at the tops of clouds originate near the bases and probably grow by coalescence with other droplets while being transported vertically through the cloud. On the assumption that this process can happen, Ludlam computed that a 30-micron-radius droplet introduced into the base of a vigorous convective cloud could grow by coalescence to break-up size, a few millimetres diameter, before reaching the freezing level and although this represented an extreme case it illustrated the principle.

Mr. Bushby queried the accuracy of reports of tropical precipitation from cumulus clouds which did not reach the freezing level, pointing out that in his experience the heights of cloud tops in tropical countries were generally underestimated. Mr. Durbin replied that he could not vouch for the accuracy of such reports but that there were many from different sources in the literature. Mr. Bushby then asked for more detail of Bowen's hypothesis on the source of freezing nuclei and this was given.

Dr. Scorer said there was no evidence to suggest that meteoric showers could provide any excess numbers of particles of the right size over the general background of meteoric particles which are always entering the atmosphere. Referring to the peaks in rainfall intensity, found by Bowen, he said rainfall statistics were unreliable. He suggested that by selecting different places for which to analyse the rainfall, peaks would have been obtained on different dates.

Mr. Oddie, after discussing the relevance of the work on nuclei to forecasting, said that no agreement had been reached regarding the parameters that should be measured in the field of nuclei. It was useless to refer to numbers of freezing nuclei without also referring to the temperature at which they acted as freezing nuclei. He doubted the reality of observations that freezing nuclei increase upwards and attributed differences in the numbers found below and above inversions to corresponding differences in water-vapour content. Finally he referred to the seeding of clouds and suggested that a more scientific approach to the problem was needed.

Mr. McNaughton asked if it was possible to carry out cloud-chamber work using supersaturations of the order found in clouds. Mr. Durbin replied that to maintain a given degree of supersaturation was extremely difficult.

Mr. Robins asked what the Pollak counter really measured. Mr. Durbin said that it gave a joint indication of the numbers and sizes of the droplets formed but did not distinguish between them.

Dr. Sutcliffe agreed that the Pollak counter gave only a rough and ready indication of the nuclei content and after enquiring if the instrument had been calibrated against the Aitken counter was told that this had been done.

Mr. Robins asked if the existence of large droplets near the tops of clouds implied heavier icing. Mr. Durbin replied that this was so but added that icing severity depended on the temperature and water content of a cloud as well as the numbers and sizes of droplets.

Dr. Sutcliffe said that prior to the release of precipitation, which would redistribute the water within a cloud, the ordinary theory of convection predicted that the greatest concentration of free water would be found near the top of a cloud.

Mr. Wallington remarked that light icing was often encountered on ascent near the top of supercooled stratocumulus cloud while none occurred below. He wondered if the temperature was higher at the top of a cloud than lower down.

Dr. Robinson said that radiation from the top of a cloud would result in a reduction of temperature at the top.

Dr. Frith asked if this would be true even if the top of the cloud were exposed to direct sunshine. Dr. Robinson replied that it would, explaining that the outgoing radiation is emitted from a shallow cloud layer whereas the incoming radiation is absorbed through a much larger depth of cloud.

Mr. Durbin said that it was not possible to make accurate measurements of temperature in cloud.

Mr. Harper remarked on the effects of ascent and descent of air within a cloud and stressed the necessity of having many observations of large drops at the tops of clouds before making any definite statement about them. Mr. Durbin replied that the slide shown was merely one example of this but other records had been obtained by the Meteorological Research Flight.

Mr. Jones said that the aluminium-foil instrument gave records of only the largest cloud droplets which might be present in only small concentrations. The instrument did not measure the amount of water contained in the cloud in the form of small droplets.

Mr. Rider wondered how the dents made in the aluminium foil had been calibrated against drop size and asked if it was possible to distinguish between dents made by droplets and ice crystals.

Mr. Murgatroyd said that the basic development of this instrument had been carried out by the Mechanical Engineering Department at the Royal Aircraft Establishment, Farnborough. They had mounted it on a whirling arm mechanism passing through a spray of drops and had, at the same time, measured the drop-size spectrum of this spray by means of the Rhodamine-dye method. Thus they obtained a calibration from a comparison of the indentations on the foil and the sizes of the drops on the dyed filter paper. The present Meteorological-Research-Flight instrument has been found to show indentations for droplets having diameters down to 100 microns and rain and snow can readily be identified. Very small crystals and the smallest droplets give rather similar indentations and the interpretation in this case is still being studied.

On the question of drop-size distribution with height it seems that a few hundred droplets form in every cubic centimetre during the initial condensation. Continued condensation then occurs on these droplets and few new droplets form in the up-draught. Since the water content increases with height the sizes of the droplets would be expected to increase with height. Moreover due to coalescence their number will decrease with height. The number of large raindrops however, is likely to be greatest near the base of the cloud because, when the droplets become big enough to be precipitation elements and fall down through the cloud, they grow by coalescence.

Another questioner asked if the answer to measuring small concentrations of nuclei did not lie in simply using a larger chamber. Mr. Durbin replied that chambers as large as a room had been used on the ground but there were serious difficulties in installing a large chamber inside an aircraft.

Asked further if some nuclei were not lost on the walls of a chamber, Mr. Durbin said that they were but in any form of cloud chamber work it was impossible to get away from boundary conditions.

Dr. Scorer remarked that experience with Coastal Command overseas showed that the Bergeron process was not always necessary for producing precipitation. Ice crystals could be produced from the freezing of drops formed by the coalescing of other drops.

Mr. Aanensen asked what laboratory evidence existed to substantiate the coalescence process and over what range of diameters would a drop coalesce with another drop of given size. Mr. Durbin replied that he was not aware of any direct experimental evidence for coalescence of very small droplets but experiments using larger droplets had been made. It had, however, been shown theoretically that for a drop of a given size there was a minimum value of the size of drop with which it would coalesce.

Mr. Sawyer, referring to the cloud-seeding experiments, wondered why, in view of the latent heat of fusion released when droplets change into ice crystals, a supercooled cloud should dissipate rather than reform. He also wondered to what extent the microphysical processes affected rainfall.

Mr. Bushby asked if rain could be stopped or even prevented.

Mr. Oddie replied that very great overseeding was necessary for this.

In reply to another questioner, Mr. Durbin said he thought that a cloud depth of about 6,000 ft. was the minimum necessary to produce rain at the ground. Mr. Bradbury doubted this, saying that in his experience continuous light rain had fallen for hours in East Anglia from stratus cloud only 3,000 ft. thick. Mr. Murgatroyd was inclined to think that only drizzle would fall from clouds 3,000 ft. thick.

Mr. Bannon wondered if he was right in thinking that the forecaster had little to gain from the field of cloud physics and Mr. Durbin replied that this was largely true. Dr. Sutcliffe commented that microphysical studies were more than simply interesting and had application to a number of fields. The extent to which these studies benefit the forecaster is not to be interpreted as a measure of their usefulness.

Dr. Stagg then summed up and thanked the opener for an interesting lecture.

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OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Five-year summaries of upper air data.

The Meteorological Office publish five-year summaries of radio-sonde observations of temperature and humidity and of radar-wind measurements made at some of its upper air observing stations. These are in the series M.O.555, Upper air data, and so far Parts 1 to 9 have been published for the period 1946–50, Parts 1, 2 and 9 being for Larkhill, Lerwick and Downham Market respectively, other parts being for stations in the Mediterranean and Middle East areas. Recently Part 1, Larkhill, has had to be reprinted as stocks of the original 1952 printing were exhausted. The reprint includes wind roses for each month for the standard levels which were not in the original and some minor errors in the 1952 printing have been corrected.

With the exception of Part 9, Downham Market, the upper air statistics in the M.O.555 series have not been corrected for the effects of lag and radiation on the temperature-element of the radio-sonde[1]. Accordingly a series of Addenda is being prepared giving corrections to be applied to the average temperatures and heights of standard pressure surfaces in each of M.O.555 Parts 1 to 8. The Addendum to Part 1, Larkhill, has already been printed and the Addenda to other Parts will soon follow.

These publications can be obtained from the Meteorological Office, M.O.10, Air Ministry, Kingsway, London, W.C.2. The price per Part of M.O.555 is 4*s*. to 5*s*. depending on the Part, postage 5*d*. extra in the British Isles; each Addendum costs 1*s*., postage 2*d*.

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LETTERS TO THE EDITOR

Record rainfall at Cherrapunji, June 14, 1876

Mr. L. S. Clarkson, Chief Meteorological Officer, Singapore has pointed out that the sentence used in the *Meteorological Magazine* for August 1956, on p. 255 describing the fall of 37·5 in. of rain at Cherrapunji, Assam on June 4, 1956 as a record 24-hr. fall for that place is open to correction. It has been reliably reported that 40·80 in. of rain fell in 24 hr. at Cherrapunji* on June 14, 1876. Our records for this place are incomplete before 1902, when the present station opened. Correspondence with the India Meteorological Department has recently elucidated some changes of site at Cherrapunji in the nineteenth century when measurements were made on the whole nearer the centre of the plateau: the falls obtained at those sites were slightly greater even than the remarkable totals obtained from the present site near the northern edge of the plateau. The early readings are accepted as authentic.

H. H. LAMB.

Tunbridge Wells hailstorm

For the benefit of readers who do not know Tunbridge Wells, the illustration facing p. 304 of the *Meteorological Magazine* for October 1956, shows the opening of the Pantiles looking towards King Charles church. The roadway is A267 carrying traffic for Eastbourne and to some extent for Hastings so the blocking on a Bank Holiday, was, to say the least of it, awkward!

St. James's church, near the top of the ridge carrying the Pembury Road, has a lofty spire which may have been struck. A 50-ft. pollard elm near the summit of the common had a 2-ft. strip of bark near the base removed by lightning and there was slight damage to the roof of the house near-by.

The hailstones froze together and next morning I saw them being removed in chunks quite 6-in. thick from the pavement outside King Charles church. In a shady drive in this road small heaps remained at 9 o'clock on the Wednesday morning.

CICELY M. BOTLEY

2, *Park Road, Tunbridge Wells, November* 2, 1956.

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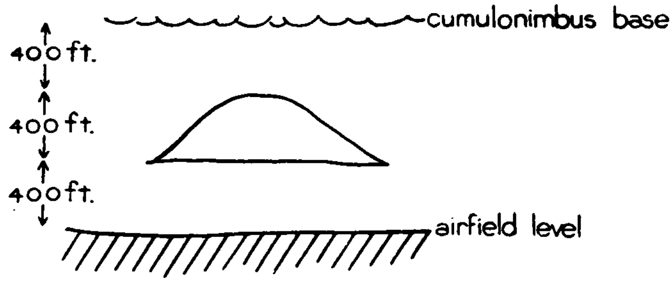
*Jennings, A. H.; World's greatest observed point rainfalls. *Mon. Weath. Rev., Washington*, **78**, 1950, p. 4.

NOTES AND NEWS

Heavy rainfall and interesting cloud forms at Wunstorf on July 2, 1956

Early on the afternoon of July 2, 1956, thunderstorm and shower activity in warm unstable air over north-west Germany was being intensified by the eastward movement of a cold front[1]. An outbreak of rain started at Wunstorf at 1430 G.M.T., when the front was immediately west of the station. The rain soon increased in intensity, and between 1430 and 1540 G.M.T. 58·2 mm. of rain were recorded: no less than 40 mm. of this total fell during the period 1450–1510 G.M.T., an intensity of 120 mm./hr. This caused a great deal of flooding on the usually well drained tarmac and in the fields and villages round about, but the most interesting phenomenon was the cloud formation.

At 1430 G.M.T. slight rain was reported, with lightning visible to the south of the aerodrome. Visibility was 15 miles and the cloud was 6 oktas cumulonimbus, base 2,500 ft. with 7 oktas altocumulus, base 10,000 ft. Pilots reported the tops of the cumulonimbus at 15,000–16,000 ft. with no higher tops in the immediate vicinity. By 1441 G.M.T. the storm had increased in intensity, and heavy rain had reduced the visibility to 1,200 yd. and brought the cloud base down to 7 oktas cumulonimbus at 1,200 ft. Shortly after this a peculiar cloud formation was observed over the airfield below the main cumulonimbus base.



The cloud, as illustrated, had a well defined base, which was estimated to be 400 ft. above ground level with the top of the dome, when first observed, about 800 ft. above ground level, i.e. 400 ft. below the main cloud base. The top of this dome began to lift visibly until at 1453 G.M.T. it had merged with the main cumulonimbus base. As this happened all cloud was obscured by the onset of rain of tropical intensity, mixed with soft hail. Similar cloud phenomena have been observed and photographed by Coulomb and Sourdillon[2].

It is well known that in the mature stage of development of a thunderstorm, i.e. when precipitation is falling, a dome of cold air is present underneath the thundercloud[1–4]. According to Coulomb and Sourdillon, two possible mechanisms may contribute to the formation of the cloud under the cumulonimbus. First, warm air drawn into the cumulonimbus slides up the slope of the "mountain of cold air" and produces a cloud at the top, similar to the plume which forms regularly over Teneriffe and other peaks. Second, there may be mechanical up-drafts within the cold air itself. There is insufficient evidence to be sure whether both factors were operative in the present case.

R. KING

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Meteorological Magazine: increase in price

It is regretted that because of increases in the cost of printing and publication it has become necessary to raise the price of the *Meteorological Magazine* to 2*s*. 3*d*. an issue with effect from the January 1957 number.

The net annual subscription will become 29*s*. including postage. The increase is due to the necessity to cover a recent increase in postage. Present subscribers will remain on the existing rate until renewal of their subscriptions is due.

REVIEWS

Regional variations in the trend of annual rainfall over the British Isles. By S. Gregory. *Geogr. J., London*, **122**, 1956, p. 346. Royal Geographical Society, London.

The September 1956 number of the *Geographical Journal* contains an article by S. Gregory on Regional variations in the trend of annual rainfall over the British Isles. In this article, using curves of ten-year running means of annual rainfall, totals for the period 1901 to 1930 (1881 to 1950 for some fifty of them) he seeks for areas of the British Isles having the same trend of variation. The trends are independent of location—mountain, valley—in the regions. He finds four areas, Region I roughly over East Anglia and the Thames Valley, Region II over Wales and a central belt from Lancashire over the Pennines to south of the North West Highlands, Region III over the south, south-west and Midlands of England, the Tyne to east of the North West Highlands and Region IV covering the English Lake District and the south-west and north-west of Scotland. Over Ireland the central belt and south coast agree with Region II, most of the south with Region III and the north with Region IV. The Regions IV and I are respectively the areas of maximum and minimum influence of Atlantic depressions.

All regions had relatively low values in the 1885–1895 epoch but subsequent variations differed. Region IV shows a sharp rise in the late 1890's and peaks around 1897–1906 and 1921–30. The variations were most marked in this Region. Region I had a "plateau" from 1909–1918 to 1922–31 followed by a slow decline. Region II rose steadily from the 1890's to 1922–31 followed by a decline. Region III had peaks in 1909–1918 and 1922–31. The range of variation increases with amount and so is greater in mountainous areas. In low areas it is apparently in Regions I and IV about 5 in., in Regions II and III about 10 in. Mr. Gregory points out the importance of the existence of such regions of more or less uniform variation in water supply.

It would be interesting to see confirmation from correlation coefficients as curve "parallels" are a somewhat uncertain basis.

G. A. BULL

Dictionary of meteorological and related terms. Spanish–English. English–Spanish. By D. Brazol, 8½ in. × 5½ in., pp. 557. Librería Hachette S.A. Buenos Aires, 1955. Price £5.

The necessity of a comprehensive book of this nature is stressed in the Foreword which says ". . . English is almost a universal language in meteorological literature, and is still more commonly used for aviation, marine and wireless communications; we must however not forget the importance of the Spanish language spoken by more than 100 million people. . . Spanish . . . one of the official languages of the World Meteorological Organization." This Dictionary is intended for "seamen, flyers, hydrologists, geographers, agriculturists, physicians, radio-operators and meteorologists".

Reviewing a dictionary is rather a formidable task but a scrutiny of this one gives the impression that from the meteorological viewpoint it is very comprehensive and little seems to have been omitted. The contents (English-Spanish and Spanish-English) are arranged into 19 separate sections each section being devoted to some particular aspect of meteorology such as wind; temperature; fog, mist and cloud; precipitation; climatology; aeronautical meteorology; maritime meteorology; hydrology; communications etc. There is also a section devoted to general technical terms and there are two useful Appendices—universal decimal classification for meteorology and conversion tables (metric and English system).

In addition to purely meteorological terms the dictionary contains a considerable variety of other technical phrases which seem to have little or no meteorological connexion. For example, in the maritime section we find such terms as "line of soundings", "quarantine anchorage" and "tow rope". A reduction in the number of such terms might improve a future edition of the book and perhaps reduce its price. On the other hand, the oceanographical and tidal terms etc. which are included seem quite appropriate.

The arrangement into sections may have its advantages but it sometimes makes it difficult to decide in which section to find a certain phrase and it obviously implies a certain amount of duplication. Thus "compass" appears in the "Maritime" section and under "Instruments". Fog and dense fog appear under section 11 "Fog, mist and cloud" and section 16 "Visibility" but "Fog bank" only appears in section 11. One needs to consult the Table of Contents to find which pages the various sections cover. It would perhaps be preferable in a later edition if the whole contents were merely arranged in alphabetical order irrespective of their specialized context.

The book contains a number of instances where lengthy phrases such as "Effect of droughts on surface water and ground water, Humidity elements (indicating the degree of saturation), Marine observations of wind (by visual estimates based on the appearance of the sea surface)" have been picked out direct from some meteorological publication and translated *in toto*. At first glance this procedure might seem a trifle aggravating, but it has the great advantage of enabling the reader to become a little familiar with Spanish as applied to meteorology without any previous knowledge of that language or of its grammar.

One major criticism of this book is that the author does not seem to have a sufficiently expert knowledge of the English language. In the English-Spanish section one finds for example the following: "Land spout = Tornado; Armet = Distance in metres; Soupy weather = Tiempo Suico (dirty weather); Bull's eye = Eye of the storm; Immersion of the ship = Calado del buque (draft of the ship)." Under "Ice terms" the author refers to a "Snow berg = Ice berg covered with snow; A calf = a big piece of floating ice"; and to "Cat ice" and "Highland ice". None of these terms are generally accepted ice terms in the English language. It is true that a berg is said to "calve" when it breaks away from its parent glacier but it is unusual to see a berg referred to as a "calf". Hurricane, whirlwind, and water-spout appear together under the Spanish equivalent of "Manga o manga marine". In Appleton's Spanish Dictionary "Manga (de Viento)" is defined as a whirlwind. A Box sextant which presumably is intended to refer to a Sextant box is defined in Spanish as "Sextant portatil (de bolsillo)" which infers that it is a sextant suitable for the pocket. Arctic sea smoke is referred to as "Niebla densa de los mares articos" (dense fog of the Arctic seas) whereas "frost smoke" is merely termed "humo polar" (polar smoke) or "humo o vaho (vapour) glacial". Surely this seems to be rather misleading. It is a pity that an otherwise good dictionary should be marred by uncertain English; the author might well be advised to seek the assistance of an English speaking meteorologist to assist him in preparing the next edition of this book.

The book contains an unusually varied number of local names for winds including "Candlemass Eve (winds)" which are referred to as "vientos fuertes; Inglaterra" (strong winds in England), and an Afghanistan katabatic wind which rejoices in the name "Bad-i-Sad-Bistros" (*sic*). The uncertainties of forecasting are perhaps emphasized by the inclusion in the English-Spanish section of an item "very doubtful (wind)" = "Viento (determinacion muy dudosa)".

As is pointed out in the Spanish Preface "The preparation of such a book is full of serious difficulties and the possibilities of errors and omissions is fully recognized by the author who will be glad to receive observations and suggestions in order to improve later editions". The criticisms contained in this review are intended to be constructive and they do not in any way detract from the usefulness of this book to anybody engaged in international meteorology.

At a price of £5 it is undoubtedly expensive; and its paper is not particularly good nor is it very well bound. Some drastic pruning of its non-meteorological contents would reduce its size and perhaps its price and some editing of its English text would be an improvement and perhaps increase its sale.

C. E. N. FRANCKOM

Dynamische Meteorologie. By K. T. Logwinow. 9 in. × 6½ in., pp. xii + 154, *Illus.*, Deutscher Verlagder Wissenschaften, Berlin, 1955. Price: *DM* 16.90.

The Russian original of this book is based on lectures to forecasters under training. The text is stated to have been kept as simple as possible with the physical relations placed clearly in the foreground.

The book gives a summary of some parts of dynamical meteorology without much mathematics though ability to use vector analysis and circuit integrals is needed. The mathematical developments have been considerably extended by the translator in footnotes. The mathematical parts, however, seem to have been selected somewhat arbitrarily and some omitted that are no more difficult than those included. The emphasis is on technique such as the use of thermodynamical diagrams (emagram, tephigram, Rossby diagram).

Although much use is known to be made in Russia of the analysis of contours of isobaric surfaces and thickness patterns the account of this subject is disappointingly brief and is little more than a statement of the gradient wind equation on contour charts and a reference to some papers written during the war. Again, V. Bjerknes's circulation-solenoid theory is developed in detail but there is no account of the relation between vorticity and divergence or of Rossby waves, constant-vorticity trajectories, or of air flow over mountains. There is a long account of Kibel's "first approximation" which, as the translator remarks, was effectively given by Exner many years ago. Interesting paragraphs are those on isentropic charts and on Shuleikin's calculation of the transfer of heat across the Arctic shores of the U.S.S.R. In the former it is stated that isentropic charts are drawn daily in Russian forecasting practice with isopleths of height and specific humidity for following the movement of moist and dry air. There is nothing on cloud physics except a comment on the unreality of the classical rain, snow, etc. stages, or on fog or visibility. The book ends with a short reference to a theory of the detailed forecasting of the diurnal variation of temperature published by Schwez in 1943 which it would be interesting to obtain for comparison with the work of Saunders.

Though the book cannot be recommended to English meteorologists for serious study of dynamical meteorology it would be useful to them for practice in German as it is written in a very easy style.

G. A. BULL

British North Greenland Expedition 1952–4: *Scientific results.* By R. A. Hamilton and others. *Geogr. J., London,* **122,** 1956, p. 203. Royal Geographical Society, London.

Mr. R. A. Hamilton, Senior Scientist of the British North Greenland Expedition, 1952–54, describes the use of air-pressure observations in finding heights along a track across the Greenland ice cap. Effectively 700-mb. contour charts were constructed using pressure readings at two stations where heights could be measured by theodolite.

G. A. BULL

Catalogue of books on mathematics, physics, astronomy and meteorology. $8\frac{1}{2} \times 5\frac{1}{2}$ in., pp. 61, H. K. Lewis and Co. Ltd., London, 1956.

H. K. Lewis's catalogue of books on mathematics, physics, astronomy and meteorology for 1956 includes a useful list of over 70 meteorological textbooks now in print with prices and mentions some now in course of preparation.

Several important books on the meteorology of the upper atmosphere are in the list of books on "Astronautics".

G. A. BULL

HONOURS AND AWARDS

The appointment of Mr. C. V. Ockenden, Senior Principal Scientific Officer, Assistant Director (Observations and Communications) of the Meteorological Office, to be an Officer of the Order of the British Empire was announced in the New Year Honours List, 1957.

Air Efficiency Award.—It was announced in Air Ministry Orders dated October 31, 1956 that Flt-Sgt J. Meadows of the Royal Air Force Volunteer Reserve, Meteorological Section, had been granted the Air Efficiency Award. Flt-Sgt Meadows is the Senior Assistant (Scientific) in charge of the meteorological office at Exeter.

OBITUARY

Takematsu Okada, D.Sc.—We regret to report the death of Dr. Okada, the eminent Japanese meteorologist, on September 2, 1956 at the age of 82 years.

Dr. Okada was Director of the Central Meteorological Observatory, Tokyo, the national meteorological service of Japan, from 1922 to July 1941. After graduating in Physics at Tokyo University in 1899 he joined the staff of the Observatory and was head of the forecasting division there from 1904 to 1920. In 1920 he was appointed Director of the Imperial Marine Observatory, Kobe.

He became a Fellow of the Royal Meteorological Society in 1921, was awarded the Symons Medal of the Society for his scientific work in 1924, and was elected an Honorary member in 1925.

His researches covered a wide field from the theory of the formation of glazed frost to the climatology of Japan.

WEATHER OF DECEMBER 1956

Cyclonic activity over the Atlantic was unusually intense but mostly well west and north of the British Isles. Mean pressure for the month was as low as 984 mb. near 60°N. 35°W., an anomaly of −13 mb. and a monthly pressure value which is not often surpassed in the northern hemisphere. Pressures were 8 mb. above normal in parts of central Europe and a mild generally south-westerly air stream was maintained over western and northern Europe, except for a cold break about Christmas associated with a meridional ridge from the west which intensified over Scandinavia. North-eastward displacements from normal position of the main centres of the Pacific, Azores and Siberian anti-cyclones were maintained in December as in November 1956. The displacement of the Atlantic system over western Europe had lasted since October. The highest value of monthly mean pressure over Siberia in December was 1042 mb., rather above normal and representing an anomaly of +12 mb. at the point where it occurred. The depression track in the Pacific appears to have been displaced south of normal and the systems travelled well east over the ocean, leaving an anomaly of +11 mb. in western Alaska.

Intense advection produced generally above normal surface temperatures in the Arctic, culminating with an anomaly of +9°C. from maritime air on the coast of north-east Greenland and +7°C. at Spitsbergen. There was excessive precipitation as in November on the windward aspect in this area (8·6 times the normal at Myggbukta). Temperatures were below normal in a belt between 50° and 70°N. across North America and between 40° and 60°N. across Asia, anomalies reaching −3° to −6°C. South of this cold zone, India and most of the United States were warmer than the December normal; the greatest anomaly was +6°C. at Atlanta, Georgia. The intensified thermal gradient near 50°N. in this sector may be linked with the deep depressions on the Atlantic, where many individual centres attained 950 mb.

The Mediterranean and North Africa were generally 1° to 2°C. colder than normal. Excessive precipitation was noted on the coast of Egypt and between Jugoslavia and the Black Sea, as well as in Iraq, Assam, on the west coast of Africa and in central America.

In the British Isles weather was exceptionally dull in many areas and mostly mild, particularly in the south, but a brief cold spell during Christmas week brought snow to many parts of the country.

During the first week an anticyclone lay to the south of the British Isles: weather in England and Wales was dull, quiet and very mild, especially in the south, with some occasional light rain or drizzle in places, but in Scotland and Northern Ireland conditions were more disturbed with periods of moderate to heavy rain and gales on the coasts. The mild weather continued during the second week but winds progressively freshened and rainfall became more general as pressure fell on the eastern Atlantic. On the 12th gales became widespread over the country and severe in the north-west as a deep depression passed north-eastwards between Scotland and Iceland; there were frequent showers, heavy at times with hail and thunder behind the disturbance. Weather continued very stormy for several days as a series of deep depressions followed on a similar track, but on the 17th the last disturbance of the series moved away north-eastwards and gales rapidly moderated. Fog became widespread on the night of the 18th/19th and persisted, dense in places. especially in the Midlands and northern England until the 23rd when rain, and in many districts snow, spread eastwards into the country. An anticyclone which had formed over Scandinavia increased in intensity and by the 24th a cold continental air stream covered much of the British Isles. On Christmas Day a trough to a depression near Greenland moved eastward across southern England; rainfall was heavy in Wales and south-west England but further east precipitation was in the form of snow which lay on the ground in some places to a depth of several inches. Winds veered to the south-west again on the 28th as another frontal system from the west brought a return of mild weather to all parts of the country. Rainfall was heavy in Wales and south-west England and this, coupled with the melting snow, led to widespread flooding in counties adjacent to the Severn valley and estuary.

Sunshine was below the average everywhere; at some stations it was the lowest ever recorded during December and at Kew it was the dullest December since 1890. Temperature was 9°F. above average in some areas during the first week and was above average for the month as a whole in spite of the brief cold spell around Christmas. Rainfall was above average over the country as a whole but was below average over North Wales, the west Midland counties and most eastern counties of England. Farmers made good progress with outside work during the mild weather of the first two weeks although diseases such as botrytis tended to flourish. The gales mid-month caused structural damage in Yorkshire and severely damaged flowers in Cornwall but, in spite of the bad weather towards the end of the month, autumn and winter work in the countryside is well in hand.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	59	12	+2·3	106	+1	48
Scotland	58	18	+2·5	119	+2	61
Northern Ireland ...	57	23	+2·5	124	0	66

RAINFALL OF DECEMBER 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square	2·75	115	*Glam.*	Cardiff, Penylan	5·15	103
Kent	Dover	2·71	88	*Pemb.*	Tenby	5·02	102
,,	Edenbridge, Falconhurst	4·16	126	*Radnor*	Tyrmynydd	7·34	89
Sussex	Compton, Compton Ho.	6·51	155	*Mont.*	Lake Vyrnwy	6·84	97
,,	Worthing, Beach Ho. Pk.	4·35	145	*Mer.*	Blaenau Festiniog	11·47	90
Hants.	St. Catherine's L'thouse	5·37	170	,,	Aberdovey	4·02	85
,,	Southampton (East Pk.)	5·53	151	*Carn.*	Llandudno	2·98	103
,,	South Farnborough	3·62	125	*Angl.*	Llanerchymedd	4·24	97
Herts.	Harpenden, Rothamsted	3·72	131	*I. Man*	Douglas, Borough Cem.	4·04	82
Bucks.	Slough, Upton	3·11	123	*Wigtown*	Newton Stewart	4·54	84
Oxford	Oxford, Radcliffe	3·17	129	*Dumf.*	Dumfries, Crichton R.I.	5·01	117
N'hants.	Wellingboro' Swanspool	2·87	122	,,	Eskdalemuir Obsy.	8·61	123
Essex	Southend, W. W.	1·81	91	*Roxb.*	Crailing	2·91	108
Suffolk	Felixstowe	1·85	89	*Peebles*	Stobo Castle	5·49	144
,,	Lowestoft Sec. School	0·99	42	*Berwick*	Marchmont House	2·37	84
,,	Bury St. Ed., Westley H.	2·38	99	*E. Loth.*	North Berwick Gas Wks.	1·69	79
Norfolk	Sandringham Ho. Gdns.	1·73	68	*Midl'n.*	Edinburgh, Blackf'd. H.	2·37	101
Wilts.	Aldbourne	4·16	122	*Lanark*	Hamilton W. W., T'nhill	4·95	115
Dorset	Creech Grange	6·12	139	*Ayr*	Prestwick	3·64	104
,,	Beaminster, East St.	6·63	139	,,	Glen Afton, Ayr San.	7·27	114
Devon	Teignmouth, Den Gdns.	4·95	117	*Renfrew*	Greenock, Prospect Hill	8·60	115
,,	Ilfracombe	4·95	102	*Bute*	Rothesay, Ardencraig	4·46	82
,,	Princetown	11·21	97	*Argyll*	Morven, Drimnin	10·67	136
Cornwall	Bude	3·99	92	,,	Poltalloch	5·69	89
,,	Penzance	6·16	108	,,	Inveraray Castle	12·28	124
,,	St. Austell	7·83	129	,,	Islay, Eallabus	7·93	134
,,	Scilly, Tresco Abbey	4·27	91	,,	Tiree	6·39	122
Somerset	Taunton	4·24	128	*Kinross*	Loch Leven Sluice	3·83	97
Glos.	Cirencester	4·06	117	*Fife*	Leuchars Airfield	2·92	118
Salop	Church Stretton	3·14	89	*Perth*	Loch Dhu	11·28	112
,,	Shrewsbury, Monkmore	2·11	86	,,	Crieff, Strathearn Hyd.	6·40	143
Worcs.	Malvern, Free Library	2·44	88	,,	Pitlochry, Fincastle	5·42	134
Warwick	Birmingham, Edgnaston	3·50	118	*Angus*	Montrose Hospital	3·37	121
Leics.	Thornton Reservoir	3·00	112	*Aberd.*	Braemar	5·55	156
Lincs.	Boston, Skirbeck	1·36	63	,,	Dyce, Craibstone	4·47	132
,,	Skegness, Marine Gdns.	1·43	65	,,	New Deer School House	4·80	140
Notts.	Mansfield, Carr Bank	3·34	115	*Moray*	Gordon Castle	2·98	111
Derby	Buxton, Terrace Slopes	6·83	120	*Nairn*	Nairn, Achareidh	2·62	128
Ches.	Bidston Observatory	1·89	71	*Inverness*	Loch Ness, Garthbeg	7·15	155
,,	Manchester, Ringway	2·63	86	,,	Loch Hourn, Kinl'hourn	21·87	158
Lancs.	Stonyhurst College	4·84	100	,,	Fort William, Teviot	16·38	161
,,	Squires Gate	3·49	112	,,	Skye, Broadford	12·95	144
Yorks.	Wakefield, Clarence Pk.	2·38	98	,,	Skye, Duntulm	6·37	102
,,	Hull, Pearson Park	1·62	67	*R. & C.*	Tain, Mayfield	2·91	102
,,	Felixkirk, Mt. St. John	2·03	84	,,	Inverbroom, Glackour	9·46	129
,,	York Museum	2·20	98	,,	Achnashellach	16·26	171
,,	Scarborough	1·86	78	*Suth.*	Lochinver, Bank Ho.	5·34	96
,,	Middlesbrough	1·42	73	*Caith.*	Wick Airfield	3·43	111
,,	Baldersdale, Hury Res.	5·29	137	*Shetland*	Lerwick Observatory	5·37	112
Norl'd.	Newcastle, Leazes Pk.	1·64	70	*Ferm.*	Crom Castle	5·41	131
,,	Bellingham, High Green	3·39	93	*Armagh*	Armagh Observatory	5·52	176
,,	Lilburn Tower Gdns.	3·70	141	*Down*	Seaforde	4·78	116
Cumb.	Geltsdale	3·81	100	*Antrim*	Aldergrove Airfield	4·33	126
,,	Keswick, High Hill	8·65	129	,,	Ballymena, Harryville	4·52	102
,,	Ravenglass, The Grove	6·70	46	*L'derry*	Garvagh, Moneydig	3·64	91
Mon.	A'gavenny, Plâs Derwen	8·08	165	,,	Londonderry, Creggan	4·18	95
Glam.	Ystalyfera, Wern House	8·19	98	*Tyrone*	Omagh, Edenfel	5·40	125

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THE COLD WEATHER OF FEBRUARY 1956 WITH SPECIAL REFERENCE TO TEMPERATURES AT KEW DURING THE LAST 75 YEARS

By R. E. BOOTH

In England and Wales February 1956 was one of the coldest months of the present century, with mean temperature of the month, 32·6°F., little above freezing and 8°F.* below the 1921–50 average, the only colder months being January 1940 and February 1947 when mean temperatures were 31·7°F. and 30·4°F. respectively. During the last 75 years there is known to have been at least one other colder February—1895. The object of this paper is to investigate in what respect and to what extent February 1956 was really outstanding in southern England and to note at the same time any general trend in February temperatures. Kew, which has an unbroken record of temperature for at least 75 years is taken as a representative station. All temperatures considered in this note are screen temperatures.

On February 1, 1956 temperature at Kew rose to only 24°F. during the day, the lowest February maximum since 1895, and fell to 17°F. the following night, the lowest minimum temperature recorded during February since 1895 except for 1947 when it fell to 14·5°F. During the period February 19–24, 1956, temperature remained continuously below freezing. Belasco[1] examined Kew records over a long series of winters for days with mean temperature below freezing point. He termed a day whose mean temperature, based on the mean of 0–24 hr. hourly readings, was below 32·5°F. a "T-freezing day". As daily means at Kew are usually calculated in this manner they will be called simply "freezing days" in this paper, and remarks confined to February.

Table I gives the number of freezing days at Kew during the 78 Februaries from 1879–1956 inclusive. It will be seen that the number of freezing February days during 1956 was only exceeded in 1947, although equalled in 1895. The last column gives the number of freezing days during each decade and it will be observed that these reached a peak during the 1890's but that there was a higher number still during the 1940's, while the decade beginning 1950 has already had more freezing days up to 1956 than any other decade since 1880 except the two just mentioned, beginning in 1890 and 1940. Closer inspection

* February was by far the coldest month of the winter 1955–6 in England and Wales. December was a mild month with mean temperature 2·3°F. above the average and January mean temperature was only 0·6°F. below the average.

of the table indicates that there was a succession of cold Februaries, with mean temperature below freezing point on several days from 1886–1902 with a break of a year or two about 1897. Apart from the cold February of 1929 with 14 freezing days there were few very cold Februaries until the 1940's and even during this decade the middle years lacked freezing days. The last four Februaries have had a progressively increasing number of freezing days.

TABLE I—FREEZING DAYS AT KEW FOR FEBRUARY, 1879–1956

	0	1	2	3	4	5	6	7	8	9	Total
						Number of days					
1870	...	...	...	...	...	...	...	...	...	4	...
1880	1	1	1	0	0	0	11	2	9	5	30
90	2	3	4	1	4	*18*	2	0	...	4	38
1900	6	6	8	0	2	0	0	5	0	1	28
10	0	2	4	0	0	0	2	9	3	7	27
20	0	1	3	0	4	0	0	2	0	*14*	24
30	0	0	4	2	3	0	3	0	0	1	13
40	10	3	*13*	0	0	0	0	*21*	3	3	53
50	0	0	0	2	6	9	*18*	...	...	...	...

Table II gives the number of freezing days between certain temperature limits during the above mentioned 78 winters, and the annual frequency distribution of these days together with a similar analysis for each of the five years with the greatest number of freezing days shown in italics in Table I. The table shows that on 2 days in 1956 mean temperature was only 22°F.; this was on the 1st and 2nd. There have been no colder days during February since 1895 except for a spell of 3 days, 13th–15th, in 1929, when mean temperature each day was about 21°F. A spell of 4 very cold days in 1895 occurred on 6th–9th.

TABLE II—FREEZING DAYS AT KEW FOR FEBRUARY BETWEEN CERTAIN TEMPERATURE LIMITS FOR CERTAIN YEARS

	1879–1956	Annual frequency distribution	1956	1947	1942	1929	1895
°F.			*Number of days*				
31·5 to 32·4	74	0·97	3	3	4	2	1
30·5 to 31·4	42	0·55	1	3	4	1	2
29·5 to 30·4	41	0·53	2	1	1	2	2
28·5 to 29·4	25	0·33	2	5	2	1	1
27·5 to 28·4	21	0·27	5	3	0	1	2
26·5 to 27·4	19	0·25	1	4	2	3	0
25·5 to 26·4	10	0·13	2	1	0	0	3
24·5 to 25·4	7	0·09	0	1	0	0	2
23·5 to 24·4	2	0·03	0	0	0	0	1
22·5 to 23·4	1	0·01	0	0	0	1	0
21·5 to 22·4	2	0·03	2	0	0	0	0
20·5 to 21·4	3	0·04	0	0	0	3	0
19·5 to 20·4	1	0·01	0	0	0	0	1
18·5 to 19·4	1	0·01	0	0	0	0	1
17·5 to 18·4	2	0·03	0	0	0	0	2
16·5 to 17·4	1	0·01	0	0	0	0	0

Table III gives some idea of the cumulative effect of spells of freezing days. It comprises all years since 1879 with a spell of 9 freezing days or more during

February. The figure against each day is not a measure of the coldness of that day alone, but of that day combined with all the preceding days in that spell and represents the accumulated number of frost-degree days; the contribution of each day to this number being $33 - t$, where t is the mean to the nearest whole degree Fahrenheit of 24 hourly temperature readings during the day. A spell of freezing days is not considered ended until the mean temperature of one or more consecutive days exceeds 32·4°F. It appears from the table that although the cold spell during 1947 was longer, the spell during 1895 was more severe. This can be attributed to the dull weather during February 1947 which was duller than any month since 1890; at Kew there was no sunshine February 2–22, the longest sunless period since records began. In 1895 there were 10 days with mean temperature below 27°F. whereas in 1947 there were only three. The table shows that February 1956 contained the third longest spell of freezing days of any February since 1895. The length of the 1956 spell was equalled in 1940 and the spell during 1929 was more severe, but during 1956 two other short freezing spells occured on the 1st–4th and 9th–12th; mean temperature fell below 27°F. on 3 of these days, but during the 10-day spell, 17th–26th, shown in Table III there was only one day with temperature below this value.

TABLE III—ACCUMULATED NUMBER OF FROST-DEGREE DAYS FOR FEBRUARY FOR SPELLS OF 9 OR MORE DAYS

days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	Frost-degree days																				
1956	1	4	10	17	22	26	31	36	39	38											
1947	3	7	10	12	13	11	15	21	25	27	29	34	40	45	49	53	58	64	71	79	85
1940	1	4	6	12	15	19	21	21	22	23											
1929	6	16	28	40	52	57	61	67	70												
1917	1	6	9	12	16	19	27	35	38												
1895	5	7	10	11	18	32	47	60	75	83	88	95	104	112	116	119	126	129			

TABLE IV—FEBRUARY TEMPERATURES AT KEW FOR CERTAIN YEARS

Year	Greatest departure of mean temperature from average	Year	Lowest mean minimum temperature	Year	Greatest No. of freezing days
	°F.		°F.		
1895	−11·0	1895	23·8	1947	21
1947	−10·1	1947	27·1	1895	18
1956	− 8·2	1956	27·1	1956	18
1929	− 7·3	1929	27·5	1929	14
1942	− 7·1	1942	29·1	1942	13

Table IV shows the five years with the greatest departure of mean February temperature at Kew from the 1921–50 average, the five years with the lowest mean minimum temperatures and the five years with the greatest number of freezing days since 1879. Table III indicates that 1956 had the third longest spell of freezing days during this same period in spite of breaks. From the above considerations February 1956 could be regarded as the coldest February at Kew, and most probably in south-east England during at least the last 75 yr., apart only from 1947.

The cold weather during the three years 1895, 1947 and 1956 was not confined to south-east England, but affected the whole country. Figs. 1, 2 and 3 give the distribution of absolute minimum temperatures reported during

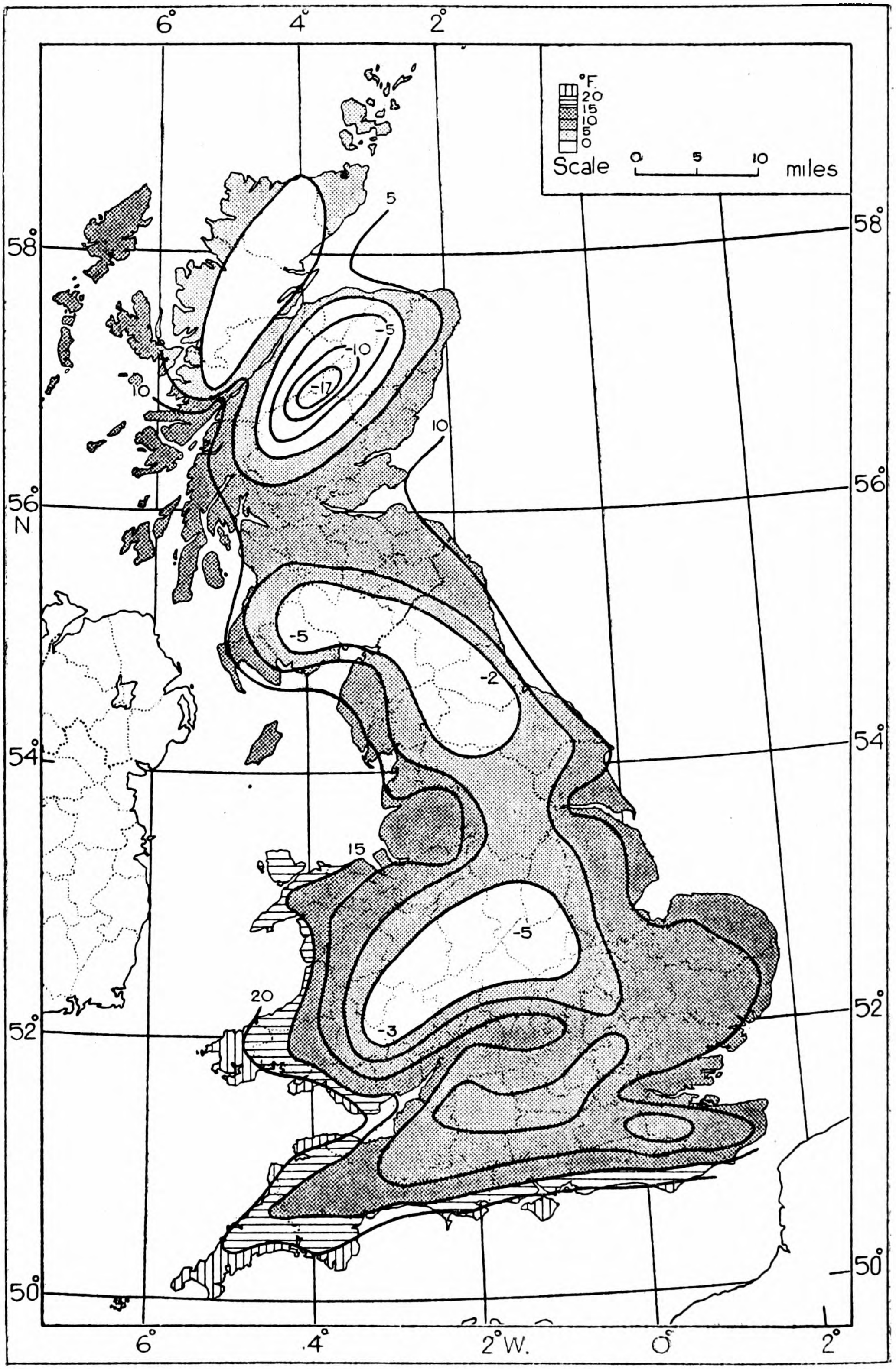

FIG. 1—DISTRIBUTION OF ABSOLUTE MINIMUM TEMPERATURES DURING FEBRUARY 1895

Temperatures are not corrected to sea level.

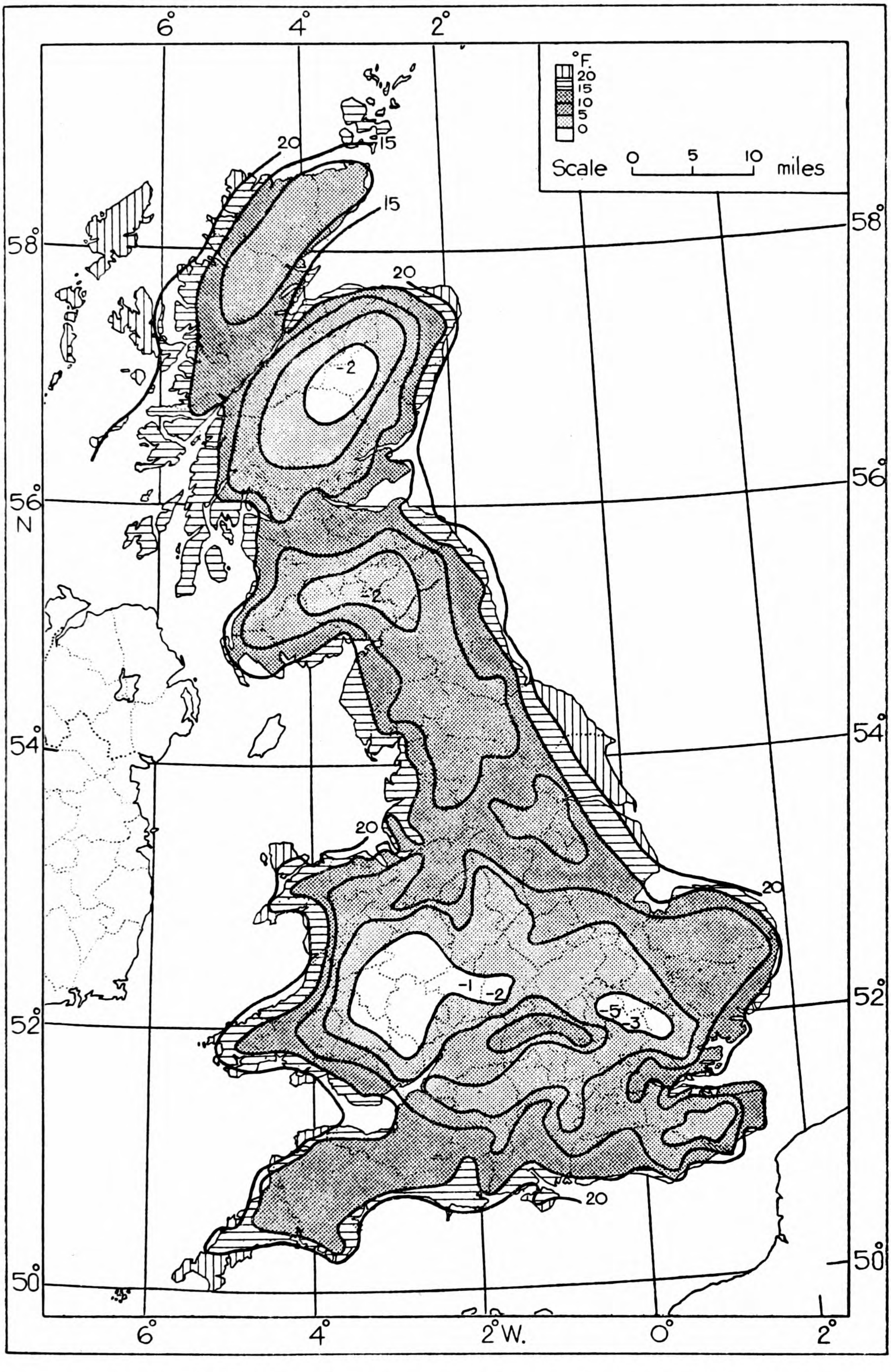

FIG. 2—DISTRIBUTION OF ABSOLUTE MINIMUM TEMPERATURES DURING FEBRUARY 1947

Temperatures are not corrected to sea level.

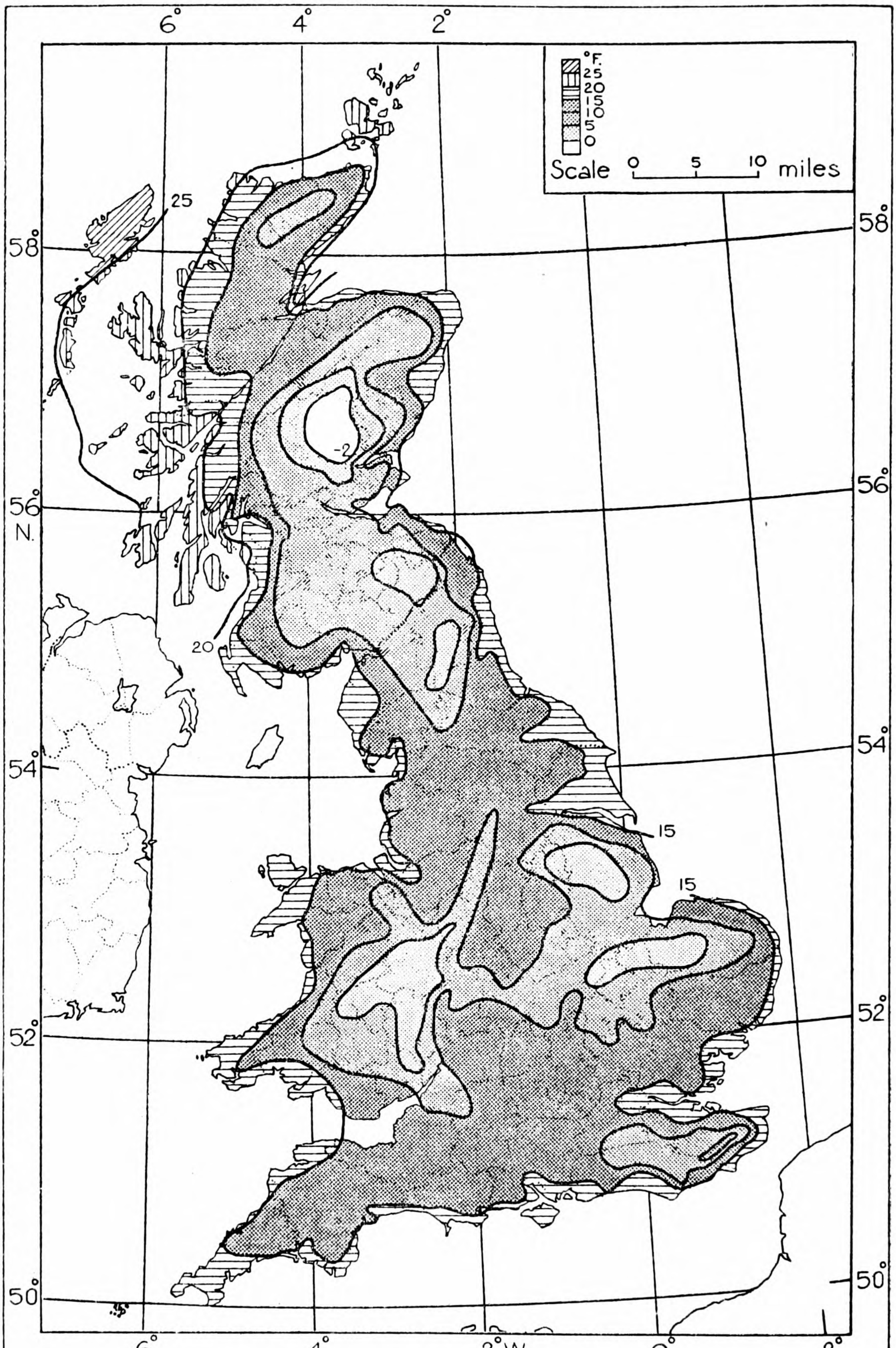

FIG. 3—DISTRIBUTION OF ABSOLUTE MINIMUM TEMPERATURES DURING FEBRUARY 1956

Temperatures are not corrected to sea level.

February of each of these three years and may be compared with the map of absolute minimum temperatures for the period 1901–1940[2] where a map of mean temperatures over the British Isles for February 1895 is also given.

In 1895 temperature fell below 0°F. over a wide area in the Midlands, northern England and Scotland; −17°F. was recorded at Braemar in Scotland. It fell below 10°F. at most places during the month except in coastal districts. During 1947 February temperature occasionally fell below 0°F. in a small area in central Wales and the west Midlands, locally around Bedfordshire and in the Cairngorms; −5°F. was recorded at Woburn, Bedfordshire. Except for coastal areas it fell extensively below 10°F. in Wales, the Midlands, East Anglia, Kent and Surrey and over most of the high ground in northern England and Scotland.

In 1956 temperature did not fall below 0°F. except locally in Scotland where −2°F. was recorded at Perth. Less than 10°F. was registered over much of the high ground north of 54½°N. and south of the Caledonian Canal, in central and southern Wales, over much of the Midlands, in Lincolnshire, Kent, Surrey and Sussex. Temperature fell below 5°F. locally in central Wales, Norfolk, Lincolnshire, the northern Pennines and in the Scottish Highlands.

Following the plan of Table IV, but this time taking England and Wales as a whole, tabulations show that the only February mean temperature since 1895 lower than that of 1956 was 1947. The same also applies to the mean minimum February temperature. It seems probable therefore that not only was February 1956 the coldest February at Kew since 1895 apart from 1947, but also in England and Wales as a whole.

The synoptic situation during the three coldest Februaries showed marked similarities. During February 1895 pressure was high over Scandinavia and decreased steadily during the first 10 days; pressure was generally low to the south-west of the British Isles. From the 12th the anticyclone over Scandinavia increased in intensity and moved steadily westward becoming centred over the North Sea on the 16th, and over the British Isles on the 18th; it then moved to the west of Ireland where it remained until the end of the month. With this pressure distribution easterly winds predominated during the first half of the month, but gradually backed to a northerly direction during the second half. From daily maps of minimum temperature it is seen that weather was most severe from February 6th to 13th[3]. The situation during February 1947 has been fully described by Douglas elsewhere in this Magazine[4], but it may be recalled that throughout most of February 1947 pressure was high over Scandinavia and was even higher around north and central Greenland and in a belt extending eastward to Siberia. The Greenland anticyclone helped to maintain easterly winds over the British Isles even after the Scandinavian anticyclone had given way. In 1956 February was dominated by easterly air streams from the continent. At times pressure was high to the west of Ireland, but twice during the month, on the 9th and 21st, anticyclones over or to the west of the British Isles, which had become detached from an extensive high pressure system over north-west Europe, formed a ridge across England as they rejoined the major continental system, bringing renewed bursts of direct continental air over the country. The lowest temperatures occurred during the first three days when air from the northern coasts of Russia was reaching this country, but temperatures were also very low from the 9th to 27th.

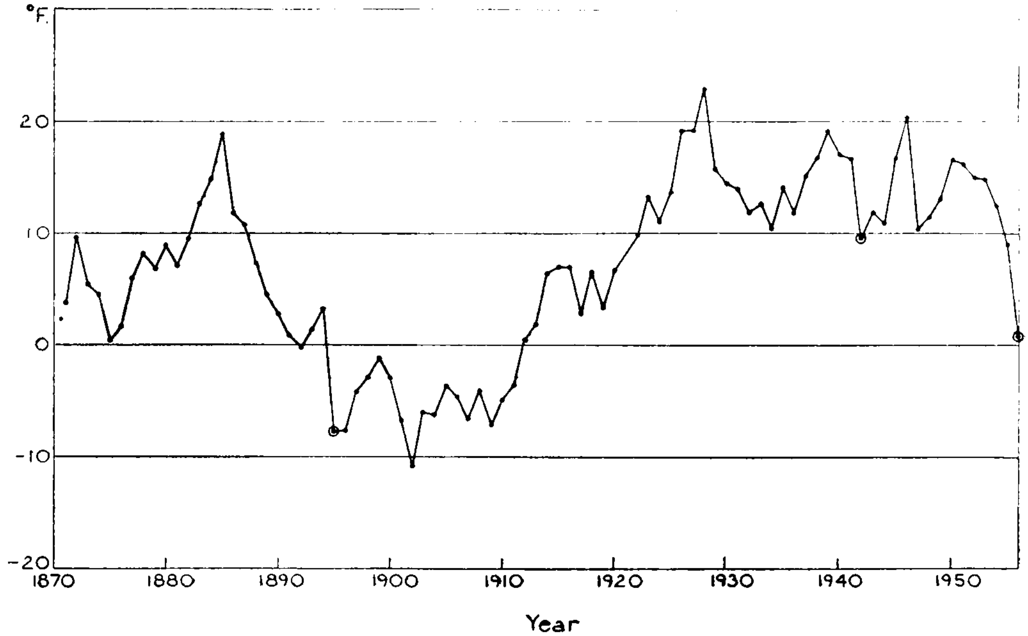

FIG. 4—ACCUMULATED DEPARTURE FROM 1871–1956 AVERAGE TEMPERATURE (40·1°F.) OF MONTHLY MEAN TEMPERATURE AT KEW DURING FEBRUARY

The values encircled show the five years with the lowest mean minimim temperatures. The five cold years include also 1929 and 1947.

The three cold Februaries were dominated by easterly winds. It was thought that as cold Februaries are associated with easterly winds, then if cold Februaries are becoming more frequent so should easterly winds. Mean February temperatures for Kew were extracted for the period 1871 to 1956, and wind directions were tabulated over as long a period as readily available, in this case 1908–1956.

Fig. 4 gives the accumulated departure of mean February temperatures at Kew from 1871 to 1956 from the mean February temperature over the whole period of 85 years. The curve, which slopes upward from left to right during a year when mean temperature was greater than the average, and downward when less, descends somewhat unevenly from a maximum value at 1885 to a minimum at 1902, ascending eventually to a second major maximum at 1928, after which, in spite of two or three secondary maxima there is a general over-all fall to 1956. This fall is very pronounced from 1953 to 1956. The five cold years referred to earlier in the text are marked in circles on the curve and it is noticeable that four of these occurred during the last 30 years. There is a striking series of cold Februaries, shown by the downward slope of the curve, from 1886 to 1895 broken only by the years 1893–4. This cold series of years is also shown by the large number of freezing days during this period in Table I; the mean minimum February temperature over these 10 years was only 32·9°F. A series of mainly warm Februaries is shown by the upward trend of the curve from 1910–28; the mean minimum temperature for these 19 Februaries was 36·6°F. and there were only 37 freezing days during this period, 16 of which occurred during the cold years 1917 and 1919. There was no very long series of warm or cold Februaries from 1928–50 but a few shorter period variations. Mean temperatures for February during the last five years have been below average and the difference from average has tended to increase progressively.

The wind tabulations consisted of listing the number of occasions when wind was observed to be blowing from each direction on an eight-point compass at 0700, 1300 and 2100 G.M.T. daily for every February from 1908 to 1956. The monthly total of winds from all directions therefore consists of 84 observations during an ordinary year and 87 during a leap year. For present purposes a general value only is required, so no correction has been made for leap years. The number of occasions winds were reported from a NE., E. or SE. direction were combined to arrive at an "index" of winds with an easterly component for each year.

For the period 1910–1928, when as previously noted the majority of Februaries had a mean temperature above the normal, the "easterly index" per annum was 17. Although there were several warm Februaries during the period 1929–56, the majority were cold; the easterly index for these 28 years was 24 per annum. The mean easterly index for the whole period 1908–1956 was 22 per annum. The difference from the mean value is even more striking if shorter periods containing only warm or cold Februaries are considered. During the periods 1910–1915 and 1920–28 each year had a February warmer than the average; the easterly index for these periods per annum was 11 and 18 respectively. On the other hand all Februaries during the periods 1929–32 and 1951–56 were colder than the average; the easterly index for these periods were 39 and 27 per annum respectively.

To sum up, it seems that since records began at Kew February 1956 was the third coldest February from nearly every point of view and also probably in England and Wales as a whole. During the last 75 years there have been an increasing number of cold Februaries since 1928 and this tendency has gone hand-in-hand with an increased frequency of winds from an easterly direction.

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SOME SPECIAL FEATURES OF THE CLIMATE OF ST. HELENA AND THE TRADE-WIND ZONE IN THE SOUTH ATLANTIC

By H. H. LAMB, M.A.

The Supervisor of meteorological observations on St. Helena, 16°S., 6°W. approximately, Mr. Gordon Lunn, has drawn attention to the rainfall and low temperatures registered in the twelve-month period from November 1954 to October 1955, which many local residents have described as the worst and wettest in living memory. Most of these months had below average temperatures.

The monthly totals in inches for the six rainfall stations on the island are given in the table below and the positions of these stations in relation to the island's topography are shown in Fig. 1. It will be seen in Table I that the wettest periods were February to April and June to August 1955 at most stations. February was everywhere the wettest month, closely followed by March at the high-level stations on all sides of the main ridge; July was the second wettest month at two stations at medium levels on the northern side,

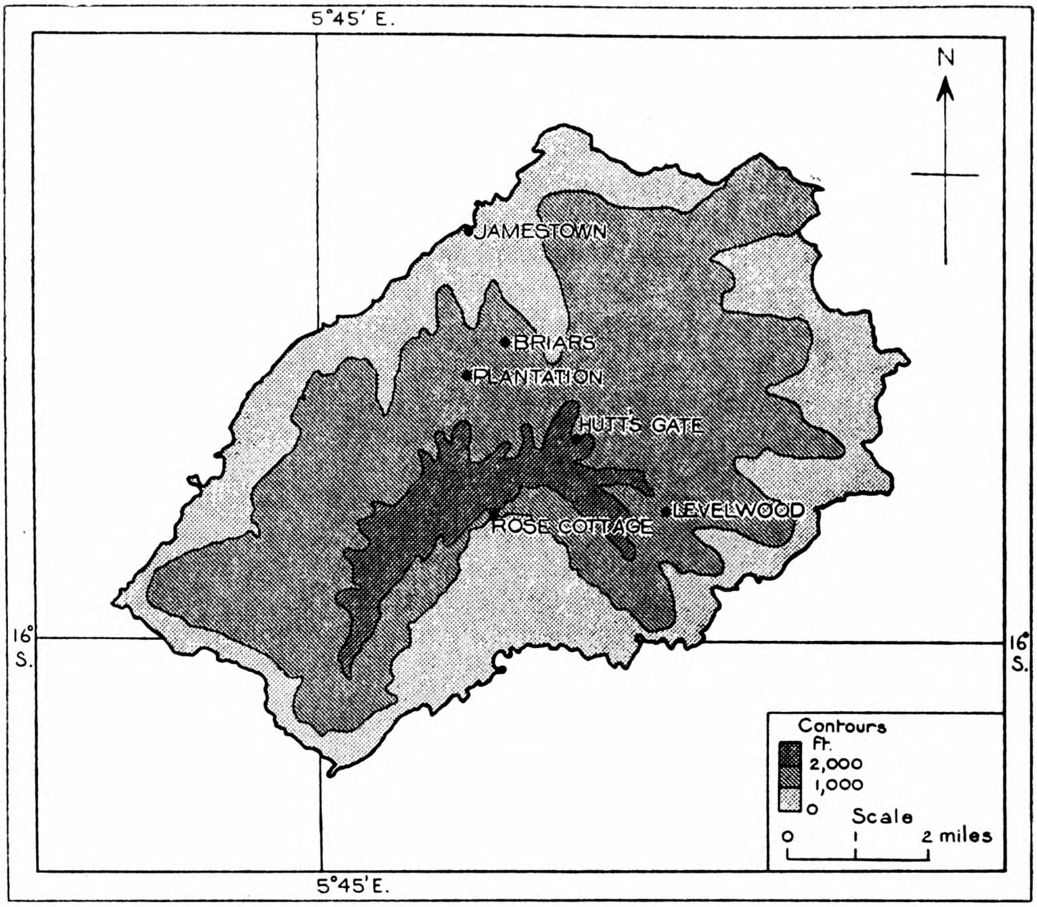


FIG. 1—ST. HELENA ISLAND SHOWING POSITION OF RAINFALL STATIONS IN RELATION TO TOPOGRAPHY

Plantation and Briars, whilst the August rainfall was outstanding only at the two stations with an eastern or north-eastern aspect, especially Levelwood.

TABLE I—RAINFALL IN INCHES AT ST. HELENA

Position and height above sea level	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Rose Cottage 2,030 ft.	1954											1·5	1·7	
	1955	0·8	9·4	7·0	6·0	3·8	5·7	6·2	5·3	2·4	3·5			53·3
Hutt's Gate 2,060 ft.	1954											1·1	1·8	
	1955	0·5	6·4	5·2	4·0	3·1	3·7	4·0	4·0	2·4	2·2			38·4
Plantation 1,800 ft.	1954											0·8	1·5	
	1955	0·6	5·7	4·6	4·5	3·1	3·9	5·1	4·3	1·4	2·2			37·7
Levelwood 1,400 ft.	1954											0·9	1·3	
	1955	0·6	4·9	4·0	3·1	2·0	2·7	3·2	3·8	1·8	2·5			30·8
Briars 900 ft.	1954											0·5	0·6	
	1955	0·1	4·3	2·6	3·1	1·3	3·4	3·7	3·0	0·8	1·1			24·5
Jamestown 40 ft.	1954											0·2	0·1	
	1955	0·0	2·5	0·7	1·6	1·1	1·6	1·4	0·6	0·1	0·2			10·1

St. Helena is usually described as being in the heart of the SE. trade-wind, which blows so steadily that in the normal year Jamestown, the capital, has 71 per cent. SE., 18 per cent. S. and 8 per cent. E. winds at the midday observation. Actually the climate of the island and, to some extent, that of the trade-wind belt of the South Atlantic in general, have remarkable peculiarities, which have so far received little notice in meteorological literature.

Jamestown itself has very much a leeside, sheltered situation and enjoys an average rainfall of only five to six inches a year. The other stations for which we have records over several years all show average yearly totals ranging from 32 to 44 in. Examination of the records shows that in reality a good many years have been about as wet as, or wetter than, 1954. (Mr. Lunn, the present Supervisor, has only been three years in the island, and 1952 and 1953 were relatively dry.) Hutt's Gate flax mill at about 2,000 ft., for which records are available for 31 yr. since 1925, with an average rainfall of 32·1 in., has four times measured over 40 in. in the year (cf. 1954, 36·8 in.): the wettest year was 1950 with 43·65 in.; in 1939 the total was 39·6 in., followed by 41·2 in. in 1940. The driest years, 1933 and 1946, had 22·4 and 22·8 in. respectively.

The moist, equable climate of St. Helena may explain an entry on the climatic return for October 1902 by Mr. J. Homagee, observer and police magistrate: "A splendid climate for consumptives . . . two gentlemen here . . . in a critical condition when they arrived—one 22 years ago and the other three years since—are now quite recovered . . . no sign of their former illness. . . ."

More remarkable than the rainfall amounts are the average numbers of days with over 0·1 mm. rain—234 a year at Hutt's Gate. The same station has an average of only two "clear days" a year and 290 "cloudy (overcast) days". Even Jamestown gets 128 cloudy (overcast) days in the average year. The figures for Hutt's Gate are comparable with the dullest skies of the sub-Antarctic ocean and those for Jamestown compare with the Atlantic coast of Nova Scotia.

Even more surprising, for a position in the main trade-wind stream in 16°S., is the fact, which partly explains the cloudiness figures, that there is a good deal of altostratus. Over a sample period from November 1946 to April 1947 33 per cent. of the observations from St. Helena included altostratus, 39 per cent. cumulus or cumulonimbus and 36 per cent. stratocumulus. Sometimes combinations of these cloud types occurred in the same report. Two ships with trained meteorologists on board, passing between St. Helena and the African coast during this period, had a similar experience and confirmed the existence of fairly extensive altostratus; the surface wind directions were more variable than at St. Helena.

The conclusion, supported by southern-hemisphere weather analysis, that the trade-wind zone of the South Atlantic is troubled by a good deal of frontal activity, represented by the trailing cold fronts of cold outbreaks from the Weddell Sea and elsewhere in the Southern Ocean is inescapable. In this connexion reference may usefully be made to some interesting work, partly unpublished, by Instructor Commander G. P. Britton, R.N., formerly in charge of investigational work at the Royal Naval Weather Centre, Simonstown, South Africa. Britton found correlations which appear to be significant:

(i) between pressure at Tristan da Cunha and pressure at Cape Town two and a half days later;

(ii) between cold-front passages northwards over South Georgia and Tristan da Cunha and outbursts of rainfall in the rainy season on the Gold Coast, about 5°N., approximately six days later.

The penetration northwards right into the equatorial zone of the cold fronts of the South Atlantic is doubtless a complementary phenomenon to the position of the intertropical convergence always north of the equator in this sector and the occurrence of no tropical storms in the South Atlantic. Similar analyses of the general weather situation over the South Atlantic and eastern South America, with cold fronts from the south ultimately crossing the equator, were published some years ago by the Pan American Airways system, Rio de Janeiro. In the northern winter cold fronts from the north were similarly shown crossing the equator over Brazil.

Dr. W. Schmitt of the South African Weather Bureau, whose experience over six years of the Southern Hemisphere Analysis Project is of the greatest value in this field, has kindly read over these pages. He comments that St. Helena, and with it a wide area to the east and south-east, seems frequently affected by frontal weather from former cold fronts moving up to the Cape of Good Hope and passing inland over South Africa as far as a line south-eastwards from about 25°S. on the west coast. On passing farther inland over the continent beyond this line these fronts become less distinct, being involved in thundery convection in the southern summer, but evidently retain their identity and frontal slope in the trades over the ocean. In some cases, with a cold wave of greater amplitude than usual, a cut-off cold low develops near St. Helena or the region south of it: the island is then likely to receive rains of extended duration from dense medium cloud. It may be of interest therefore to add that at Hutt's Gate, St. Helena July and August 1955 were the coldest July and August in 21 years of record, 1935–55: the minimum temperature of 50°F. on August 20, 1955 at Hutt's Gate was the absolute lowest value so far reported from the island.

FRONTS IN THE INTERTROPICAL CONVERGENCE ZONE: AN OBSERVER'S LOG AND SOME REFLECTIONS THEREUPON

By H. H. LAMB, M.A.

Publication of the following extracts from the weather diary of the whaling ship *Balaena's* southward voyage to Antarctic waters in 1946 may serve as a contribution to our understanding of the intermittent frontal activity in the intertropical convergence. The writer's attention has been turned again to these observations, following the recent realization that similar phenomena identifiable in the South Atlantic are common enough to make altostratus cloud a prominent characteristic of the extraordinary climate of St. Helena[1] and of much of the zone of SE. trade winds.

By pure chance the *Balaena's* southward voyage direct to the Canary Islands and on towards Cape Town was so timed as to keep more or less continuously in view the cloud system (see photographs in the centre of this magazine) associated with a cold front which passed the ship off Finisterre, north-west Spain on October 17, 1946, until the ship apparently passed through it again in the intertropical convergence about 8½°N. on October 26. The front passed through a quiescent phase when it became for a while quasi-stationary in the belt of high pressure near the Canary Islands, but its activity and the depth of cloud development increased again as it moved on south.

The general synoptic situation over the given sector of the northern hemisphere is here illustrated in Figs. 1–4 by the analysis taken from the

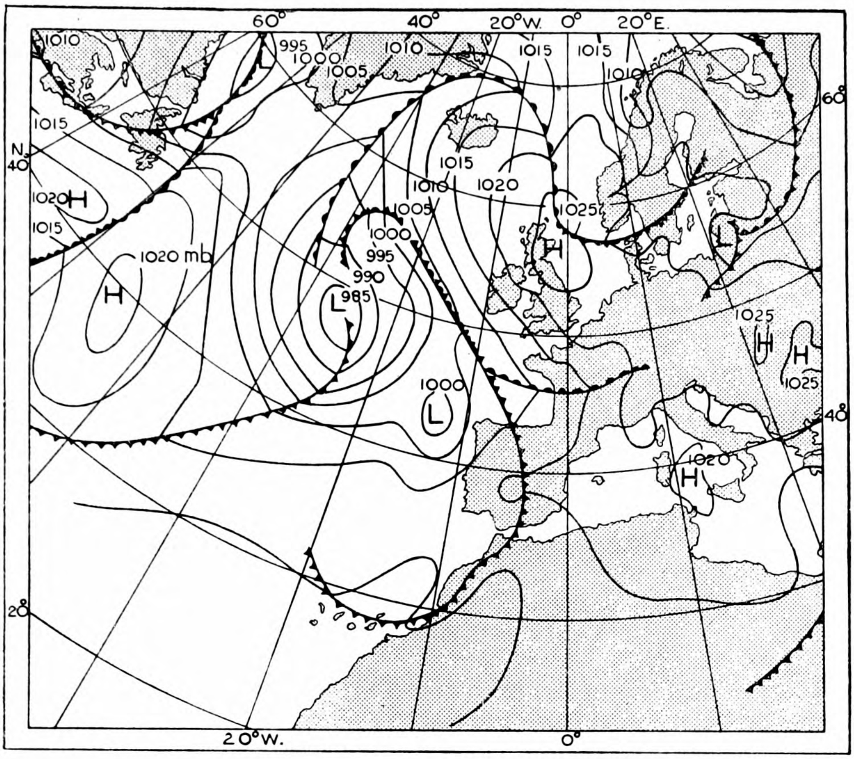


FIG. 1—SYNOPTIC CHART 1800 G.M.T. OCTOBER 17, 1946

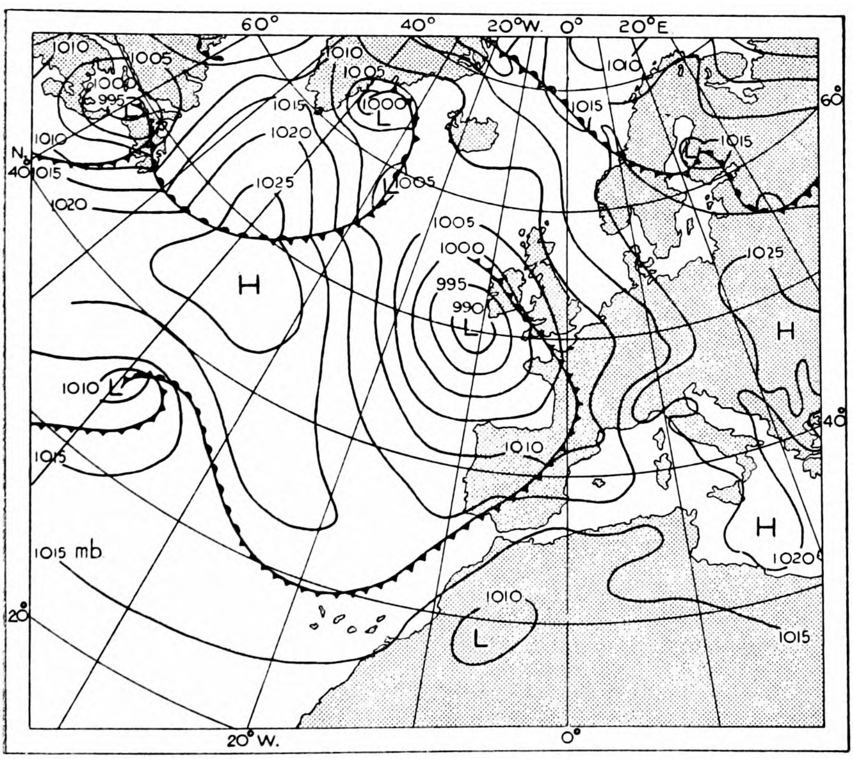


FIG. 2—SYNOPTIC CHART 1800 G.M.T. OCTOBER 19, 1946

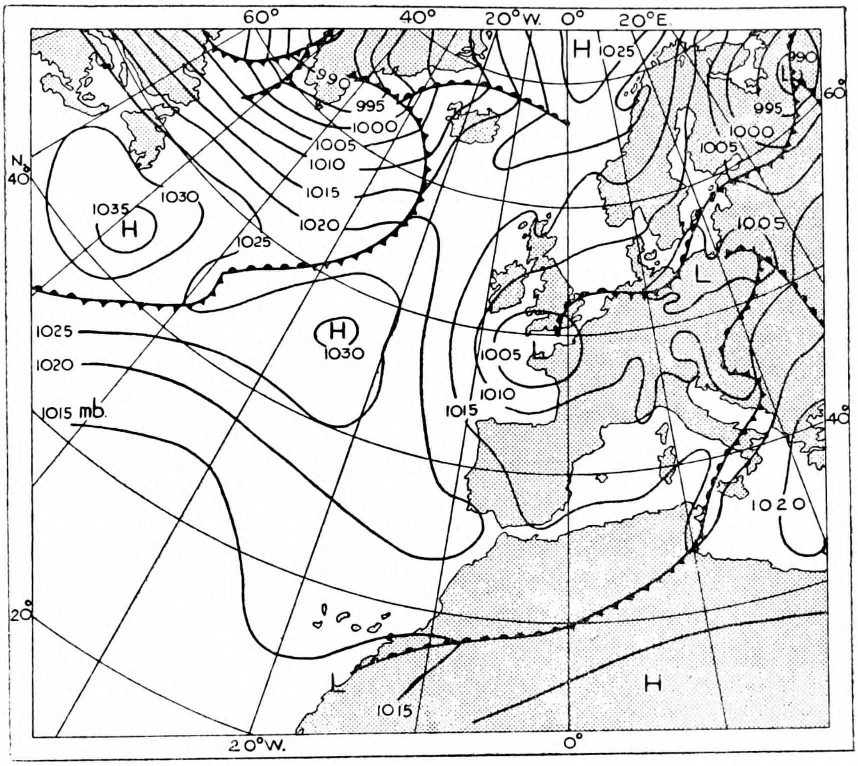


FIG. 3—SYNOPTIC CHART 1800 G.M.T. OCTOBER 21, 1946

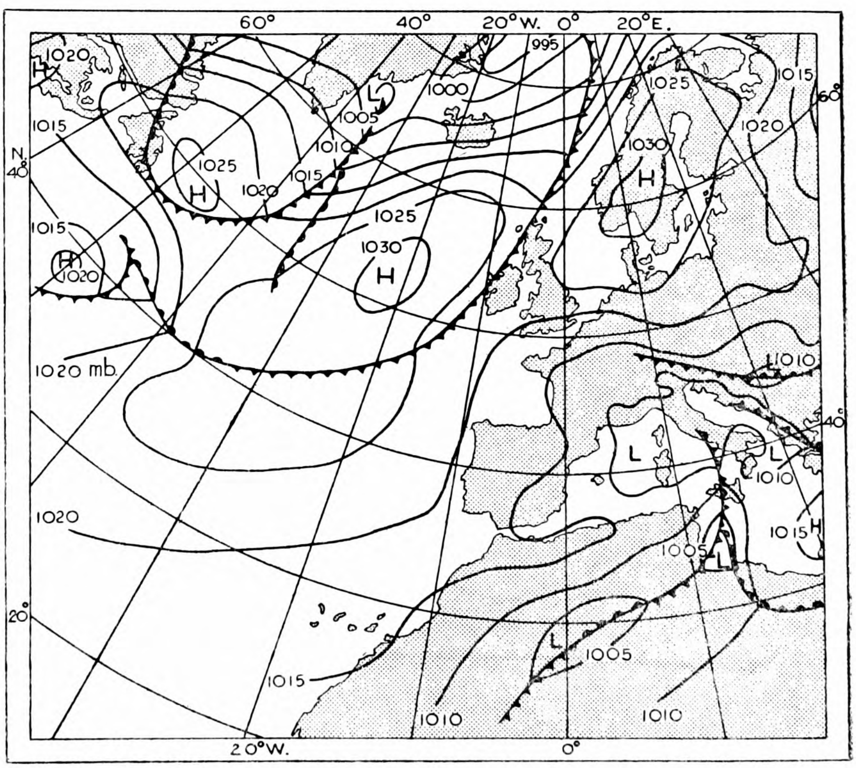


FIG. 4—SYNOPTIC CHART 1800 G.M.T. OCTOBER 23, 1946

north-west German daily weather reports, Hamburg for the evenings of October 17, 19, 21 and 23, 1946. A secondary cold front, shown on the German charts, gave drizzly rain as it overtook the *Balaena* on the night of October 18–19; but this was only a minor complication since the secondary front was again encountered by the *Balaena* approaching the Canary Islands on the morning of the 20th, just north of the now quasi-stationary main cold front with which it later substantially coalesced in the neighbourhood of the Islands.

The following are extracts from the original weather log, written on or about the days in question:—

17.10.46 0800 G.M.T., off Finisterre.

Sky clearing from the west after 4–5 hr. rain, which was sometimes moderate to heavy. Banded As Ac and Fc over land in Spain, the cloud systems orientated north–south approximately. Coastal mountains visible up to skyline . . . Wind SW. force 3.

17.10.46 Forenoon and early afternoon, Finisterre to 42°N. 97°W.

Sky clear most of forenoon apart from retreating frontal cloud-sheet and big Cu on eastern horizon and advancing As Ac and dense Ci coming up from western horizon. Wind backs to S. by E. and soon becomes force 7, later force 8–9.

17.10.46 1600–2000 G.M.T., 41·5°N. 9·7°W. at 1800 G.M.T.

Rain of slight intensity began about 1600 G.M.T. and lasted 3–4 hr. . . . much wind. By 1800 wind had veered and dropped to S. force 6 and from then onward continued gradually veering and dropping all through the following day. (Post-depressional trough).

18.10.46 0030 G.M.T., 40·5°N. 9·7°W. off Portugal.

Post-frontal sky, frontal cloud belt lying to the east: 9/10 As Ac . . . height judged about 9,000 ft. probably indicating the depth of the post-frontal cold air stream.

18.10.46 1200 G.M.T., 38·0°N. 10·5°W.

All day we seem to be skirting the frontal rain belt which lies not far to the east of the ship over the approaches to Gibraltar. Three distinct, though brief showers (10 min. duration) coming from the medium cloud-sheet fell on the ship and rain was in sight . . .till about 1600 . . .

18.10.46 1800 G.M.T., 36·7°N. 11·2°W.

Wind now SW. by W. force 3 to 4 . . . apparent that the frontal cloud sheet Ac Sc getting gradually lower and of more anticyclonic appearance. It remained 9/10 to 10/10 all day, orientation continuous with that observed with the frontal rainbelt on 17th . . .

19.10.46 0000 G.M.T., 35·7°N. 11·7°W.

Wind has veered much more rapidly during the night, and the sky, which became 10/10 at midnight with drizzly rain, now shows a clearing segment in the north-west. . . .

The Sc is still lower this morning (attributable to shallower cold air mass) . . . the ceiling slopes visibly upwards from about 1,600 ft. in the south-east (nearer the front, where it looks . . . thicker cloud and gloomy) to not lower than 3,000 ft. at the cloud edge some miles north-west of the ship. (Noted that the cloud sheet became very thin and anticyclonic looking for a time, though the north-west edge remained clear-cut.)

19.10.46 1800 G.M.T., 32°N. 13·7°W.

Renewed spreading of the Sc. from west and south-west suggests a wave or ripple on the weak, trailing front. By midnight the sky became almost-10/10 covered.

20.10.46 0700 G.M.T., 29·3°N. 15·0°W.

By morning the frontal Sc cloud sheet had narrowed again, and the edge moved away south, ahead of the ship, so that the sky is only about 4/10 covered. We overtook this cloud belt about 0700, and passed through a light shower. At this time the sky had decidedly the appearance of a weak front lying about east north-east to west south-west. . . . The wind veered more and more to NE. or ENE. force 2 to 3 as the front was approached. After passing south of the shower line the wind became very temporarily SE. force 1, then settled down to ENE. force 2 again. We entered a narrow belt of clear sky and saw ahead another belt of similar Sc base estimated 3,300 ft. tops 5,000–6,000 ft., orientated parallel with the previous cloud belt which lay only a few miles north of it. There was also big Cu, base 2,800 ft. penetrating right through the southern Sc system and with the peaks of the Canary Islands embedded. . . .

20.10.46 1200 G.M.T., Las Palmas, Gran Canaria (arrival).

The two Sc cloud belts with clear-cut edges continued westwards over the ocean as far as the eye could see. The height of the thin Sc appears to indicate more or less the depth of the post-frontal cold air stream hereabouts as 3,000–5,000 ft. as against 10,000–12,000 ft. off the Portuguese coast on the 17th–18th. (The cloud-sheet had gone through some variations of development and was at this stage relatively weak or quiescent but still thick enough to prevent the sun being visible, except in the middle of the day.)

The ship stayed in port at Las Palmas all day on the 21st. The cloud systems remained quasi-stationary over the islands and with little change of character, apart from slight drizzle in the night of the 20th–21st and a gradual lifting of the Sc cloud base on the morning of the 21st to perhaps 4,000 ft. The orientation of the cloud structure and edges gradually swung to east-south-east to west-north-west. A segment of clear sky was visible throughout along the northern horizon. About midday on the 21st the whole cloud system, still discernibly in two parallel belts though the separation was by this time quite small, began to move south again. The sky over the Canary Islands largely cleared from the north at sunset, first revealing the great mass of Teneriffe (12,100 ft.) in the guise of a great mountain apparently based on the stratocumulus. The surface wind picked up from NNE. to force 3.

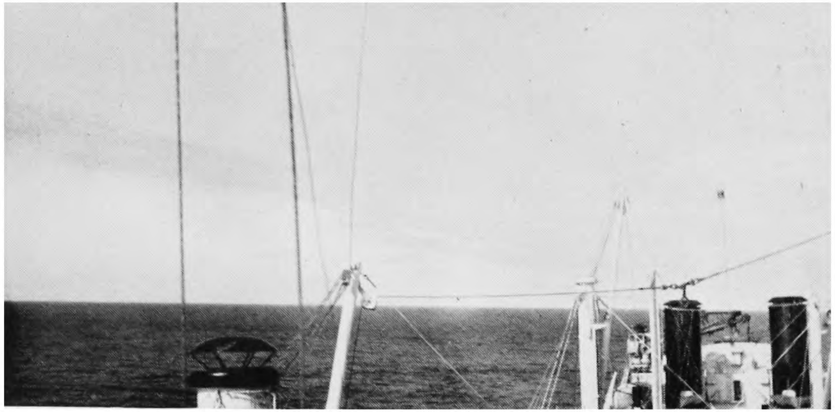
On the 22nd the WH. F. *Balaena* sailed from Las Palmas for the southward voyage at first light. The Sc. cloud sheet, its base now at 4,500–5,000 ft., was still in view and still lay about the hills of the western islands in the Canaries group. The orientation of the cloud edge had swung to about north-north-west to south-south-east (indicating greatest southward advance of the system in longitudes east of the ship near the coast of Africa and beyond).

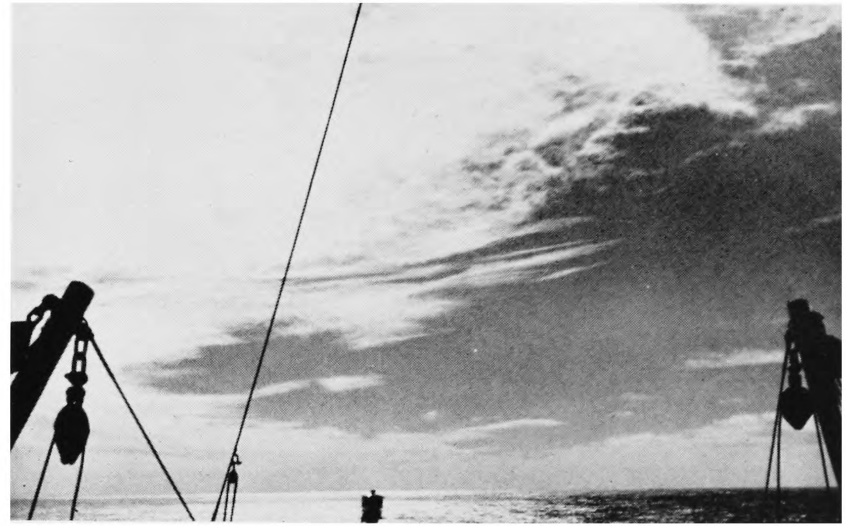
At 1800 G.M.T. on the 22nd the ship had reached 26·2°N. 15·8°W., the Sc cloud sheet was still in view as a north–south line near the western horizon and had lifted to perhaps 6,000–7,000 ft. The question of whether this cloud edge now represented the old frontal surface or some other effect parallel to the African coast line might now be open to argument, but could be gainsaid by historical continuity over the past 5–6 days and the fact that parallelism with the African coast was a phase of its history which had only just come about. Moreover, the cloud edge must have been over 200 miles from the coast.

During the 23rd, while the ship steamed south as far as 20°N. 18°W., the Sc system was for some time still visible on the western horizon, but becoming more remote. Later Ci and Cs came into view across the south-eastern, then the southern and western segments of the sky, and gradually became general and dense in places on the 24th. There was no other cloud to note all day, presumably because the relatively cold upwelling water near this part of the African coast inhibits convection. The water was coolest when the ship was nearest the African coast, and the breeze freshened to N. force 5.

At midday on the 25th the ship had reached 12·3°N. 17·6°W., the breeze had veered and dropped to NE. force 3 and the sky contained only abundant Ci and Cs along the south-eastern and western horizons and some more in the north. We had been out of the zone of cold water since midday on the 24th when the sea-surface temperature had risen rapidly to over 80°F. Still no convection cloud appeared, until a tremendous line-squall cloud belt of Cb and Ac stretching from horizon to horizon which was passed about 0500 G.M.T. on the 26th near 9°N. 15½°W. Lightning had been seen ahead of the ship from 2000 G.M.T. on the 25th.

The orientation of this Cb system, which was here south-east to north-west, was consistent with the theory that it represented maximum southward and south-westward advance of the same cloud system which had been in view from the *Balaena* for seven days, from the 17th to the 23rd inclusive, when it got too far ahead of the ship in 20–22°N. At that time the cloud edge consisted of stratocumulus and altocumulus, which had been getting steadily higher since its advance south from the Canary Islands. It is reasonable to suppose that a conversion of the cloud system to cumulus and cumulonimbus forms, though still associated with altocumulus, would take place as it advanced over much warmer waters: additionally, the advance out of the subtropical region of relatively high pressure would also favour increasing vertical motion, as long as the convergent system of surface breezes associated with the front persisted. Extrapolation of the front still shown on the German charts over the western Sahara, and active over Algeria and the western Mediterranean on the 24th–26th, also suggests that its continuation should lie very close to the intertropical convergence off the west coast of Africa near 10°N. on the 26th.





Top left—EDGE OF WEAK FRONTAL CLOUD-SHEET STRATOCUMULUS IN 32–33° N. ABOUT 13° W.

Some 200 miles east of Madeira on October 19, 1946. Photograph looking north, showing clearance, seen as pale clear sky in the picture, approaching from the north-west. The cloud-sheet overhead appears dark in this picture.

Top right—WEAK FRONTAL CLOUD-SHEET IN 32–33° N., ABOUT 13° W.

The afternoon of October 19, 1946: photograph looking south-west. The segment of clear sky appears dark and the thin edge of the cloud system brilliantly sunlit in this picture. The clearing edge has reached the zenith over the ship and the continuous, weak frontal cloud system is seen ahead of the ship along an arc from the eastern to the southern horizon.

Bottom left—QUIESCENT FRONTAL CLOUD-SHEET OVER THE CANARY ISLANDS

Northern edge of the main frontal cloud system chiefly stratocumulus but some cumulus over the islands, orientated east-north-east to west-south-west over the Canary Islands, October 20, 1946 about 0900 G.M.T. Photograph looking south, view approaching Gran Canaria, about 28° N. 15½° W. The dark area overhead is clear sky.

(see p. 76)

North-west

North-east

North-east

South-east

FRONT IN THE INTERTROPICAL CONVERGENCE

Frontal cloud line largely cumulus and cumulonimbus but also much cirrostratus near $8\frac{1}{2}$°N. $15\frac{1}{2}$°W., 150 miles off Freetown, about 0900 G.M.T. October 26, 1946. Panoramic view between north-west and south-east, the right-hand side of the top picture and the left-hand side of the bottom picture facing about north-east: the ship's heading was by now south-east and the wake is seen to the north-west near the left-hand margin of the top picture. This is believed to be the same cloud system as that shown in the first three photographs, having acquired greater vertical development after passing from the latitude of subtropical high pressure into the intertropical convergence. The actual pressure fall was about 8–10 mb.

(see p. 76)

SECOND FRONT IN THE INTERTROPICAL CONVERGENCE

Photograph looking south-west about the same time as the previous panorama was taken, showing the base of a second cloud line, also largely cumulus and cumulonimbus, in the intertropical convergence near 8½°N., 15½°W. at 0900 G.M.T. on October 26, 1956. The ship was between these two cloud systems at this time. Both cloud systems were giving moderate rain at some points along their length. Perspective and foreshortening made it hard to judge the curvature of these roughly parallel lines of cloud, but they seemed to converge towards the west-north-west; in the other direction they separated towards north-east and south-east. The southern system appears therefore to have had the characteristic curvature of a front advancing north-eastwards in the southern hemisphere.

(see p. 76)

Examination of the charts for north-west Africa leads to the conclusion that this is actually a common situation. Such situations over north Africa were described as typical of the region by Petitjean in 1932[2].

Even more thought provoking is the observation in the *Balaena* weather log on October 26, 1946:—

At 0900 G.M.T. in approximately 8½°N. 15½°W. the ship lay between two well marked cloud lines, each orientated about south-east–north-west and probably some 10–15 miles apart, consisting of Cu and Cb base 1,500 ft., and occasionally 500–800 ft., tops of great height . . . associated Ci Cs plus altocumulus cumulogenitus in small amounts. One very interesting feature of these cloud lines was that their respective (slight) curvatures were in opposite senses: perspective suggested the two systems converging towards the west-north-west . . . but to the east, the eye could see them diverging more and more from each other, as if the northern cloud line led off into the interior of the Sahara somewhere east (and eventually north-east), whilst the southern system led off somewhere to the south-east and south.

In other words, the more southerly cloud system had the form and orientation of a frontal cloud system which might have advanced from the southern hemisphere[1].

After passing through the second cloud and thunder-shower system, the *Balaena* encountered southerly breezes force 2–3, which gradually strengthened over several days into the south-easterly trade wind of the South Atlantic. In this instance, there was, as a matter of fact, a good deal of altostratus in the South-Atlantic trade-wind zone and the observer had the impression again of skirting a quasi-stationary frontal system to the eastward.

It seems likely that continuity of the cloud systems advancing towards the intertropical convergence from higher latitudes in the northern and southern hemispheres would be best preserved over the oceans, though the cloud development necessarily passes through various vicissitudes on the way, as recorded in this case where observation was almost continuous. Such observations are therefore easiest made over the oceans and especially over the eastern sides of the oceans; they may nevertheless have some relevance in other sectors—for altostratus–altocumulus cloud sheets associated with cold fronts from the Mediterranean have been traced at least as far as Kufra oasis (24°N., 23°E.) in winter. The line of convergence in the surface winds sometimes survives after all frontal clouds have disappeared over the Sahara, to give line squalls and dust storms, haboobs, in the northern Sudan. Abyssinia and the eastern Sudan experience similar sand storms[3] in the northern summer with line squalls coming from the south and south-east.

The writer has examined the logs of two British private expeditions under F. Rodd to the Sahara for further evidence bearing upon the type of phenomena observed over the ocean.

These expeditions went from Kano and Katsina about 13°N. in the northern part of British Nigeria crossing the intertropical convergence zone to Agadez and Auderas (17 to 18°N.), operating northwards between longitudes 7 and 9°E., in the summers of 1922 and 1927. The parties set out in May, reached Agadez between mid July and early August and stayed north of 17°N. until after the end of the rainy season, working as far north as Iferuan (19°N.) by October or November before returning on different routes south to Nigeria or west across the desert and bush to the Niger river.

During the rainy season pretty regular daily convection cloud rains were experienced both north and south of the intertropical convergence, these cloud systems invariably travelling from approximately east to west and accompanied by gusty or squally easterly winds at the surface, though often preceded by westerly breezes in the morning. The regular movement of the convection clouds from east is no doubt explained by the easterly thermal wind south of the Sahara. Care is needed in interpreting these weather diaries, since the traveller has not always distinguished between the direction of movement of clouds and the direction of advance of cloud systems. On a certain number of days however systems of a different kind from the purely convection cloud development can be confidently identified: these systems generally covered the sky for periods ranging from some hours to a couple of days with altostratus and sometimes also altocumulus often described as high stratus and stratocumulus; sometimes the sky became covered with cirrocumulus. These cloud belts, which were commonly but not in all cases, accompanied by rain, appear to have passed over from south to south-west or from north according as the expeditions were south or north of the intertropical convergence. The behaviour of the surface wind in relation to the latter type of system was very much like a frontal change as we know it in other latitudes: thus after variable breezes on May 7–9, 1922 near 14°N., when the sky was overcast for a prolonged period, a fresh SW. breeze set in and the sky soon began to clear from south and south-west. The humidity rose, as it commonly does in Africa with the arrival of air that has had a shorter track from the sea. Similarly at Auderas (17½°N.) on August 8, 12, 19, 22 and 31, 1922, cloud systems passing over from north to south were preceded by light, mainly W'ly to NW'ly breezes which shifted to NE. and strengthened as the system passed. The identification with a tongue of cold air from the northern temperate zone is particularly clear, from the North Atlantic and Mediterranean analysis on the sequence of United States Weather Bureau Historical Weather Maps, in the case at the end of August; and the expedition's observer in 17½°N. was struck by the fact that the cirrocumulus was moving from the west on August 31 and September 2, 1922, a very rare occurrence, although on one or two other occasions the usual easterly current at medium and high cloud levels was absent and the cirrocumulus reported to be stationary.

The experiences of the 1927 expedition were quite similar. In some cases the systems of continuous layer cloud were mentioned as coming up on an arc across the whole southern or northern horizon.

The expeditions were travelling north during the period of northward advance of the intertropical convergence in May–July, but seem to have passed finally north of it about June 1, 1922 near 14°N. and about June 18, 1927 near 15°N. Before these dates all but one or two of the occasional systems of high stratiform cloud came up from the south; afterwards all the systems of this type which actually passed right over the expeditions came from the north. Once, near 17°N. on July 9, 1927, a cirrocumulus system approached from the south and withdrew again, and on one other occasion, August 30, 1927, near 17½°N. a rain belt approached from the south-west and slowly withdrew again. Diurnal convection rains became a regular occurrence in late July, August and early September in the mountain country near Agadez and Auderas. From late September until mid-November there were mostly clear skies, with surface winds from between E. and N. heavily predominant; in this period the only rainfall was with continuous cloud belts which passed from north to south over the region.

The possibility suggests itself that, over the oceans at least, the phases of full frontal activity in the so-called permanent intertropical front may occur when still organized frontal systems from higher latitudes have freshly come into the intertropical convergence zone. Cold fronts advancing northwards right across the equator have also been suggested by Forsdyke[4] near the east coast of Africa and a recent note[5] records similar events in Ceylon. Very slight air-mass differences, if any, can survive to this point and the frontal activity probably dies down at some stage when vertical convection has achieved sufficient mixing; though, if, independently a temporary weakening of the trade-wind streams and of the resulting convergence in the intertropical zone between the circulations of the two hemispheres should occur, this would also be expected to result in a decline or cessation of activity. Such a weakening would normally precede the advance of each further frontal disturbance line from higher latitudes.

On the return voyage in April–May 1947, the *Balaena* encountered quite a different phase of developments in the intertropical zone.

At several points in the trade winds of the South Atlantic the ship overtook several belts of light showers, orientated west-north-west to east-south-east across her course north-north-west from Cape Town, though typical trade-wind cumulus (growing bigger towards the equator) was the more prevalent condition. The last shower belt was passed i.e. overtaken, near 3°S. on April 30, followed by a typical frontal wind shift to WNW. force 2 which lasted for several miles north of the cloud line. Farther north the light S'ly breeze was gradually resumed. Over the ensuing two days WH. F. *Balaena* passed through the doldrums in fair weather with no front detectable; the light breeze gradually and continuously veered through SW., W. and NW. to become NNE. by midday May 2, 1947 near 7°N. 14°W. under skies that were quite cloudless apart from a thin veil of cirrostratus. The weather remained fine until a 60–80 miles wide belt of dense cirrus–cirrostratus orientated north-north-east to south-south-west was passed near 21°N. 18°W. on the 5th. Another more fully developed cloud system orientated east-north-east to west-south-west was encountered near the Canary Islands with appearance of light orographic rain on the islands.

The return voyage thus afforded an illustration of the case in which no frontal activity exists in the intertropical convergence zone. At such times the name intertropical front is really inapplicable and seems best avoided, since the lack of activity appears to be accompanied by a uniform air mass: in a word, there is nothing there.

There seems no difficulty in adapting our understanding of the trade winds[6] to take account of the observations presented in this article. As long ago as the early 1890's, Meinardus[7] had noticed from minute analysis of the sailing ships' observations in the Indian Ocean for the years 1885–1890 the essentially frontal character of the weather in the intertropical convergence, even distinguishing cases in which there were two, one and no frontal lines in the equatorial zone; he also stressed the occurrence of light variable or westerly wind components immediately beyond the front (*sic*) of the main trade-wind stream, these light westerlies occurring regardless of whether the front had crossed the equator or not. The only element which may be new in the observations here presented is the suggestion of historical continuity and movement of fronts of middle latitudes into the convergence zone from either side and towards one another, so that the precise latitude in which Meinardus's and Flohn's equatorial westerlies occur must be subject to continual variation. Flohn[6] actually presents the observations of a Japanese whaler crossing the intertropical convergence near 153°E. i.e. in Melanesia, in November 1947, in which apparently four fronts with wind shifts, cumulonimbus activity and sometimes altostratus were passed between 5°N. and 9°S. Two of these frontal lines were picked out as the northern and southern intertropical convergences, presumably because these two marked off the division of winds reasonably called part of the trade-wind streams from winds with pronounced westerly components on the equatorward side. Flohn identifies the control of the equatorial westerlies, which appear to be quasi-geostrophic at least with $\phi > 5°$, with events which produce cyclonic vorticity in the required zone. He also points to the prevalence of uplift weather phenomena in the westerly air, particularly at the front, rather than in the equator-ward moving trade-wind stream itself. This weather distribution doubtless involves a latitude effect of the Coriolis parameter. We may write the gradient wind equation, considering for simplicity straight meridional flow, with velocity constant,

$$\frac{1}{\rho}\frac{dp}{dx} = 2v\omega \sin\phi + A ,$$

where ρ is air density, dp/dx the pressure gradient, v the wind velocity, ω the angular velocity of the rotating earth, ϕ the latitude and A represents the accelerations due to other forces. Other things being equal, the gradient wind should increase as $\sin \phi$ decreases. The rate of change of $\sin \phi$ with latitude increases towards the equator. Air streams moving at a steady speed towards the equator will be too slow for the pressure gradient and there must be a general tendency for lateral spreading and subsidence in them, whereas air which moves away from the equator tends to move too fast for the pressure gradient with general horizontal convergence and vertical expansion.

The implied explanations of the equatorial rains are far removed from the older theoretical conception of direct association with the zone of maximum solar heating; Flohn believes that the trade winds are in fact driven towards the intertropical convergence by the subtropical anticyclones. The intertropical convergence is then an indirect result of the organized general circulation which produces subtropical anticyclones. From this viewpoint it seems inevitable that much of the activity in the intertropical convergence should be related to systems driven into it from outside and that, in particular, each time a subtropical anticyclone cell is rejuvenated by the arrival of a former polar anticyclone from middle or higher latitudes a cold front will be pushed towards the equator with a fresh impulse in the trade-wind stream.

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METEOROLOGICAL OFFICE DISCUSSION

Slant visibility

The discussion held on Monday, November 19, 1956, at the Royal Society of Arts was opened by Mr. R. P. W. Lewis and Dr. R. Frith.

Mr. Lewis began by defining slant visibility or slant visual range, as the distance from the pilot's eye to the farthest point on the ground, ground marker, or approach or runway light, that he could see. Slant visual range was, however, only useful in so far as it defined the amount of ground or ground lighting which was visible, and this extended from the farthest visible point to the nearest visible point determined by the cockpit cut-off of the aircraft. This amount of ground could be measured either by its length or by the angle it subtended at the pilot's eye: it was not certain whether a pilot during his final approach to land needed to see a constant length of ground or a varying length of ground subtending a constant angle; there was evidence that a pilot kept his eyeballs fixed during the final approach in which case he could presumably only appreciate ground subtending a constant angle. When the aircraft touched down the slant visual range became the runway visual range.

The important cases to consider were those of critical landing conditions with bad visibility where the runway visual range gave a misleading idea of slant visual range. These conditions might be due to low cloud, fog, smoke or industrial haze, and heavy precipitation, especially snow. The case of heavy precipitation was not considered, and that of low cloud briefly dismissed as being essentially a problem of the accurate determination of cloud base, not visibility. The third case of fog was then considered in some detail.

The differences between day and night visibility were first discussed, the latter being possibly easier to deal with because effects of contrast, diffused sun and sky light, reflected sunlight, and so on were either absent or more standardized in form. The speaker then showed how, for a layer of homogeneous fog lying on the ground with perfect visibility above it, the length of ground lighting visible to a pilot varied with the height of the aircraft and the runway visual range[1]. The effect of a vertical variation of fog density was to alter the slope of the full lines in the figure: if density increased upwards, the lines would bend back (with increasing height) more sharply so that visual guidance became poorer; if the density decreased upwards, the lines would curve the other way. There were reasons[2] for supposing that a radiation fog should be thicker on top, and observations of slant visual range made using balloon-borne lights showed that this type of structure did occur and that slant visual range could decrease with height. It thus appeared that there were reasons why the amount of ground visible to a pilot should decrease down to the fog top and then increase again down to ground level whether the fog were homogeneous or not. However, the angular field of vision must for simple geometrical reasons remain constant above fog top, and below it must either remain constant or increase. There might thus be danger if the fog top were below the critical height, i.e. the height below which the aircraft must not descend without the pilot having adequate visual guidance, for, if the runway visual range were adequate and the slant visual range seemed adequate at the critical height, the pilot would decide to complete the landing but might then lose visual guidance on the way down. The same thing might happen even if the fog top were above the critical height and there was a marked vertical gradient of fog density with a maximum between the critical height and the ground, but this was not physically a likely contingency. However, no authenticated reports of such dangerous conditions during landings by civil aircraft had been received by the Meteorological Office despite repeated requests, and one had to assume that these conditions were very rare. This meant that the collection of reliable statistics would take many years. There was additional evidence[2] that fogs passed through the stage of critical visibility rapidly, tending to be thin or dense.

The speaker then pointed out that so far he had been treating fogs as horizontally stratified; however, real fogs were far from uniform in the horizontal, nor was their density constant in time, and the drifting patchiness of such a real fog probably caused much greater difficulties in the way of changing visibility during the aircraft's final approach to land than did any systematic variation in the vertical. This was illustrated by simultaneous visibility measurements at London Airport and Northolt, and by records from photo-electric visibility meters.

The fourth case when bad visibility was due to smoke or industrial haze was then dealt with. It appeared from an analysis of observations made at

Renfrew that in this case slant visual range was always greater than runway visual range. This was presumably because smoke was thickest near the ground where it was produced, and where an inversion would form at night.

The speaker then considered the practical utility of possible observations of slant visual range, distinguishing two cases:—

(i) when the aircraft was at its operating height

(ii) when the aircraft was at or near its critical height and the pilot intended to land.

In (i) the pilot wished to know whether he would have a reasonable chance of landing if he descended to the critical height. This descent would take about half an hour for a modern jet aircraft so that a forecast of conditions for about half an hour ahead was necessary. At present this involved a forecast of runway visual range. Knowledge of slant visual range was only likely to be useful in marginal conditions when it presumably needed to be known very accurately, and it was very doubtful if such an accurate forecast of slant visual range was possible. This meant in practice that, if the decision to descend to critical height was made dependent on slant visual range forecasts a number of unnecessary diversions would be made which would have to be set against the occasions when aircraft were spared abortive descents. Probably, if the report and forecast of runway visual range were satisfactory, a pilot would always wish to come down and see for himself. In (ii) if it were possible to make rapid measurements of slant visual range and transmit them to the pilot immediately, useful guidance could probably be given for the final approach to land; warning of deterioration of visibility below critical height for example, would have a valuable psychological effect. However, the patchiness of fog previously discussed made the value of any slant visual range measurements most dubious. However, even if good actual measurements of slant visual range could not be made, further study of fog might make it possible to give general advice to pilots on the basis of ground measurements, especially if a good way of estimating fog top could be found. At present it seemed that the best advice was that, if conditions were marginal on the ground and the aircraft were still above the fog at the critical height, then conditions would worsen as the descent continued. There seemed indeed to be very little reason for assuming that direct measurements of slant visual range could in any way help us to improve on this advice.

Mr. Lewis concluded by reminding the audience that there were great difficulties in the way of translating observations of visibility made on the ground by eye or instrument into what the pilot sees: one had to consider the effect of differing cockpit cut-off angles, the condition of the wind-screen, the fatigue and degree of dark adaptation of the pilot, as well as the strength and pattern of the approach and runway lighting (including their relative intensities) and the contrast with background illumination.

Dr. Frith began by repeating the previous speaker's warning that visual range is not determined by the density of the fog alone; and although a good deal is now known about the visibility of lights of different candle power, the visibility of objects of various shapes, sizes and colour, and about the effect on visibility of background brightness, very little is known about the variation in visual acuity from person to person or the effect on vision of weariness or strain. It was emphasized also that if the requirement was to measure what a pilot would see all the way down from the critical height, then a measurement from one point alone would not be enough. On the other hand detailed and accurate measurements of slant visual range would only be justified if the information was needed for an aircraft just about to land.

The audience were reminded that the effect of cockpit cut-off is such that, in a uniform fog, the visual guidance will increase as the aircraft descends. For example, in a uniform fog with a visual range of 2,000 ft. and a cockpit cut-off of 12°, then the guidance available to a pilot would increase from about 1,000 ft. at 200 ft. to 2,000 ft. at touch-down. This should be set against any deterioration of visibility due to fog patchiness or horizontal stratification.

The speaker then described various techniques for the measurement of slant visibility. The only one which has actually been used to any extent relies upon the observation of a light, or a number of lights, carried by a tethered balloon. This is a simple and practical method; but for use on airfields something which does not involve balloons is called for. A measure of slant visibility can be obtained using two intersecting searchlight beams, one directed vertically and the other at an angle, and varying the intensity of the vertical beam until the two beams are matched at the point of intersection. Errors arise if the beams are passing through fog of different densities. It is not known how serious this may be because we do not know what sort of variations of mean fog density to expect between two paths, intersecting at 200 ft., and 600 ft. apart at the ground.

Slant visibility may also be measured using an instrument similar to the pulsed-light cloud-base meter[3]. This instrument, suitable modified, could be used to measure the amount of back scattered light from the fog. In a clean fog the amount of back scattered light is a measure of the visibility but this is not true in a fog in which there is appreciable absorption. It seems probable that there will be significant absorption in smog and, if this is so, the pulsed-light technique may not provide an accurate measure of visual range.

A technique using flares was proposed by H. N. Green of the Royal Aircraft Establishment, Farnborough, and an elaboration has been suggested by J. W. Sparks, also of Farnborough. Sparks proposed that a flare be fired upwards to, say, 300 ft. and whilst falling from that height to the ground produced a uniform intensity of, say, 1 million candle power. This flare is "seen" from a point on the ground some distance away by a photo-electric device which, by a cunning arrangement involving a rotating toothed shutter, amplifies the signal from the flare but not the signal from any background. Thus the technique could be used both by day and by night. Like the balloon method it is simple and direct and it appears to be the one most likely to provide reliable and accurate results for routine use on airfields.

The Director opened the general discussion by welcoming visitors from outside organizations including the Ministries of Supply and of Transport and Civil Aviation.

Mr. Holland asked whether balloon observations could be usefully made half a mile off the runway.

Dr. Frith replied that the variation in visibility would be too great.

Mr. Cumming emphasized the danger of flying balloons anywhere on an airfield, and spoke of the difficulties of estimating visual range accurately and allowing for the great variability of physical conditions, intensity of lighting, and background illumination. He questioned the value of slant visual range reports to pilots; he thought they would be useful only when slant visual range decreased below the critical height, but this condition had never been found.

Capt. Woodman (British Overseas Airways Corporation) spoke of the difficulties facing the pilot. Patchiness of fog could cause him great trouble, perhaps more than poor general visibility. Pilots' experience of really bad conditions near the ground was limited, and if they suddenly lost visual guidance they at once went up again and diverted. He emphasized the need for more knowledge of fog and its structure; he thought that relatively small patches of bad visibility existed.

Mr. Worthington asked whether air-to-ground visibility was the same as ground-to-air visibility.

Dr. Frith replied that it was, provided that the background illumination was the same.

Mr. Burgess (Ministry of Supply) described experiments carried out by the Blind Landing Experimental Unit from October 1950 to March 1953 at Woodbridge Airfield. An observer was positioned opposite the threshold of the runway, and a balloon-borne light was moved according to his instructions so that both its height and range along a line parallel to the runway centre line were altered. From his observations the observer could build up a diagram of the fog structure and use it to calculate the heights at which a pilot would see the different bars of the Calvert Approach Lighting System assuming that his aircraft was on the glide path. This information was passed to the pilot of an actual aircraft who then made an approach and landing. The total time taken for the measurements and the approach and landing was about 15 to 20 min. Good agreement was obtained between the measurements and what the pilot actually saw; he normally saw lights from about 25 ft. above the forecast height. Eighty sets of measurements (both night and day) were made and the results were summarized. In nearly 30 per cent. of the conclusive measurements, the runway visual range bore little or no relation to the slant visual range. In one particular case the results were

runway visual range = 1,200 ft.
slant visual range at 50 ft. = 900 ft.
slant visual range at 100 ft. = 900 ft.
slant visual range at 150 ft. = 1,800 ft.

The results were obtained at one airfield only and so might not be representative. B.L.E.U. felt strongly that further work on slant visibility was necessary, especially since approach and landings speeds of new aircraft were increasing.

Dr. Stewart said that the scarcity of direct observations of slant visibility made it worthwhile to use all available indirect information. He showed a diagram in which vertical visibility observations from London Airport were plotted against horizontal visibility at the same time. The vertical visibility was almost always less than the horizontal, indicating that the fogs were usually thicker aloft than at the surface. The observations could be explained semi-quantitatively on the assumption that condensation in up-currents made the fog droplets larger near the top of the fog.

With this assumption, an idealized model of fog structure could be made, in which the visibility conditions were characterized by two quantities, the height of the fog top and the slant visibility from the fog top. Using these quantities as co-ordinates any fog could be represented by a point on a diagram, and points falling within certain areas on the diagram would represent conditions dangerous to aircraft. Dr. Stewart showed that if observations made at Cardington were plotted in this way very few of the representative points fell within the danger area. He deduced that dangerous conditions were certainly possible but seemed to be rare, occurring for only a few hours per year; he emphasized, however, that the choice as to what area on the diagram represented dangerous conditions was not really a matter of meteorology at all and that his choice of area, and hence his conclusions on frequency, were open to question. It was at least as important to decide what conditions really were dangerous as it was to find out how frequently different types of conditions occurred.

Mr. Holgate wondered whether observations from the top of the control-tower would be useful.

Dr. Frith thought they would show the general nature of the fog but not what it was like at another particular spot on the runway; the local heating due to the tower itself would be a disturbing factor.

Mr. Russell (Ministry of Supply) expressed alarm at the lack of knowledge of the vertical structure of fog and emphasized the need for further research.

Mr. Davies recalled a case where aircraft experienced difficulty in landing, and a powerful crimson searchlight revealed several distinct haze layers.

Mr. Gold emphasized that each fog was unique and thought that general rules would be of little value. It was unfortunately impossible to do a laboratory experiment on fog because local conditions, e.g. the type of surface over which the fog existed, made such a difference.

The Director, in conclusion, said that his only professional contact with the subject had been in connection with the calculation of the screening effect of a smoke screen, but that ordinary experience in a motor car was enough to demonstrate its difficulties and the psychological aspects of sudden recognition. He thanked the openers and the visitors for their contributions, and said the discussion had shown the importance of the subject and also how heavy was the responsibility of the meteorologist, not only for human safety, but also for the cost of diversions to the airlines.

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2. STEWART, K. H.; Radiation fog. Investigations at Cardington, 1951–54. *Met. Res. Pap., London*, No. 912, 1955.
3. ALMOND, R. E.; Electronics applied to meteorological instrumentation. *Met. Mag., London*, **84**, 1955, p. 115.

REVIEWS

Climate of central Canada. By W. G. Kendrew and B. W. Currie. $9\frac{1}{2}$ in. × $6\frac{1}{2}$ in., pp. 194, *Illus.*, Meteorological Division, Department of Transport, Toronto, 1955. Price: $1.

The arrangement of the book is the conventional, but satisfactory, one of an opening chapter on the general climatology of the area as a whole, followed by chapters on each of five separate regions.

Chapter 1 gives a good description of the general climate. Although, to the meteorologist, there are some rather elementary descriptions of meteorological processes, and to the commercial user, the tables in later chapters are the main interest, the general level of the discussion in Chapter 1 is a fair compromise. The standard of the descriptive writing is good, particularly in the sections on blizzards and "physiological" or "sensible" temperature.

It is a great pity that no detailed map of the geography is included in the book. Place names are often used which, many readers will find, require reference to an atlas. There are a few minor misprints including two cases where the reader is referred to the wrong diagram. On several occasions the diagrams are inconveniently placed; maps showing the mean cloud amount occur in the middle of the chapter on visibility, more than twenty pages away from the appropriate text. Chapter 1 includes a map of the main frontal zones. It would have been interesting to know how this was obtained, but we are not informed.

Chapters 2–6 deal individually with the various regions. There is not a great deal of text here, and there are a few repetitions of points made in Chapter 1. The main interest is in the tables of which there are a great number. These chapters are well planned, each having the same arrangement and numbering of paragraphs dealing with individual meteorological elements. There are many small tables in the text, and the type and arrangement of these are consistent from chapter to chapter.

Particularly useful statistics are contained in the sections on temperature, rainfall and snowfall. These include probabilities of different departures from normal monthly mean temperature, probabilities of a day with rain having rainfall within specified limits and frequencies of certain ranges of aggregate snowfalls at the end of each of the four winter months. General climatological tables are given at the end of each chapter. The observation hours used in computing mean pressure and temperature are not stated. Otherwise all necessary definitions are given.

The book may be summarized as one which contains a large amount of useful material in tabular form and a readable and informative text in Chapter 1. The book deserves a more permanent cover than the one of soft card used in the present edition.

H. D. HOYLE

A Mariner's Meteorology. By C. G. Halpine and H. H. Taylor. 9¼ in. × 6 in., pp. xi + 371, *Illus.*, D. Van Nostrand Co. Inc., 1956. Price: 42*s*.

This book is written by two American naval officers and, as stated in the Preface, it was "prepared primarily as a textbook for Midshipmen at the United States Naval Academy", but the authors go on to say that "all the material contained herein is applicable in its broad sense to everyone who goes to sea, whether professional or amateur".

The book is no doubt of value to the naval officer, particularly if he wishes to study the rudiments of the application of meteorology to aviation. As an informative treatise on meteorology for merchant seamen or for yachtsmen it seems to have a rather limited value. Its chief fault seems to lie in the fact that it attempts to cover so many varied aspects of meteorology without any attempt at specialization, and for some unknown reason it devotes almost as much attention to the meteorology of the United States mainland as it does to that of the oceans. For example, the question of tropical storms is dealt with in 12 pages, in which are included seven diagrams, whereas "Weather reports" takes up 35 pages. The specimen synoptic maps in the appendices are entirely related to the United States mainland and the relative text, discussing a particular forecast, blandly says: "On account of the lack of observations over the Atlantic Ocean the size of the area of bad weather cannot be determined accurately. . . ." Such a statement is scarcely encouraging to the large number of voluntary observing ships which regularly provide quite a reasonable network of observations in the relevant portion of the Atlantic Ocean.

Nevertheless, the book has some very good points. For example, there is an admirable graphic drawing showing the characteristics of the earth's atmosphere, in which the authors have included a wealth of information about heights up to 1,000 miles from the earth's surface. There is an excellent composite drawing of cloud formation from stratus to cirrus and some fine cloud photographs, alongside each of which is shown the appropriate symbol and a little drawing bringing out their characteristics, and a "thumb nail" description of the salient features. There is an admirable diagrammatic sketch showing the general circulation of the earth's atmosphere, on a globe, extending from the surface to the tropopause. There are also some good drawings and a simple and straightforward text describing the Coriolis force. The sections through frontal surfaces are also graphic (the best are taken from *Life* magazine). Some photographs are included to illustrate the Beaufort scale; a good idea, but some of them are badly chosen as they fail to give a realistic impression of the actual sea state to which they are meant to refer.

There is an extremely brief chapter on climatology, in which is included ocean currents, and another brief chapter on oceanography; all three subjects seem to be rather inadequately dealt with. There is a very interesting and well written chapter entitled "Weather at war" which includes a well illustrated section concerning the dangers of radio-active "fall-out". At the end of the book is a reasonably comprehensive glossary.

It is rather surprising that in the introduction to a book on maritime meteorology no mention is made of Maury (1854), although Leverrier's activities for collecting meteorological data for Europe in 1855 are quoted. When discussing the aneroid barometer, the authors refer to "certain types of minor errors". They make no reference to the necessity of frequently comparing it with a mercurial instrument. When talking about pressure tendency, the complication of the ship's progressive movement is not taken into account. A serious omission for the mariner occurs in a description of the signs indicating the approach or development of a tropical cyclone, where no mention is made of the large diurnal variation of pressure found in the tropics, and the mariner is not shown how the magnitude of a pressure fall due to an approaching and developing tropical cyclone can be distinguished from a normal pressure fall due to diurnal variation of pressure in the region. The description of the creation of a tropical cyclone is rather over simplified. When discussing upper air observations, although radio-sonde is mentioned, a description of radio wind technique is surprisingly omitted. On the subject of arctic smoke, no mention is made of the large temperature difference between air and sea which is essential for its formation. The authors claim that "it rarely presents a hazard to shipping".

In extreme cases arctic smoke can reduce visibility to less than $\frac{1}{4}$ mile and can extend to a considerable height. There is also the icing danger on the ship's structure to be associated with it.

The Beaufort scale as shown in this book is complicated somewhat by showing some equivalent wave heights for a United States Navy "Sea State Code" and the World Meteorological Organization's "International State of Sea Code". On the other hand, the height equivalents officially approved by the W.M.O. for association with the Beaufort scale are not shown. The visual storm warning signals shown in this book only refer to the United States waters and no reference is made to the existence of an "international" visual warning system which is used to some extent by most other countries.

Under the chapter entitled "Weather reports", a suggestion is made that "before departing for areas of the world unfamiliar to him, the mariner should obtain climatological information of these areas from the nearest weather central". An officer in a tramp ship would have a rather busy time if he carried out this procedure. Quite a lot of information of this nature is fairly readily available from Sailing Directions. When discussing weather maps, reference to observations from ships is omitted.

The chapters concerning the basic physics of the atmosphere are the best feature of this book. They are written in a very interesting and readable manner and are easily understandable by the student having only elementary scientific knowledge.

C. E. N. FRANKCOM and R. F. M. HAY

Between the planets. 2nd edn. By F. G. Watson. 9 in. × 6½ in., pp. x+188+40, *Illus.*, Harvard. University Press. London: Cumberlege, 1956. Price: 30*s.*

Astronomy and meteorology have both attracted increased public interest in recent years; to many, the two subjects are in fact closely akin. Most scientists would, of course, consider them poles apart, contrasting the largely immutable and orderly arrangements of the universe with the intangibility and complexity of the atmosphere. None the less there is perhaps one branch of astronomy whose problems approach, a little, those of meteorology, a branch—we might term it micro-astronomy—where the author finds "statistical procedures necessary to describe the many variations and the average over-all state".

This book deals with the myriads of small bodies, which, with the sun and the planets, comprise the solar system; it is clear that any interchange of material with outer space is on a small scale. After surveying briefly the solar system as a whole, the author deals first with its largest non-planetary members, the asteroids. Of comparatively recent discovery, these "flying mountains" are known to number many thousands, a few of them with orbits bringing them very close to the earth. Next the comets, the most spectacular of celestial phenomena and still not without an element of mystery, are described both from a point of view of their orbital motions and internal structure.

Of most direct interest to meteorologists are meteors, the very name indicating an early confusion with atmospheric phenomena, yielding as they do valuable information about the atmosphere around the 100-Km. level. These are discussed in detail in three chapters, including one on meteor showers, recently the subject of an attempted correlation with rainfall abnormalities, and one on radio observation of meteors and their ionized trails. There follow chapters on meteorites, including detailed analyses of their composition, together with descriptions of several craters known or suspected to be of meteoritic origin. Finally we come down to interplanetary dust, the author adhering to the theory that therein lies the explanation of the zodiacal light.

The author has given, in racy style, a comprehensive survey of his subject. The illustrations, closely related to the text, are excellent, the comet photographs being particularly striking, while of especial interest is one showing seven successive photographs of a meteor trail, its movement relative to stars and its gradual distortion being apparent.

P. GRAYSTONE

ERRATA

DECEMBER 1956, PAGE 372, line 27: *for* "At the 31st meeting" *read* "At the 39th meeting".

JANUARY 1957, PAGE 31; Column headed Difference from average daily mean; *for* "+0·6" *read* "−0·6".

AWARDS

Civil-airline personnel

An award of books was recently made to captains and navigators who have provided the best series of weather reports, in flight, post-flight, or on debriefing, during the twelve months ending April 15, 1956.

The recipients were:

Captain R. H. Payne, B.E.A.C.
1st Officer D. E. Goldsworthy, Britavia
Captain G. M. Allcock, B.O.A.C.
Captain S. A. Calder, Britavia.
Captain G. R. Buxton, B.O.A.C.
Navigator H. L. Chandor, B.O.A.C.
Captain W. J. Wakelin, B.E.A.C.
Captain R. A. J. Hanson, B.O.A.C.
Navigator G. F. Andrews, B.O.A.C.
Captain K. E. Buxton, B.O.A.C.
Navigator H. Fogg, B.O.A.C.
Navigator J. S. Blain, B.O.A.C.
Captain K. W. Fordham, B.O.A.C.
Navigator F. S. Tanner, B.O.A.C.
Navigator J. Broadley, B.O.A.C.
Captain C. M. Longden, B.O.A.C.
Captain R. H. Rose, B.E.A.C.

CORRIGENDUM

The first two recipients of Meteorological-Office awards to civil-airline pilots were not the two officers whose awards were recorded on p. 349 in the November 1956 number of this Magazine.

The first recipients were Captain L. V. Messenger, O.B.E. and Captain J. T. Percy, both of British Overseas Airways Corporation, who were presented by the Director with brief cases on October 24, 1955, for long and meritorious service in providing weather reports over the North Atlantic.

METEOROLOGICAL OFFICE NEWS

Retirement.—Mr. R. L. Sims, Senior Experimental Officer, retired on January 12, 1957. He was first engaged as a computer at the Royal Observatory, Greenwich, and after service with the Royal Field Artillery and the Meteorological Section, Royal Engineers in the First World War, he joined the

Office in February 1920 as a Technical Assistant. Apart from a period in 1937–38 in the Forecast Division at Headquarters, his 37 years' service was spent at aviation outstations including a tour of duty overseas. From 1951 until his retirement he served at Upavon.

Academic successes.—Information has reached us that the following staff have been successful in recent examinations; we offer them our congratulations.

General Certificate of Education (Advanced Level): J. M. Bayliss, D. E. Bradbury, F. E. Harrold, C. J. Heather, J. C. Howe, P. N. Mann, H. M. Race, C. G. Richer and L. P. Steele.

Higher National Certificate in Mechanical Engineering: K. E. Cowlard.

The International Geophysical Year Expedition.—The Royal Society Expedition's main party of 20 under the leadership of Col. R. A. Smart, R.A.M.C., reached Halley Bay on January 4, 1957.

WEATHER OF JANUARY 1957

As in December 1956, the great cold trough over eastern Canada and the Iceland depression were the dominating features of the circulation over the northern hemisphere. By January the depth and extent of the low-pressure region had so far increased that westerlies spread across Siberia north of 55°N. as far as 120°E. Temperatures were 8° to 10°C. above their usual winter minimum in north-east Siberia, and the Asiatic winter anticyclone was below normal intensity and displaced south-east. Temperatures over most of the polar basins and Alaska (greatest anomaly +10°C.) were also above normal.

The lowest mean pressure for the month was 980 mb. or slightly below near 62½°N., 37½°W. between Iceland and south Greenland, approximately equal to the lowest monthly mean pressure in any January since 1873 and 17 mb. below the 1900–1939 normal. The anomaly is to be attributed to intensity of the individual depressions and constancy of position, not to any displacement.

Pressures were above normal everywhere in a broad arc from Alaska (maximum anomaly +18 to 20 mb. over the Canadian Rockies), central and south-eastern United States of America (anomalies +3 to +4 mb.) and the Azores (anomalies +1 to +2 mb.) to central Europe (anomalies up to +6 mb.).

The month was mild, up to 3°C. above normal, all over north-western, central and northern Europe (anomalies +4°C. in Finland), but rather cold over the Mediterranean and southern Europe and also in part of north-west Siberia.

Mean temperatures were 3° to 6°C. below normal over most of Canada and locally 8° to 11°C. below normal over the Canadian Rockies. Mexico and the Mexican Gulf was 1° to 3°C. warmer than normal, but low temperatures from Canada and the northern United States spread over the Atlantic as far as the Azores and the West Indies (about 1°C. below normal).

Precipitation totals were much above normal, locally over five times the normal, in eastern and northern Greenland, also in northern Alaska. There was another region with over five times the normal rainfall across more or less all the north of India.

In the British Isles a period of rather cold anticyclonic weather from the 10th to the 19th came between periods of almost equal duration of milder but more disturbed cyclonic weather at the beginning and end of the month.

During the first three days fronts, associated with a complex low-pressure area near Iceland, crossed the country, bringing occasional rain with mild, rather dull weather generally. Rain was widespread on the 4th and 5th as secondary depressions accompanied by gales and heavy rain moved north-eastwards near or across north-western districts of the British Isles. Temperature reached 57°F. in places on both days and remained above 50°F. over most of England and Wales throughout the intervening night. Fog formed around dawn at many places in southern England on the 7th and persisted all day locally. Colder air spread south-east on the 9th and 10th as an anticyclone became established off southern Ireland, and on the 12th the north-westerly winds over the British Isles freshened temporarily and showers became more general as a depression moved south-east to southern Scandinavia. As the anticyclone intensified and moved northward, winds over the country veered to north-east on the 14th bringing sleet showers to many eastern coastal districts. Pressure rose to the unusually high value of 1050·9 mb. at Benbecula and Belmullet, Co. Mayo on the 16th before the anticyclone began to decline and move south-eastwards across England to the continent. After a quiet period which lasted nearly a week in most parts of the country, winds rose to gale force again in Scotland on the 19th. During the next four days a major frontal belt lay over the British Isles giving fairly widespread rain and although temperatures were generally higher than of late there was occasional snow in the north. Mild polar maritime air spread over the country from the Atlantic on the 24th to give showers in most areas, scattered thunderstorms and some sleet or snow in the western and northern districts. Weather from the 25th to the end of the month was dull, wet and mild as vigorous Atlantic depressions moved north or north-east towards Iceland and associated fronts crossed the British Isles. There were severe gales over the Atlantic throughout this period and occasionally off our north-western coasts when gusts exceeded 90 kt. at times on the 31st.

Mean temperatures generally were about two degrees above the normal, the cold spell in the middle of the month being easily outweighed by the two mild spells. Rainfall was below the average over most of England and more than 150 per cent. of the average in the neighbourhood of the Brecon Beacons, Snowdonia and over most of Scotland south and west of a line from Perth to Cape Wrath.

The mild weather has brought on most outside crops; greens and spring cabbage particularly have a very forward appearance. Most growers fear that a spell of severe weather will cause a great deal of damage. In many areas the ground is soaked, sometimes even waterlogged; the dampness has encouraged the spread of diseases, both among growing crops and those in store.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ..	60	19	+2·5	97	+2	102
Scotland ...	59	15	+1·9	147	+2	120
Northern Ireland ...	58	22	+0·9	159	+1	139

RAINFALL OF JANUARY 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	1·59	85	*Glam.*	Cardiff, Penylan ...	4·90	133
Kent	Dover	2·07	97	*Pemb.*	Tenby	3·62	97
,,	Edenbridge, Falconhurst	2·43	99	*Radnor*	Tyrmynydd	6·85	109
Sussex	Compton, Compton Ho.	3·72	117	*Mont.*	Lake Vyrnwy	9·16	158
,,	Worthing, Beach Ho. Pk.	1·87	80	*Mer.*	Blaenau Festiniog ...	17·45	171
Hants.	St. Catherine's L'thouse	2·35	95	,,	Aberdovey	4·45	115
,,	Southampton (East Pk.)	2·93	110	*Carn.*	Llandudno	2·51	104
,,	South Farnborough ...	1·43	68	*Angl.*	Llanerchymedd ...	4·42	140
Herts.	Harpenden, Rothamsted	1·33	64	*I. Man*	Douglas, Borough Cem.	3·70	110
Bucks.	Slough, Upton	1·44	77	*Wigtown*	Newton Stewart ...	4·46	108
Oxford	Oxford, Radcliffe ...	1·61	89	*Dumf.*	Dumfries, Crichton R.I.	5·21	162
N'hants.	Wellingboro' Swanspool	1·32	71	,,	Eskdalemuir Obsy. ...	10·21	189
Essex	Southend, W. W. ...	·94	64	*Roxb.*	Crailing...	3·40	176
Suffolk	Felixstowe	1·04	68	*Peebles*	Stobo Castle	4·91	164
,,	Lowestoft Sec. School...	1·27	76	*Berwick*	Marchmont House ...	3·20	142
,,	Bury St. Ed., Westley H.	1·39	78	*E. Loth.*	North Berwick Gas Wks.	2·29	134
Norfolk	Sandringham Ho. Gdns.	2·22	114	*Midl'n.*	Edinburgh, Blackf'd. H.	2·97	169
Wilts.	Aldbourne	2·44	98	*Lanark*	Hamilton W. W., T'nhill	5·60	170
Dorset	Creech Grange... ...	3·19	98	*Ayr*	Prestwick	4·24	149
,,	Beaminster, East St. ...	3·97	114	,,	Glen Afton, Ayr San. ...	7·03	138
Devon	Teignmouth, Den Gdns.	2·90	99	*Renfrew*	Greenock, Prospect Hill	9·25	143
,,	Ilfracombe	3·76	114	*Bute*	Rothesay, Ardencraig ...	6·94	154
,,	Princetown	11·68	146	*Argyll*	Morven, Drimnin ...	10·58	167
Cornwall	Bude	2·55	84	,,	Poltalloch	8·29	164
,,	Penzance	3·33	88	,,	Inveraray Castle ...	13·81	168
,,	St. Austell	3·82	89	,,	Islay, Eallabus	8·05	172
,,	Scilly, Tresco Abbey ...	...	...	,,	Tiree	5·83	137
Somerset	Taunton	1·78	75	*Kinross*	Loch Leven Sluice ...	5·37	170
Glos.	Cirencester	3·75	144	*Fife*	Leuchars Airfield ...	2·76	152
Salop	Church Stretton ...	2·14	82	*Perth*	Loch Dhu	13·85	152
,,	Shrewsbury, Monkmore	1·06	54	,,	Crieff, Strathearn Hyd.	6·89	171
Worcs.	Malvern, Free Library...	1·46	66	,,	Pitlochry, Fincastle ...	4·77	136
Warwick	Birmingham, Edgbaston	1·30	58	*Angus*	Montrose Hospital ...	2·40	121
Leics.	Thornton Reservoir ...	1·66	84	*Aberd.*	Braemar	3·30	103
Lincs.	Boston, Skirbeck ...	1·68	104	,,	Dyce, Craibstone ...	...	...
,,	Skegness, Marine Gdns.	1·80	104	,,	New Deer School House	2·24	96
Notts.	Mansfield, Carr Bank ...	1·66	77	*Moray*	Gordon Castle	2·17	107
Derby	Buxton, Terrace Slopes	3·81	85	*Nairn*	Nairn, Achareidh ...	2·28	126
Ches.	Bidston Observatory ...	1·09	52	*Inverness*	Loch Ness, Garthbeg ...	6·51	148
,,	Manchester, Ringway...	1·45	61	,,	Loch Hourn, Kinl'hourn	20·63	164
Lancs.	Stonyhurst College ...	4·27	100	,,	Fort William, Teviot ...	16·09	166
,,	Squires Gate	2·77	105	,,	Skye, Broadford ...	...	...
Yorks.	Wakefield, Clarence Pk.	·99	52	,,	Skye, Duntulm... ...	8·89	168
,,	Hull, Pearson Park ...	1·64	91	*R. & C.*	Tain, Mayfield... ...	3·31	136
,,	Felixkirk, Mt. St. John...	1·56	78	,,	Inverbroom, Glackour...	8·01	149
,,	York Museum	1·03	58	,,	Achnashellach	13·73	151
,,	Scarborough	1·52	76	*Suth.*	Lochinver, Bank Ho. ...	6·71	158
,,	Middlesbrough... ...	1·38	86	*Caith.*	Wick Airfield	3·07	125
,,	Baldersdale, Hury Res.	4·65	139	*Shetland*	Lerwick Observatory ...	5·25	123
Norl'd.	Newcastle, Leazes Pk....	1·03	52	*Ferm.*	Crom Castle	5·75	173
,,	Bellingham, High Green	4·77	167	*Armagh*	Armagh Observatory ...	4·56	181
,,	Lilburn Tower Gdns. ...	2·85	138	*Down*	Seaforde	5·65	179
Cumb.	Geltsdale	3·95	141	*Antrim*	Aldergrove Airfield ...	3·68	135
,,	Keswick, High Hill ...	8·99	178	,,	Ballymena, Harryville...	4·74	128
,,	Ravenglass, The Grove	3·47	104	*L'derry*	Garvagh, Moneydig ...	5·66	165
Mon.	A'gavenny, Plâs Derwen	3·71	100	,,	Londonderry, Creggan	5·16	143
Glam.	Ystalyfera, Wern House	9·88	156	*Tyrone*	Omagh, Edenfel ...	6·07	172

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JET STREAMS OVER NORTH AFRICA AND THE CENTRAL MEDITERRANEAN IN JANUARY AND FEBRUARY, 1954

By H. H. LAMB, M.A., J. FLEMING, M.A., H. D. HOYLE, B.Sc. and J. ROBINSON, B.Sc.

Summary.—Most studies of jet streams in the subtropical zone have only been made possible by statistical treatments of many cases, based upon observation sequences at single widely-scattered stations. This paper is largely devoted to the description of one jet-stream situation of outstanding intensity over the Mediterranean and north Africa—a sector which has not hitherto been dealt with in this connexion—where the network of high-level observations made possible a synoptic study.

The resulting analysis establishes the occurrence, over the Mediterranean and north-Africa region between October 1953 and April 1954, of occasional maximum winds somewhat in excess of 200 kt. It also suggests lateral movements of various maxima in the upper westerlies from both south and north, which, because of the strong shears commonly occurring, lead to very large and rapid variations of upper-wind speed along the east–west air routes over the Mediterranean.

Introduction.—Several times during the winter 1953/4 north Africa north of 20°–25°N. and much of the Mediterranean were covered by a belt of strong high-level winds of very great breadth and intensity. The reported wind speeds somewhat exceeded the highest values of the six previous winters since the radio-sonde and radar-wind network had been developed in that part of the world. Several observing stations in the Malta Flight Information Region reported winds of 180 to 220 kt. and some stations purported to show much higher values. Between whiles there were lulls in the circulation, sometimes lasting ten days or more, when no winds of more than 80 to 90 kt. appeared to exist at any height anywhere in this sector. Little or nothing was known about the manner of formation of the strong-wind belt over north Africa, though it was doubtless part of the same system as the better known winter jet stream over south-west Asia and possibly an earlier phase of it.

The period which best lent itself to close study of the jet stream was January 1–10, 1954. Throughout these days the broad features of the situation were so nearly constant that one could use all the observational data of the ten days to amplify and cross-check one another. This checking for internal consistency was a vital part of the investigation. The region has one of the richest networks of observing stations in the subtropical zone, but these are operated by many different nations using different radio-sonde instruments. Moreover radio transmission errors and clerical mistakes produce some wind reports that are unbelievable and others that can only be accepted after careful scrutiny. The period was one of outstandingly strong winds aloft, though possibly not quite the strongest of the 1953/4 winter.

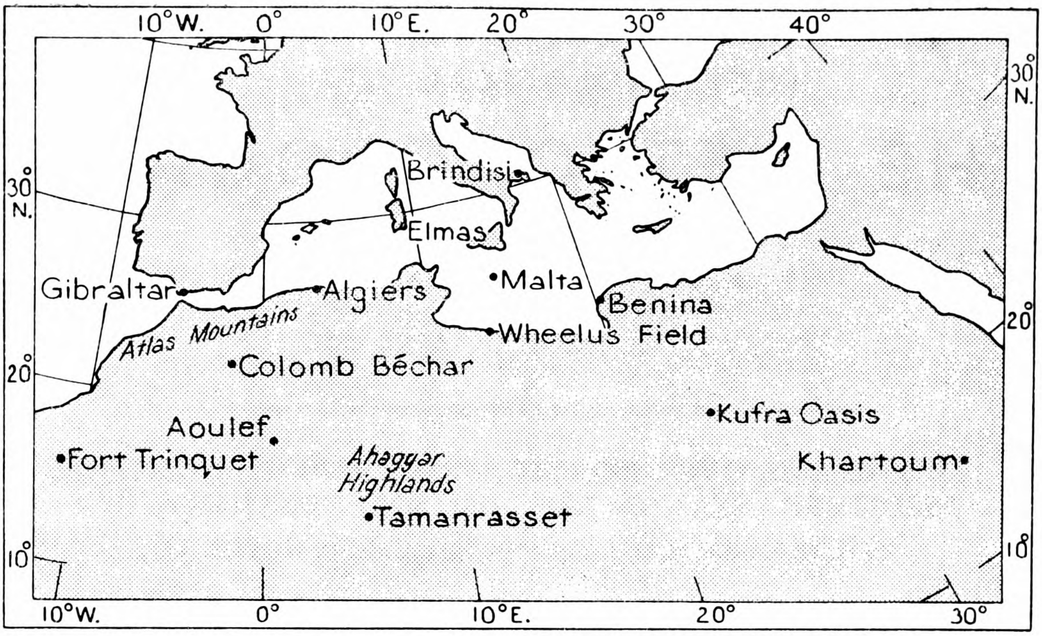

FIG. 1—MAP TO SHOW STATION POSITIONS AND PLACE NAMES

The observations.—The stations at which regular upper air observations were made in the region considered are shown in Fig. 1. Normally, even in this sector, the gap in the network of high-level observing stations south of the line Algiers–Tripoli–Benina–Cairo is a great obstacle to examining subtropical jet streams[1].

Wheelus Field, Tripoli, made four ascents daily; Elmas, Malta and Benina, Benghazi, made two daily; the other places made only one ascent a day. Not all the ascents reached the 200-mb. level. Over the western part of north Africa there were useful additional radio-sonde observations made once a day at Aoulef, 27°04′N., 1°08′E., Colomb Béchar, 31°51′N., 20°3′W. and Fort Trinquet, 25°14′N., 11°35′W., but these data were not regularly received. Khartoum lies south of the strong westerly régime aloft, even in mid-winter. The Tamanrasset and Kufra ascents were made with pilot ballons, which, however, penetrated above the maximum-wind level on some occasions.

In the case here examined the subtropical jet stream, which at first lay over the desert about 25°N. in the west and 30°N. over Egypt, moved northwards and emerged over the Mediterranean radio-sonde network, between Malta and the Libyan coast from January 4–6.

Several different analysis methods were used and their results compared for consistency; the statistics for each station were also independently examined, in order to achieve an acceptable comparability of the upper-wind observations reported from places where different instruments and techniques were in use. The observations of *Canberra* and *Comet* aircraft were also used.

The early January period, general survey.—From January 1–10, 1954, north Africa, north of 20°–25°N., and most of the Mediterranean south of 35°–40°N. were continuously covered by a broad belt of very strong high-level winds about 250°–270°. The temperate-zone westerlies farther north were

TABLE I—WIND SPEEDS AT DISTANCES FROM THE AXIS OF THE STRONG-WIND BAND OVER NORTH AFRICA AT 300 MB., JANUARY 1–10, 1954

Wind directions are between 240° and 280°

Distances in nautical miles (± 50)

	Time	North of axis				South of axis						
		500 Elmas	400 Brindisi Algiers*	200 Malta	0 Benina Wheelus Field†	200 Aoulef	300	400 Tamanrasset	500 Kufra	600	700	1,000
	G.M.T.				*knots*							
January 1, 1954	0200	27	30	53	81 85†	...	...	...	...	...	...	...
	1400	33	15	37	96 105†	...	...	...	120 at 27,000 ft.	...	...	...
January 2 1954	0200	19	5	77	123 82†	...	...	70‡	...	...	...	...
	1400	47	10	94	119 148†	...	...	...	...	...	...	...
January 3, 1954	0200	52	15	104	159 168†	...	...	...	...	...	...	...
	1400	27	35 83*	131	144 178†	*114*	120‡	48 at 0900 G.M.T.	...	...	...	...
January 4, 1954	0200	23	30	149	149 194†	...	...	...	...	...	...	...
	1400	...	...	132	138	...	...	45	84	...	...	...
January 5, 1954	0200	78	65 110*	123 at 30,000 ft.	132	...	130‡	...	...	60‡	...	...
	1400	73	...	135	138	*133*	...	...	...	...	...	...
January 6, 1954	0200	98 at 28,000 ft.	...	106	131 166†	...	...	...	...	...	...	...
	1400	85	53	88	128 112†	*103*	75‡	...	...	50‡	...	...
January 7, 1954	0200	51 at 26,000 ft.	...	111	139	...	...	...	...	...	...	...
	1400	51	41	84	157 174†	*56*	...	52	72	...	...	*29*
January 8, 1954	0200	54	35	84	154 110†	...	...	...	...	...	...	...
	1400	26	47	93	125	*79*	...	...	108	...	...	...
January 9, 1954	0200	35	...	76 at 30,000 ft.	117 170†	...	110‡	...	...	80‡	...	...
	1400	21	...	58	119 115†	*105*	...	...	125	...	...	*17 at* Niamey 13½°N., 2½°E.
January 10, 1954	0200	27	9	54	161 140†	...	...	...	...	...	...	...
	1400	...	40	56	141†	*97*	120‡	...	...	...	70‡	...

Values in italics denote winds reported by stations somewhat outside the limits of longitude at 5° and 25°E., but nevertheless belonging to the same wind system.

* The values for Algiers are indicated by an asterisk. † The values for Wheelus Field are indicated by a dagger.

‡ Denotes winds reported by Comet aircraft in flight between 10° and 13°E.

TABLE II—WIND SPEEDS AT DISTANCES FROM THE AXIS OF THE STRONG-WIND BAND OVER NORTH AFRICA AT 200 MB., JANUARY 1–10, 1954

Wind directions are between 240° and 280°

	Time	North of axis			Distances in nautical miles (± 50)	South of axis	
		500 Elmas	400 Brindisi Algiers*	200 Malta	0 Benina Wheelus Field†	200 Aoulef	500 Kufra
	G.M.T.				*knots*		
January 1, 1954	0200	...	...	57	89 93†	...	...
	1400	...	...	57	75 99†	...	...
January 2, 1954	0200	25	...	74	119 120†	...	...
	1400	36	34	90	153 138†	...	...
January 3, 1954	0200	45	...	92	190	...	...
	1400	54	61 78*	117	...	*169*	...
January 4, 1954	0200	70	...	180	...	...	...
	1400	...	80	129	...	...	...
January 5, 1954	0200	96	115*	99 at 40,000 ft.	...	...	...
	1400	117	...	137	...	*141*	...
January 6, 1954	0200	...	...	131	154 at 250 mb. 186† at 36,000 ft.	...	...
	1400	56	67	98	160 at 250 mb. 175†	...	...
January 7, 1954	0200	...	...	103	158 at 37,000 ft.	...	...
	1400	79	...	89	148 at 250 mb.	*111*	78 at 38,000 ft.
January 8, 1954	0200	64	...	86	136†	...	...
	1400	...	...	89	153 at 50,000 ft.	*93*	145 at 37,000 ft.
January 9, 1954	0200	40	...	77 at 40,000 ft.	147 158† at 250 mb.	...	...
	1400	41	...	68	123 at 250 mb. 110†	...	...
January 10, 1954	0200	...	...	85	183 at 250 mb. 40†	...	...
	1400	...	...	81	146†	*174*	...

Values in italics denote winds reported by stations somewhat outside the limits of longitude at 5° and 25°E., but nevertheless belonging to the same wind system.

* The values for Algiers are indicated by an asterisk. † The values for Wheelus Field are indicated by a dagger.

blocked by a quasi-stationary anticyclone, about 1040 mb., in the neighbourhood of the British Isles and eastern Atlantic. Cold air of Arctic origin flooded into the Mediterranean, yielding the heaviest snows for many years in Austria and north Italy, the heaviest snow for 25 years in Milan.

About the same time over north Africa south of the strongest high-level winds, higher temperatures occurred up to the 300–200-mb. layer than for a month or two past. The warmth seems only explainable by advection of warm air from farther south over Africa. Dynamical warming is unlikely to have been at work below the level of maximum wind at the right-hand side of the strong stream in a region within a few hundred miles of the confluence[2] and remote from the exit.

Tables I and II give the wind speeds reported at 300 and 200 mb. respectively at various stations arranged according to their distance on either side of the axis of the strong-wind belt in about 5°–25°E.

The situation culminated with the strongest winds occurring near the Libyan coast in 32°–33°N. The evidence suggests only rather slight variation in intensity of the main velocity maximum during the ten days. Benina and Wheelus Field were near the axis of the upper-wind system throughout the period January 1–10, 1954, and observed the strongest winds of all. Only on the 1st and on the 9th and 10th were the greatest wind speeds farther south, at the mid-desert stations, Aoulef and Kufra.

Gaps in the central column in Table II are in many cases due to balloons being lost before the 200-mb. level was reached at both Wheelus and Benina, owing to the very strength of the wind. This may be presumed to mean that some of the greatest velocities were missed.

Table III summarizes the average wind speeds reported in Tables I and II during the seven days January 2–8, excluding the occasional instances of winds outside the range 240° to 280°. These cases occurred only on the fringes of the system.

TABLE III—AVERAGE WIND SPEEDS FOR CERTAIN STATIONS FOR JANUARY 2–8, 1954

	Elmas	Brindisi	Malta	Wheelus Field	Benina	Aoulef	Tamanrasset	Kufra
				knots				
300 mb.	56·1	28·3	108·9	150·9	137·9	97·0	48·3	88·0
				Number of ascents				
	12	4	14	7	14	5	3	3
				knots				
200 mb.	64·2	60·5	109·5	151·0	154·5	128·5	...	111·5
				Number of ascents				
	10	4	14	5	8	4	0	2

This table gives a general indication of the structure of the strong-wind belt during the seven days. It confirms the position of the axis of the system close to Wheelus Field and Benina. No importance is attached to the lower wind speeds consistently reported at Brindisi and Tamanrasset than at the stations (Elmas and Kufra) farther out from the axis of the strong-wind belt on either flank. Only a small number of ascents were available for these stations. Moreover topographical effects may be involved.

Table IV shows the strongest winds in the Meteorological Office records for the six years 1948–53 at various stations in the Mediterranean and south-west Asia. The information in this table made it possible to reject with some confidence the frequent winds over 250 kt., and occasionally well over 300 kt., reported by one foreign station during this sequence, shortly before the balloon was lost near the top of the ascents, i.e. at low angles of elevation.

TABLE IV—STRONGEST WINDS REPORTED 1948 TO FEBRUARY 1954

	300 mb.	270 mb.	256 mb.	239 mb.	227 mb.	207 mb.	202 mb.	200 mb.	195 mb.	153 mb.
					knots 1948–1953					
Malta ...	144	...	167	...	...	...	...	155	...	...
Benina ...	155	...	...	189	...	...	...	169	...	...
Nicosia ...	160	...	...	...	...	...	...	181	...	225
Habbaniya	172	...	...	...	183	183	...	171	...	...
Bahrain...	150	...	...	...	...	...	...	155	171	...
					January 1954					
Malta ...	...	...	...	...	...	...	...	180	...	...
Benina ...	...	...	...	...	...	...	190	...	...	...
					February 1954					
Malta ...	...	222	...	...	...	...	...	...	...	...

Estimation of maximum wind speeds during the sequence January 1–10, 1954.—To get a closer estimate of the probable maximum speeds attained during the sequence analyzed, the number of reports in 20-kt. intervals amongst the accepted ascents were studied. These are set forth in Table V.

TABLE V—FREQUENCY OF UPPER WIND SPEEDS IN VARIOUS RANGES OBSERVED AT THE MAIN UPPER AIR STATIONS, JANUARY 1–10, 1954

	Wind speed in knots								No. of balloons lost before maximum was reached*
	69	70–89	90–109	110–129	130–149	150–169	170–189	190–209	
300 mb.				*Number of occasions*					
Benina ...	0	1	1	6	7	4	0	0	
Wheelus Field	0	0	1	5	1	2	3	0	
Malta ...	5	5	4	1	5	0	0	0	
All Stations in Table I ...	24	12	12	16	14	6	3	0	
200 mb.									
Benina ...	0	2	0	2	2	5	1	1†	
Wheelus Field	0	0	2	2	3	1	2	0	
Malta ...	4	6	4	3	2	0	1	0	
All stations in Table I ...	13	13	8	10	9	7	5	1	
Any level				(*Known values of the maximum wind.*)					
Benina ...	0	1	1	1	1	6	0	0	5
Wheelus Field	0	0	2	1	3	1	2	0	3
Malta ...	3	3	6	2	5	0	0	0	1
All stations in Tables I and II	12	8	11	9	10	8	2	0	9

* Maximum was certainly >180 kt. and probably >190 kt.

† This one case at Benina was a reading of 190 kt. a little below the 200-mb. level. The balloon was lost at 202 mb. and the observers considered the 200 mb. wind was probably a little over 200 kt.

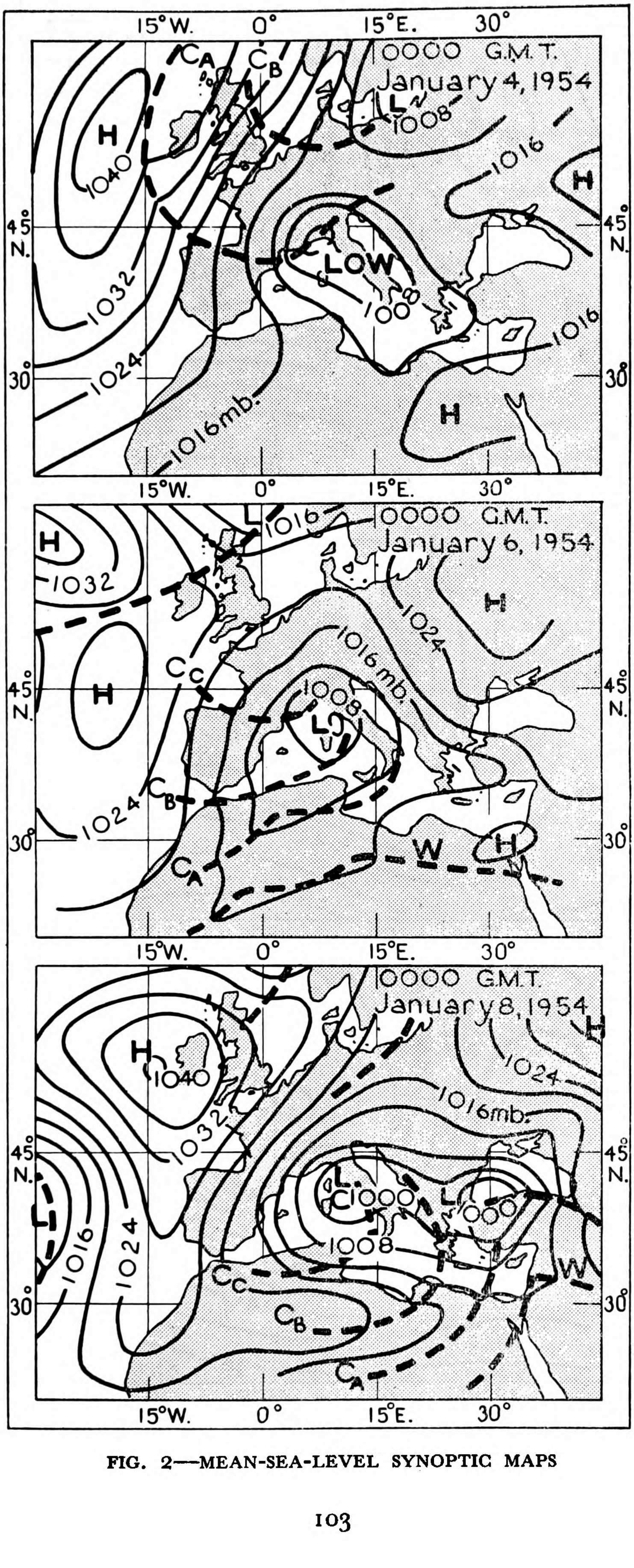

FIG. 2—MEAN-SEA-LEVEL SYNOPTIC MAPS

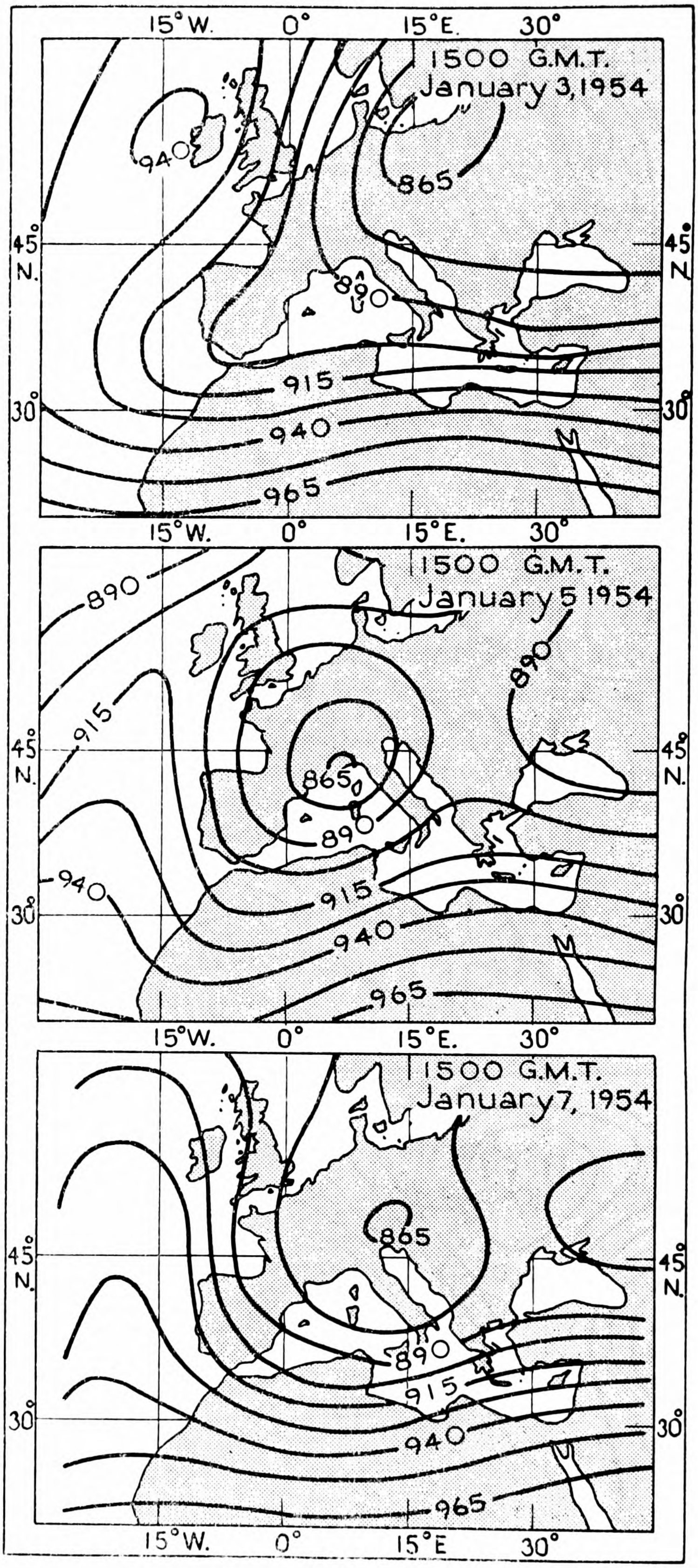

FIG. 3—300-MB. CONTOURS
Contour heights are in tens of metres

It seems legitimate to conclude from this table that the absolute maximum wind speeds reached in this jet stream, which was unlikely to be just over one of the observing stations at the time of ascent, were:—

at 300 mb. 190 ± 10 kt. (Malta about 160 kt.)
at 200 mb. 205 ± 10 kt. (Malta about 180 kt.)
at any level 220 ± 15 kt. (Malta 180–190 kt.)

Methods of analysis used.—The data accepted after the sifting processes described were analyzed in four different ways:

(i) "Horizontal" charts at mean sea level 700, 500, 300, 200 and 100 mb., here illustrated by three surface charts (Fig. 2) and three charts at 300 mb. (Fig. 3). It happened that the most satisfactory surface charts were the midnight ones, whereas the best upper-air charts were at 1500 G.M.T. Those reproduced here have been chosen to correspond with each other as nearly as the 9-hr. time interval allows.

(ii) Plotted graphs showing changes of wind speed with time over the ten days at all possible stations at the 200 and 300-mb. levels. This process permitted some reasonable attempts at interpolation where observation values were missing.

(iii) Time cross-sections were next drawn, making use of all available observed values and the graphs (ii) above, to show the changing wind speeds at all heights over Elmas, Malta and Benina. The time cross-section over Malta, for which most data were available, is shown in Fig. 4 and serves to illustrate the main stages of the sequence.

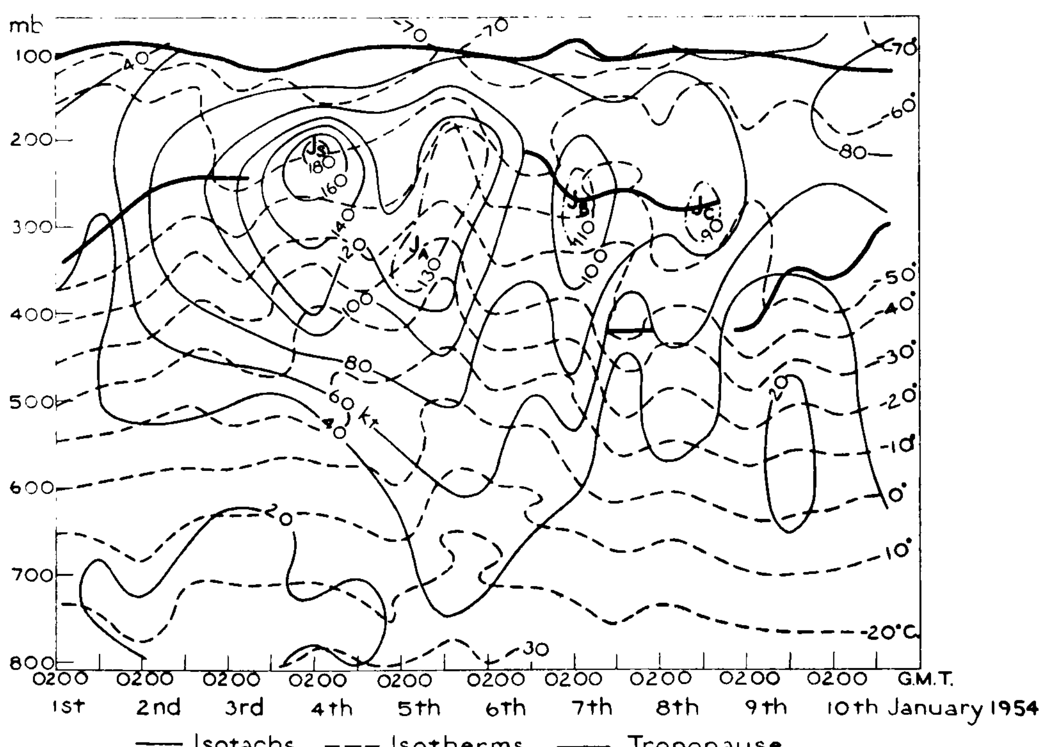

FIG. 4—TIME CROSS-SECTION OVER MALTA JANUARY 1–10, 1954

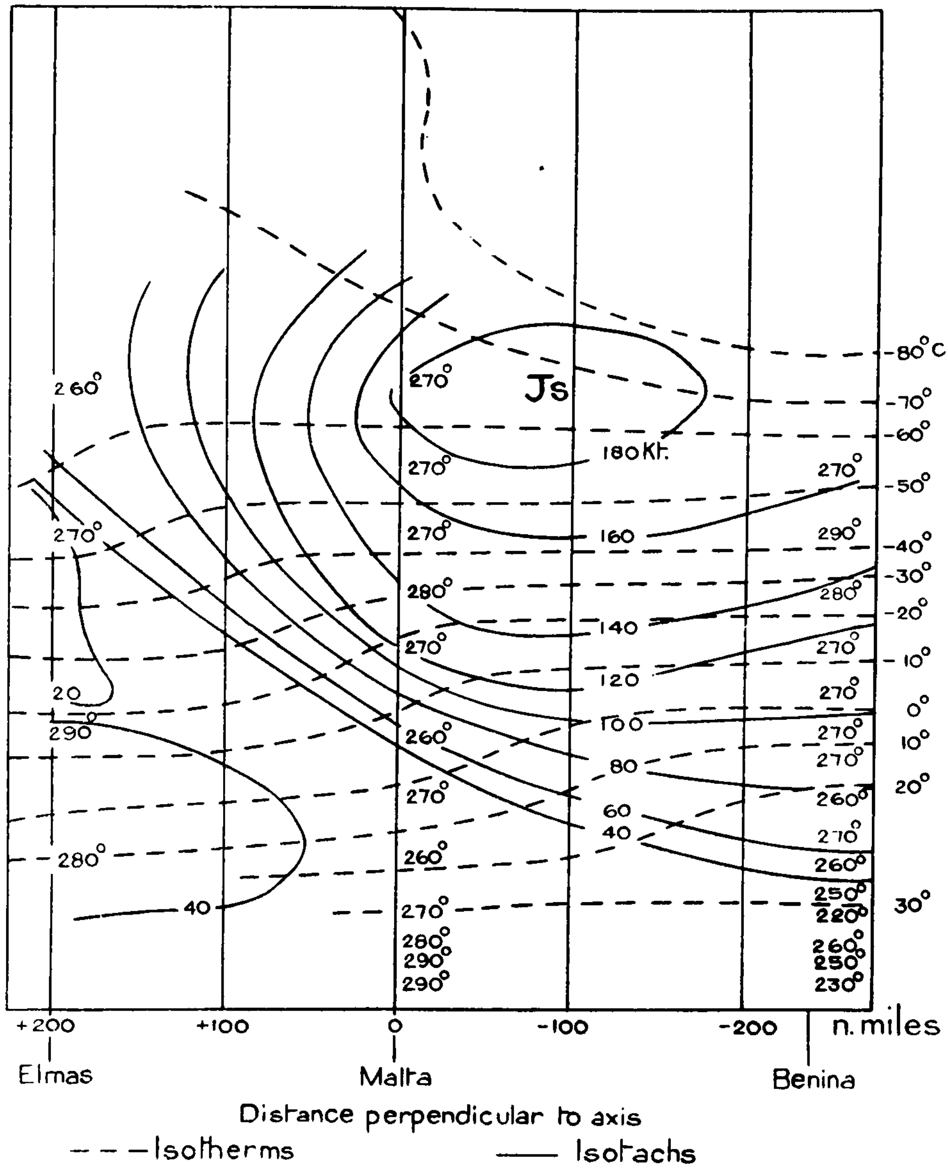

FIG. 5—VERTICAL CROSS-SECTION 0300 G.M.T. JANUARY 4, 1954
270° etc.: Observed wind directions in degrees from true north

(iv) Space cross-sections, drawn twice daily, for the 0200 and 1400 G.M.T. radio-sonde ascents, along the two axes Elmas–Malta–Benina and Aoulef–Wheelus–Malta–Brindisi.

Two cross-sections along the Elmas–Benina axis at 0200–0300 G.M.T. on January 4 and 6, have been chosen for reproduction here as Figs. 5 and 6 because they have the fullest data and show interesting phases of the development.

Results.—The essential features which emerged from the upper-wind analysis were as follows:

(i) At the desert stations, Aoulef, 27°04′N., 1°08′E., and Kufra Oasis 24°13′N., 23°20′E., also as reported by *Comet* aircraft over the Sahara on the north–south route between Tripoli and Kano, the high-level winds were strongest early and late in the period January 1–10, 1954 and they

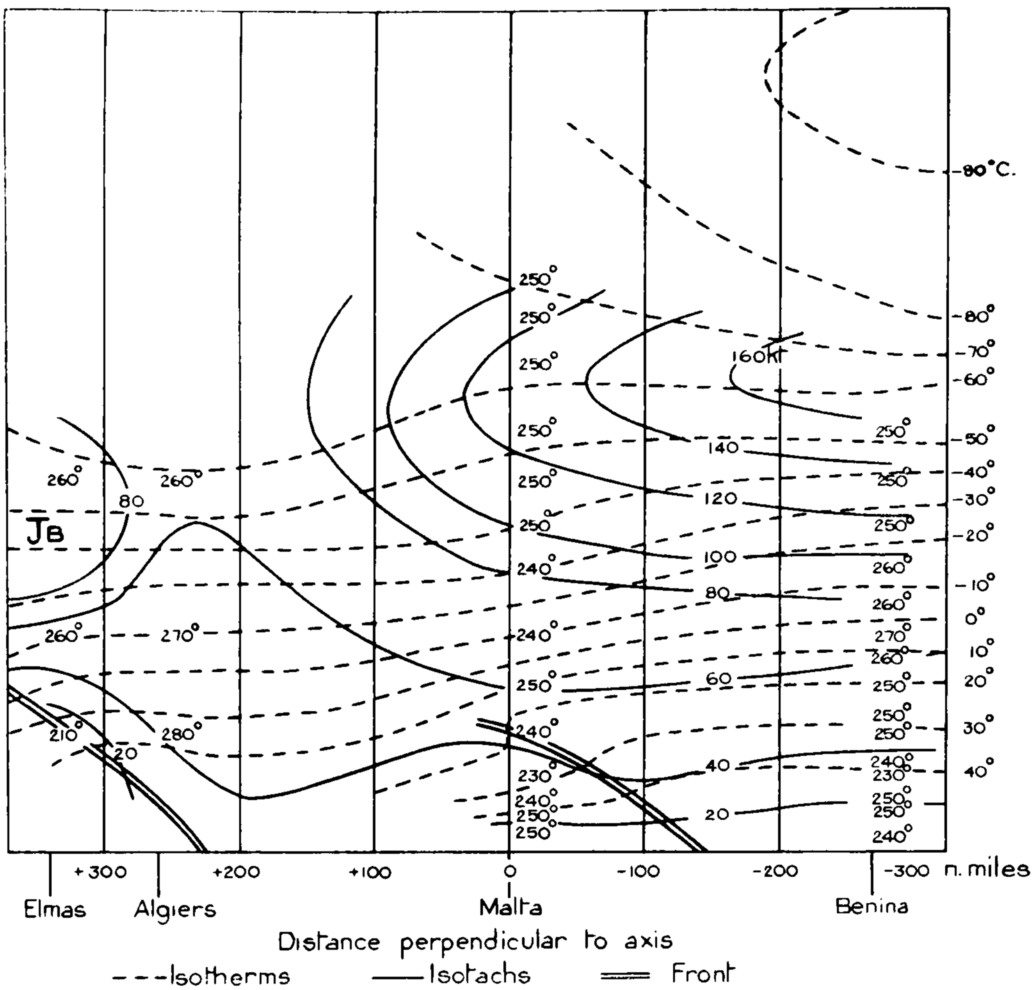

FIG. 6—VERTICAL CROSS-SECTION 0300 G.M.T. JANUARY 6, 1954
250° etc.: Observed wind directions in degrees from true north.

were then stronger over the desert with maxima over 170 kt., than anywhere else in this sector of the northern hemisphere. In the middle of the period the winds over places in 24° to 28°N. were much lighter, under 100 kt. at all heights, the minimum occurring on January 6 or 7.

(ii) At the Libyan coast, Wheelus Field and Benina, both about 32°N., the upper winds were under 100 kt. on the 1st, but quickly rose to an outstanding maximum of the order of 200 kt. by the 3rd–4th, high speeds being more or less sustained thereafter.

(iii) At the more northerly stations in the central Mediterranean the upper wind speeds were quite low at first, but gradually rose to several peaks in the middle of the period, between the 4th and 8th, and then fell off generally to light to moderate speeds by the 9th–10th. This broad trend is inverse to that at the desert stations, (i) above, apart from the complexity represented by several successive maxima with some decrease of wind between the northern stations: at Malta, Fig. 4, the first maximum was the strongest and at the highest level, about 200 mb., showing in these respects most resemblance to the maxima at the more southerly groups of stations.

(iv) The cross-sections leave little room for doubt that a jet stream J_S on Fig. 5, moved north out of Africa, passing over Benina on the 3rd, approached Malta on the 4th and then withdrew south-eastwards re-crossing Benina on the afternoon of the 6th. The northward movement was associated with temporary warming of the lower troposphere over north Africa and an accompanying northward advance of the high tropical tropopause as far as Malta. On Fig. 5, which represents the maximum movement to the north of this subtropical jet stream, the core is judged to be about 50 to 100 nautical miles south of Malta, a position far north of the normal January position of the subtropical jet[3].

(v) A further important feature of the subtropical jet stream as it approached Malta, cf. Fig. 5, was the sloping zone of tremendous shear underneath and somewhat north of the jet, which could not be associated with any front or frontal surface that had come from the north during the period studied. This sloping zone of shear may well have had some connexion with the warm front, marked W on Fig. 2, found moving north over the central Sahara.

(vi) The cross-section for the afternoon of the 4th, which is not reproduced, for the first time showed a second jet stream, rather over 80 kt. near the 400-mb. level, near Elmas, associated with the cold front C_A, Fig. 2, which swept south over Malta early on the 5th. The lower level of the wind maximum in itself probably marks this system out as having recently come from higher latitudes—quite apart from its obvious association with the cold front. This system passed over Malta, where it produced a second wind maximum, about 135 kt., at 350 mb. on the morning of the 5th, J_A on Fig. 4, with a subsequent increase in the main stream at higher levels. From the Elmas–Benina cross-sections J_A appears to have become virtually absorbed already in a single broad maximum with J_S by the afternoon of the 5th.

(vii) A second polar-front jet stream from the north, accompanying the second cold front, C_B, appears on the morning of the 6th near Elmas as J_B on Fig. 6, with maximum winds at about the 350-mb. level. This jet also continued to move south, though more slowly than J_A and was still traceable as a separate entity on the afternoon of the 6th. It was responsible for a third maximum of winds aloft over Malta $>$110 kt. near the 300 mb. level on the morning of the 7th, but may already have become part of the main broad core of strong upper winds near the north African coast: wind was 158 kt. at 37,000 ft. over Benina at that time. The cold front C_B had passed Elmas at 1200 G.M.T. on the 5th, but was retarded by development of minor waves along it before passing Malta at 0200 G.M.T. on the 7th, and Benina at 1800 the same evening.

(viii) A third cold front from the north, C_C, much less significant in the thermal field than C_A or C_B, passed rather quickly south-eastwards across the central Mediterranean between the afternoon of the 7th and the morning of the 9th. There were signs of another maximum of upper winds, about 80 kt., appearing over Elmas late on the 7th and approaching 100 kt. at 250 mb. over Malta, J_C on Fig. 4, at 1500 G.M.T. on the 8th. In this case, too, absorption into the main system seems to have occurred by the time the polar-front jet reached Malta, or soon after.

(ix) These systems from the north brought the low polar tropopause with them. In a tropopause funnel on the afternoon of the 7th, this polar tropopause descended to about 425 mb. near Malta.

(x) At various times during this coalescence of jet streams in early January the belt of westerly winds over 100 kt. at 300 mb. was more than 600 nautical miles in width from north of Malta to mid-Sahara. The same belt may have exceeded 750 nautical miles at 200 mb. These figures should be compared with the greatest known widths elsewhere, i.e. 600 nautical miles at 250 mb. over the Norwegian Sea on November 29, 1951 and a mean width for January over Iraq of 690 nautical miles[4]. Clearly there were several stages at which, for a time, two or more separate maxima lay side by side within the strong-wind belt of January 1–10, 1954, over the central Mediterranean, the main maximum being always the southernmost one, which was also rather higher up than the polar-front jet streams until the moment of their absorption.

(xi) Violent turbulence was reported in clear air along the northern flank of the strongest wind, but evidence is insufficient to say whether this turbulence is always there or whether it is confined to the northern side. There were no reports of turbulence from the southern side of the strongest wind stream, in spite of regular post-flight summaries received throughout the winter 1953/4 from the *Comet* air line, Tripoli–Kano, Nigeria.

(xii) The anticyclonic shear at the right of the main jet stream over north Africa between January 1 and 10, 1954 was of the same order of magnitude as the cyclonic shear to the left; in some cases the anticyclonic shear appears to have been the greater of the two. This is believed to be very rare with polar-front jet streams in middle latitudes. We have, as yet, no means of gauging whether it is a usual feature of jet streams in the Mediterranean and north Africa.

(xiii) The magnitude of the anticyclonic shear also attracted notice as it clearly approached and possibly exceeded the Coriolis parameter. To check this a careful search was made for occasions when measurements of the shear could be based directly on reliable observations.

The following pairs of observations giving outstanding values of the anticyclonic shear were the only ones during early January 1954 for which measurements might reasonably be significant: even so, the stations were not abreast of each other at the same point of the main-stream.

Case 1—January 3, 1954, 1400 G.M.T. at 300 mb.

	Mean latitude	Wind speed	Direction
Wheelus Field	32½°N.	178 kt.	270°
Benina	32½°N.	144 kt.	278°

The Wheelus velocity report is considered likely to be an over-estimate by a matter of 10–20 kt. Even so the anticyclonic shear implied is 14 to 24, say 20 kt., in 50 nautical miles, since Benina lay that much to the right of the streamline through Wheelus. The implied shear is $-0{\cdot}4$ hr.$^{-1}$.

Case 2—January 4, 1954, 1400 G.M.T. at 300 mb.

	Mean latitude	Wind speed	Direction
Benina	28°N.	138 kt.	266°
Tamanrasset	28°N.	45 kt.	250°

In this case both the observed velocities are accepted, but Tamanrasset winds may be reduced even at 300 mb. by the mountains just to the east and north-east. The implied shear is $-0\cdot2$ hr.$^{-1}$.

Case 3—January 7, 1954, 1400 G.M.T. at 300 mb.

	Mean latitude	Wind speed	Direction
Benina	28°N.	157 kt.	247°
Tamanrasset	28°N.	52 kt.	250°

The implied shear is $-0\cdot2$ hr.$^{-1}$.

In none of these cases were the stations near enough abreast of each other, relative to the jet stream, for confident assertion of the actual shear values. It remains true that the mean shear over distances of 100 to 400 miles on the right of the jet axis at the level of the wind maximum ran very close to, or exceeded, the Coriolis parameter* in all these cases. Consequently either the critical value must have been locally exceeded somewhere or the shear was remarkably uniform over hundreds of miles. The jet stream was nearly straight in all these cases, any curvature existing being slight and anticyclonic.

(xiv) A further case during the following month is very interesting.—February 8, 1954, 0300 G.M.T.

	Mean latitude	Malta Wind speed	Malta Direction	Benina Wind speed	Benina Direction
mb.	°N.	kt.	°	kt.	°
500	34	55	259	105	260
400	34	113	252	119	270
300	34	198	260	138	265
270	34	222	250	142	270
250	34	207	260	145	271
200	34	167	258	159	270

All these observations were accepted. This was a situation with a very intense jet moving laterally quite quickly across the area. By the afternoon radio-sonde ascents at 1400 G.M.T. February 8, the 300-mb. wind at Benina had risen to 185 kt. and at Malta had dropped to 90 kt., a decrease of 108 kt. in 12 hr. at the 300-mb. level over Malta. Great anticyclonic shear is implied between Malta and Benina, at levels between 300 and 200 mb. only, on the morning ascents. The implied shear values are:—

300 mb.	$-0\cdot2$ hr.$^{-1}$
270 mb.	$-0\cdot3$ hr.$^{-1}$
250 mb.	$-0\cdot2$ hr.$^{-1}$

A Canberra aircraft flying between Tunis and Tripoli on February 8, later in the day at 1300 G.M.T., reported severe turbulence in clear air at 25,000 ft. and down to 21,500 ft., but this aircraft at the time in question was immediately north of the jet stream in the region of great cyclonic shear, the average shear Benina–Malta at 1400 G.M.T. being $+0\cdot34$ hr.$^{-1}$.

(xv) In the case of January 1–10, 1954 the formation of a cold trough over the western Sahara went almost hand in hand with, or was closely

* The values of the Coriolis parameter in these latitudes are:

25°N.	30°N.	35°N.	40°N.
0·22	0·26	0·30	0·34 hr.$^{-1}$.

followed by, ridging immediately to the east, which brought the main subtropical jet stream north out of Libya to lie over the central Mediterranean for two days or so.

This type of development constitutes a major forecasting problem for the safety of jet aircraft on east to west flights over the Mediterranean. The high-level westerly winds have been observed to increase and decrease by as much as 100 kt. in 12 hr. over Malta, when the jet stream moves north or south and when it intensifies. Aircraft flying from Cyprus to Malta have been troubled by rapid increases of head winds of this order at 35,000–45,000 ft. The experience emphasizes the importance of jet-stream warnings to all aircraft on such courses and of regular, careful mapping of the winds up to 200 mb. in this part of the world.

(xvi) The structure of all the westerly jet streams in 25°–35°N. here examined appears in many ways similar to the jet streams in higher latitudes including, remarkably enough, a plausible association of each maximum with a frontal surface and sloping zone of strong shear below the jet. In this instance the zone of strong shear sloping downwards to the south underneath the subtropical jet stream when this lay over the Mediterranean was continuous down to the 600–700-mb. layer near the north African coast, see Fig. 5, and possibly still lower over the desert to the south, where there was a warm front. In other respects, however, the situation with two jet streams occasionally merging into one and with the subtropical jet stream the stronger and higher up of the two shows obvious resemblances to the winter jet streams over the Pacific Ocean sector as investigated by Hoyle[5]; though much of the detail is likely to be peculiar to each sector with its own geography.

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A WIND-VANE FOR RECORDING OR INDICATING MEAN WIND DIRECTION

By G. E. W. HARTLEY, M.A.

When wind direction is recorded, the usual procedure is to record the actual movements of a pivoted wind vane; and the record so obtained shows all the fluctuations of wind direction which the vane is capable of following. Unless the exposure of the vane is exceptionally open, the record will usually cover a fairly wide band of direction, and the mean direction is obtained from this by inserting a line which is as nearly as can be judged always at the centre of the band.

In wind measurements taken at the site of the proposed Severn Bridge, and near the Forth Bridge, where wind inclination to the horizontal was recorded as well as normal wind direction, it was found that the record of wind inclination even with a quick chart speed was a broad band in which it was practically impossible to insert a mean line; and an elaborate damping system developed by Admiralty for a wind resolver was used to extract the mean direction record. This system worked well, but is expensive and complicated and has a number of places where adjustment may be required. In the vane to be described an attempt is made to have the damping built into the vane, so that the movements of the vane spindle show the mean wind direction. The vane employs a system which has frequently been used before in various forms; a vane-type windmill carries a worm on its spindle, which engages with a fixed worm-wheel; when the windmill is turned by the wind, it rotates about the axis of the fixed worm-wheel until it reaches a position where the wind no longer causes it to turn.

The portion of the vane which carries the windmill turns the direction shaft or spindle. This sytem has been used in the Beckley anemometer and in the windmill-type d.c. generator anemometers used by the Admiralty, and was also used in the rotating-cap windmill, formerly used for grinding corn and pumping water. The objection to the system is that as the vane approaches true wind direction the force causing it to approach decreases rapidly; so that in light winds the vane may stop at an appreciable angle short of the true wind direction. In some applications, this does not matter; but for accurate recording of wind direction it does.

The methods adopted to try to overcome this defect in the instrument to be described are

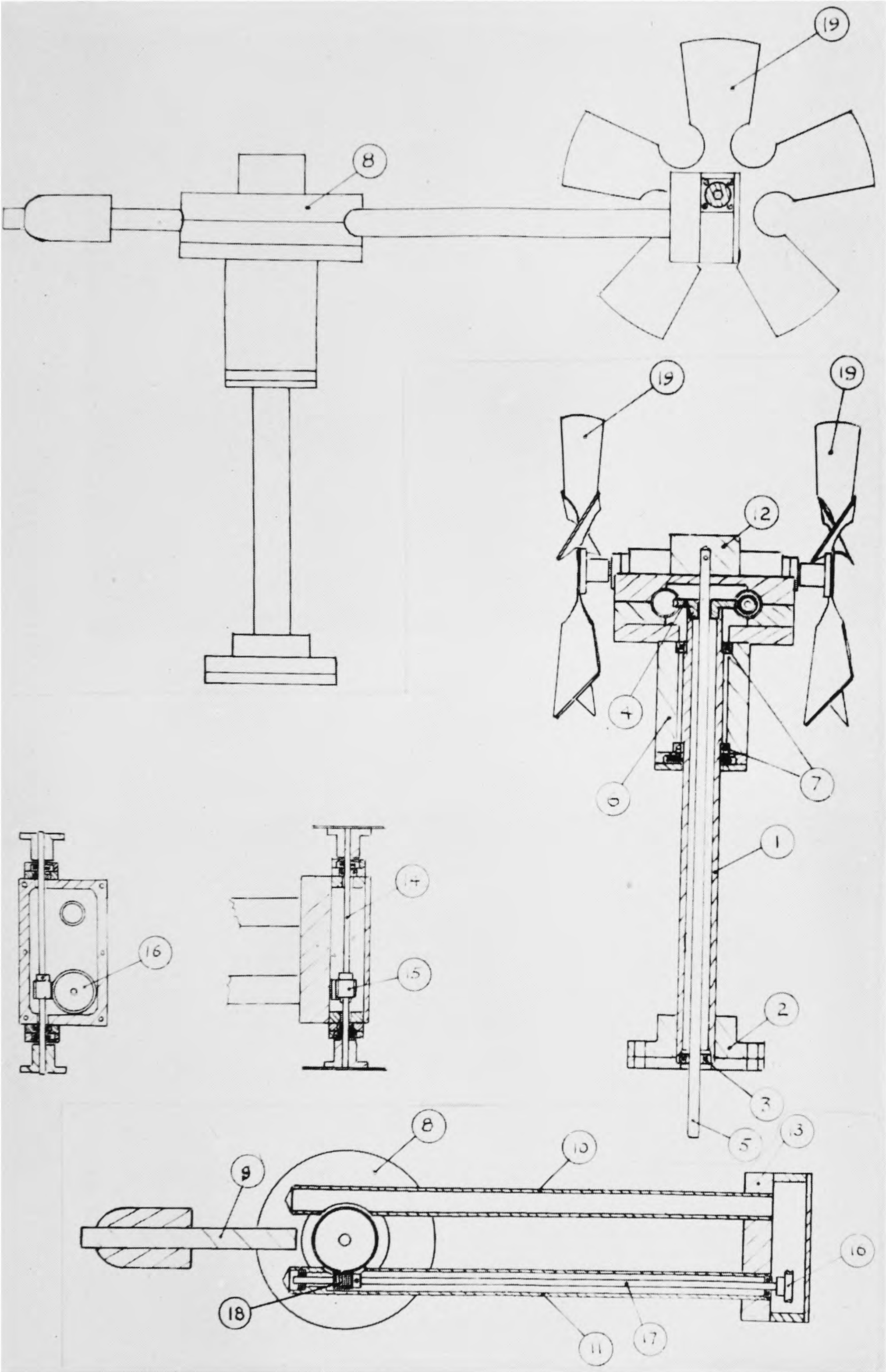
(i) to place the rotating windmill some distance out in front of the direction-shaft axis, so that it will be shielded as little as possible by the centre portion of the vane,

(ii) to mount all rotating parts in well protected and freely running ball-bearings,

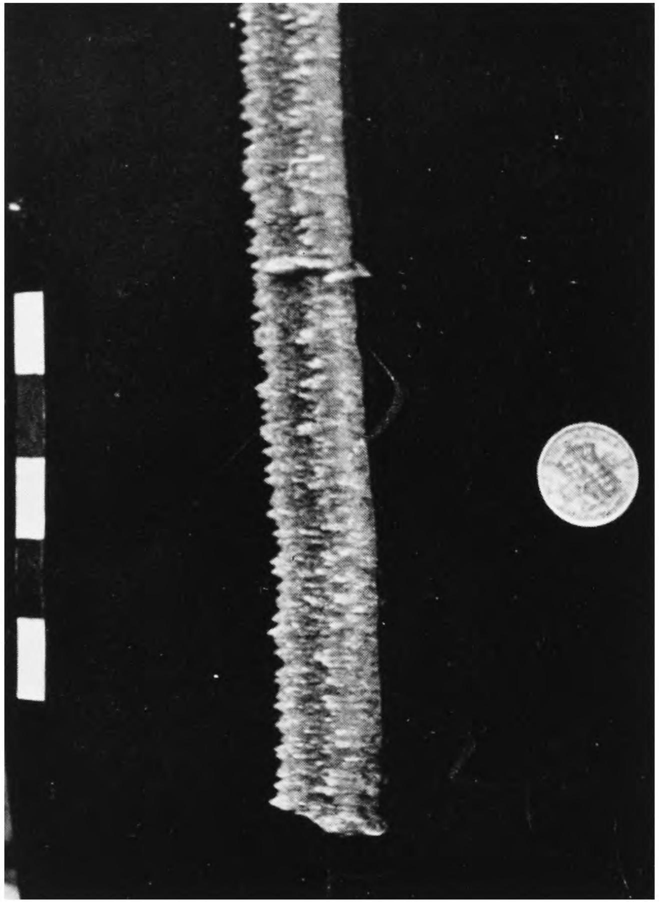
(iii) to make the worm-gear ratio as low as conveniently possible so that the windmill is doing very little work,

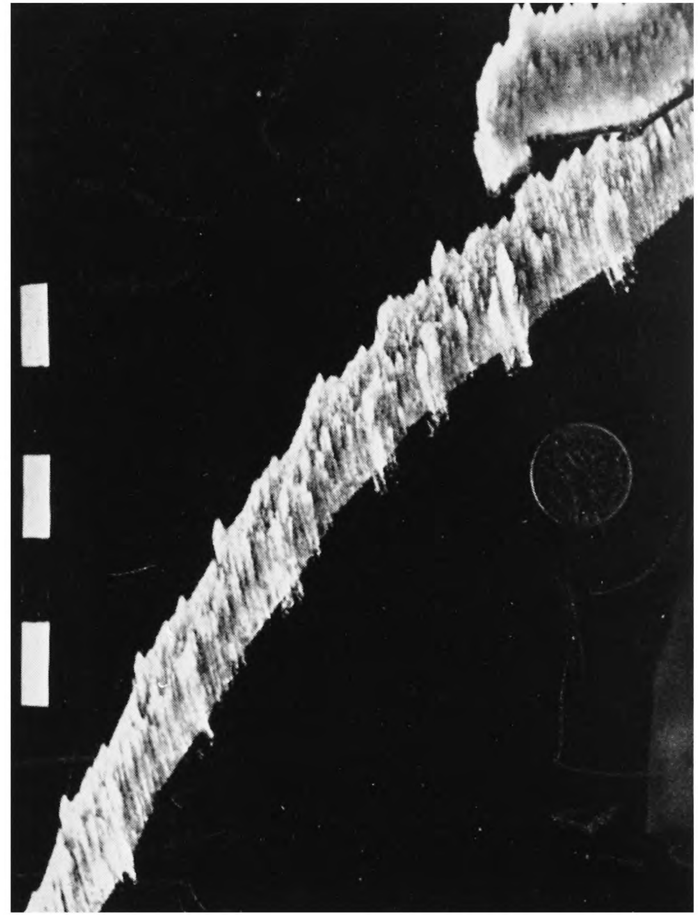
(iv) to balance the rotating portion as accurately as possible, and incidentally to arrange it so that it may rotate about a horizontal axis, if required, to record vertical inclination of the wind.

The vane is shown in the photograph opposite. A vertical tube (1) has at its lower end a flange (2) and a housing for a ball-bearing (3). Fixed to its upper end is a fixed worm-wheel (4) in the centre of which is a clearance hole through which passes the direction-transmitting spindle (5). The part of the vane which rotates in the wind consists of a sleeve (6) carried on ball-bearings (7) outside the centre tube (1) and having at its upper end a split cylindrical block (8) which when clamped up grips a balance weight (9) and two tubes (10) and (11). A boss (12) holds the upper end of the spindle (5). At the other end of the tubes (10) and (11) is a rectangular housing (13) which carries the windmill spindle (14) in ball-bearings suitably weather protected; and a worm (15) on the spindle engages with a worm-wheel (16) at one end of another spindle (17) carried inside the tube (11). On this spindle is a worm (18) which engages with the fixed worm-wheel (4). The spindle (14) carries at its ends two 5-bladed fans (19) 7 in. in diameter whose blades are bent in the same sense, at 40° to the plane at right angles to the axis. When caused to rotate by the wind, these windmills, through two stages of worm-gear reduction, 40 : 1 and 60 : 1, cause the whole of the rotating portion (6, 8, 10, 13 etc.) to turn round



WIND VANE FOR RECORDING OR INDICATING MEAN WIND DIRECTION

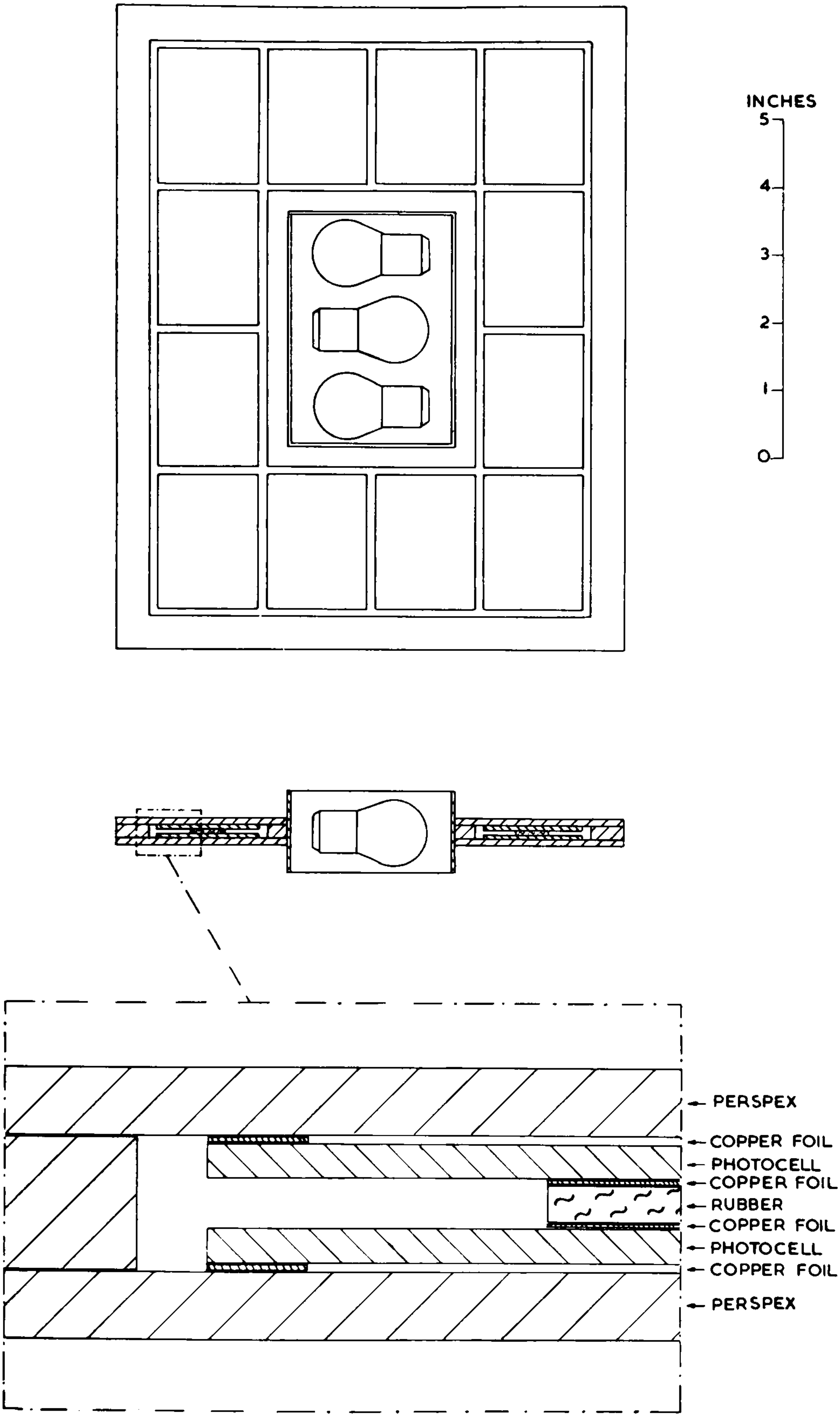




Reproduced by courtesy of W. G. Pendleton

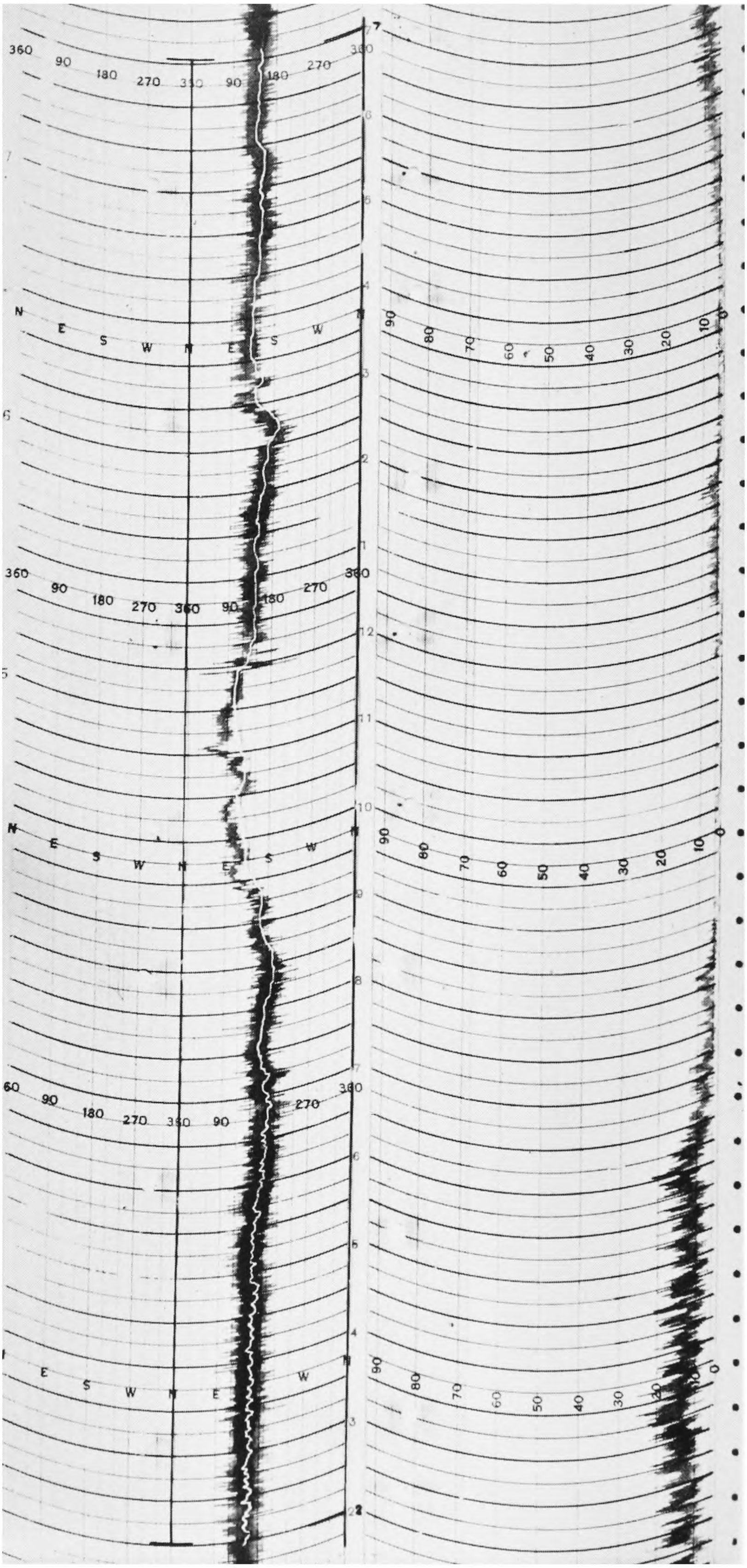
RIME AT TERNHILL, DECEMBER 21, 1956

A one-inch scale and a half-crown piece are shown for comparison



FOG DENSITY INDICATOR

(see p. 117)



TYPICAL RECORD SHOWING MEAN WIND DIRECTION SUPERIMPOSED ON AN INSTANTANEOUS WIND-DIRECTION RECORD the fixed tube (1) until they are in such a position that the wind no longer causes them to rotate. This turning of the rotating portion also causes the spindle (5) to turn; and this is used to operate the direction-recording or transmitting device. All ball bearings are protected where necessary by means of oil soaked felt washers in housings outside the ball-bearings. The direction of rotation of fans relative to worms is such that the fans turn towards the direction of the wind, i.e. the balance weight is down stream.

Wind-tunnel tests.—The vane was set by hand at about 45° from true wind direction, and the time taken to reach 0° (or as near as possible) from 30°, in 5° intervals and from either side of 0°. The results are shown in Table I.

TABLE I—ACCURACY OF THE RECORDING WIND VANE

Wind speed	Vane movement	Displacement from true wind direction									
		25°	20°	15°	10°	5½°	5°	2°	1½°	1°	0°
kt.	From	*Time in seconds*									
30	E. to N.	4	9	15	24	...	36	...	...	...	65
	W. to N.	4	9	15	23	...	36	...	...	...	65
	From										
20	E. to N.	5	12	22	33	...	55	...	...	110	...
	W. to N.	6	14	25	38	...	62	100	...	...	...
	From										
10	E. to N.	11	25	42	64	...	105	...	190	...	...
	W. to N.	12	26	42	65	...	103	150	...	...	...
	From										
5	E. to N.	25	60	120	200	300	...	...	...	...	...
	W. to N.	23	55	95	150	...	190	...	...	...	...

These tests indicate that at speeds above 10 kt. the vane will show true direction to not worse than $\pm 2°$, though at 10 kt. it may take about 3 min. to do so. At speeds below 10 kt. the accuracy falls and the time increases.

Tests in natural winds.—The direction spindle of the vane was coupled to a Magslip transmitter, carried in a weather-proof housing below the vane, and the vane set up on the 40-ft. tower on the roof of the Meteorological Office at Harrow. The receiving Magslip operated a single-pen Meteorological-Office pattern direction recorder.

A Mk IIIb "In-line" pattern wind-vane connected to another recorder and mounted on a 34-ft. tower also on the roof of the Meteorological Office at Harrow, was used to provide a normal record for comparison. Both vanes were held to the same known direction, while the recorders were set to read that direction, with a probable error of $\pm 3°$.

A typical record is shown in the photograph opposite; the record of mean wind direction has been superimposed on the instantaneous wind-direction record taken from an electrical anemograph. This was done by tracing the mean wind record in white ink on a transparent sheet and photographing the electrical anemograph chart with the transparent sheet on top. It will be seen that when the wind speed is over 10 kt., between the hour lines 2–7 on the left-hand side of the chart, the mean trace lies near the centre of the instantaneous trace; but where the wind speed falls below 5 kt. between the hour lines 9–11.30, the mean trace does not follow the instantaneous trace.

It may be possible, by making the distance between the rotating fans and the vertical axis of the vane greater, to make the vane more sensitive at low wind speeds; but in its present form the vane will provide useful information on mean wind direction except at the lowest wind speeds. Trials of the vane to record vertical inclination of the wind have so far been limited to wind-tunnel tests; the performance is the same as with the vane axis vertical. To use the vane in this way in natural winds it would have to be mounted on another vane which would hold the windmill vane into wind, the procedure hence producing some complications.

Suggested uses.—

(i) In remote sites, where inking presents a difficulty, the fact that only a mean line is drawn will reduce considerably the amount of ink needed; so that with a simple cam recorder, and a glass pen and reservoir of the type used in the Meteorological Office Impulse Recorder, a week's, or even a fortnight's run should be possible; by using a silver pointer as a pen, and a metallized paper chart, a run of four weeks should be obtained with a suitable clock.

(ii) In cases where the wind flow is very turbulent, e.g. over crops, near the ground, where an ordinary vane would frequently box the compass, and give a trace covering 360°, from which it would be very difficult to extract the mean direction.

AURORAL DISPLAY OBSERVED FROM UNUSUALLY LOW GEOMAGNETIC LATITUDES

By B. McINNES, B.Sc.

Summary.—The interest of auroral observations from low geomagnetic latitudes is described. Observations of the auroral display of September 8, 1956 are reported, with brief details of some related effects.

Introduction.—Auroral displays occur most frequently in two rings of about 20° radius, centred on the north and south geomagnetic poles; these rings are known as the auroral zones. There is, however, frequent movement of the centres of auroral activity from these two mean positions, displays appearing overhead at places both inside and outside the zones. The frequency of observation falls off rapidly with decreasing geomagnetic latitude of the observer till at 45° it is less than one night per year on the average, according to available records.

Interest in low latitude observations.—There has recently been an increase of interest, fostered specially by Prof. S. Chapman, in the observation of those displays which move unusually far out from the auroral zones so that they become visible from low geomagnetic latitudes. The area between geomagnetic latitudes 45° north and south has been called the minauroral belt by Chapman. He has recently suggested that the chance of seeing an auroral display from this belt may be decidedly greater than past records indicate[1, 2]. The following notes of such an occurrence are published here not only for their intrinsic interest but also to support an appeal for further observations of this particular display and to encourage the careful watch by suitably placed observers that will yield more of these valuable minauroral observations.

Auroral observations.—An observation of the aurora on September 8, 1956 has been reported from a ship in geomagnetic latitude 43°S. The ship was at 31°40′S., 113°45′E., on her way from Fremantle to Durban when the aurora was first seen at 1435 universal time. The geomagnetic co-ordinates of this position are 43°S., 184°E. The observer was Mr. J. English, First Officer of the s.s. *Orion*. The display continued to be seen till nearly 1600 universal time. At 1435, which was just after moonset, an auroral glow was observed over the southern horizon. Rays appeared in the south-east and slowly wheeled across the sky towards the west, diffusing and becoming deep red. As the deep red faded in the south-west, a fresh set of rays sprang up in the east and developed as before. The auroral light reached 20° altitude.

The observation is confirmed and expanded by another report from a ship in an even lower geomagnetic latitude. This report evidently concerns a peak of activity of the display described above, since the aurora was seen only during the ten minutes 1446 to 1456 universal time. The ship was the M.V. *Port Phillip*, on a voyage from Fremantle to Cape Town, and the observers were Mr. J. E. Toghill, Second Officer and Mr. G. F. Brandon, Fourth Officer. The position was 29°22′S., 65°37′E., which has geomagnetic coordinates 37°S., 129°E. During the ten minutes mentioned, auroral light appeared in the southern sky between 20° each side of due south and up to 40° elevation, its colour changing from dull crimson to bright red and then back through crimson to extinction.

The sunset line, which was about an hour west of the second ship when the ten-minutes peak of activity was observed from it, passed across the British Isles at about 1830 universal time. Aurora was observed from Kirkwall, Orkney, geomagnetic latitude 62°N. at 2100 universal time and from Malin Head, Co. Donegal, Ireland, geomagnetic latitude 59°N., at 2200 universal time. Other reports of aurora seen later in the evening came from other observers in Scotland, but none of these was south of geomagnetic latitude 60°N.

A bright rayed arc was reported by an aircraft over the North Atlantic, flying in geomagnetic latitude 63°, at 0400 universal time on September 9; this remained visible till 0800.

Further observations.—It is hoped that there may be more reports of this display to come from other ships that were in the Indian Ocean or in the Pacific between Australia and the Hawaiian Islands at the time. The display was almost certainly seen from Australia and attempts are being made to collect the observations made there.

Geomagnetic disturbance.—The three-hour-range planetary indices of geomagnetic disturbance show a world wide magnetic storm at the time of the display, as follows:—

	0–3 hr.	3–6 hr.	6–9 hr.	9–12 hr.	12–15 hr.	15–18 hr.	18–21 hr.	21–24 hr.
	indices of geomagnetic disturbance							
Sept. 7	3_o	2+	3−	2_o	2_o	2_o	1+	1+
Sept. 8	1_o	1_o	4−	5+	8+	8_o	6_o	3+
Sept. 9	3−	3−	4+	4+	4−	3−	4_o	3+

These indices, which have 28 possible values, from 0_o to 9_o, are derived from measurements of the variations of the magnetic elements at magnetic observatories all over the world. The original records are continuous traces called magnetograms.

Fig. 1 is based on the magnetograms made at Lerwick Geophysical Observatory on September 8, 1956. Lerwick is at 63°N. geomagnetic latitude. During the peak ten minutes of the display there were unusually steep changes of the elements: during 1447 to 1450, D increased by over 700γ; during 1448 to

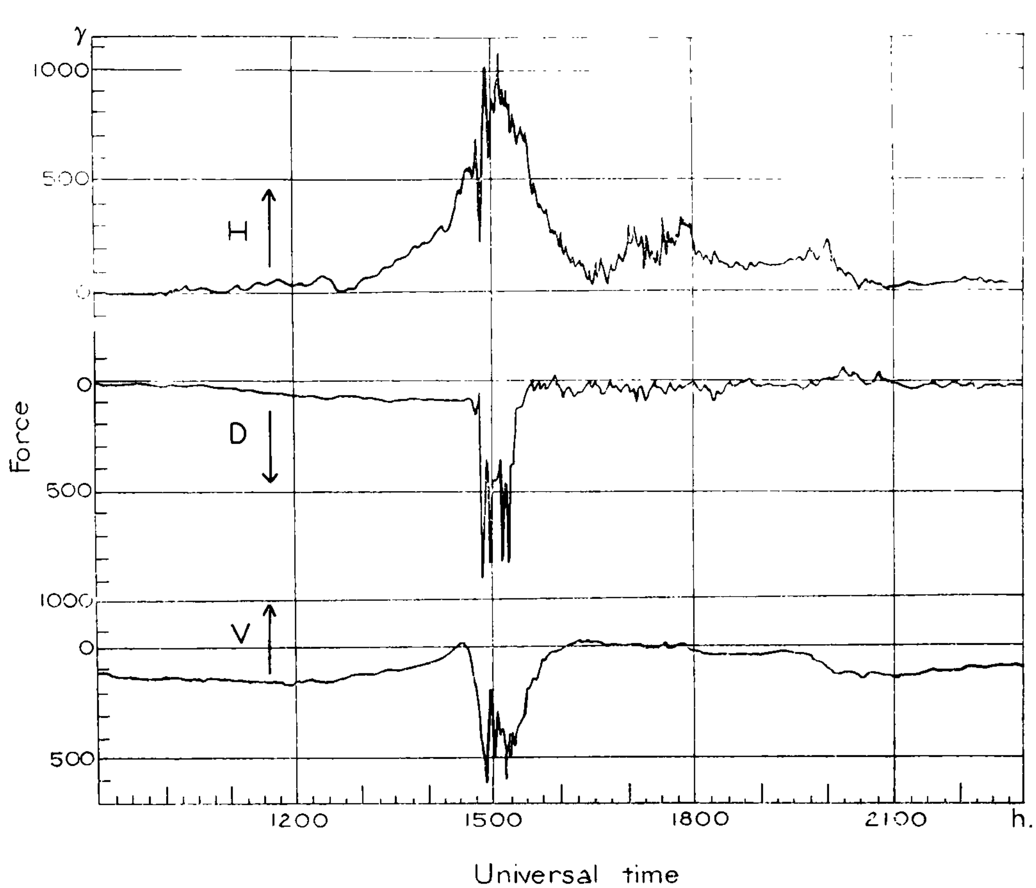


FIG. I—VARIATION OF H, D AND V AT LERWICK GEOPHYSICAL OBSERVATORY ON SEPTEMBER 8, 1956

The direction of increase of each element is indicated by an arrow.

1454, H increased by about 800γ. The magnetogram made at Hermanus Magnetic Observatory in South Africa, at 34°S. geomagnetic latitude shows similar sudden changes. The details of the relationship between the auroral display and the geomagnetic disturbance are of considerable interest; the importance of accurate timing of the auroral observations is obvious.

Radio echoes.—The transmitter of the rotating aerial equipment at the University of Manchester's Experimental Station, Jodrell Bank, geomagnetic latitude 56°N., was unfortunately switched off from 1218 till 1500 universal time on September 8. But thereafter the following observations were made.

1500 strong echoes from about geomagnetic latitude 59°N. over an azimuth angle of ±30°; very intense at 500-Km. range at 20° east of geomagnetic north.

1510 intense echoes east of geomagnetic north continuing; westerly echoes die out.

1515 echoes less intense.

1520 echoes disappear for a minute.

1525 weak echoes east of magnetic north continuing.

1537 all echoes disappear after gradual decrease in intensity.

Radio star scintillation.—Another effect which gives information about ionospheric disturbances connected with aurora is the fluctuation of the signal received from the Cassiopeia radio source: this signal is continuously observed at Jodrell Bank, the measure used averaging between 1 and 2 during a normal day. The hourly values for September 8 were as follows:

10–11 hr.	11–12 hr.	12–13 hr.	13–14 hr.	14–15 hr.	15–16 hr.	16–17 hr.	17–18 hr.	18–19 hr.
3	3	4	5	7	7	4	4	3

Solar activity.—Since auroral displays follow solar-flare activity by about 18 to 30 hr., the state of the sun's surface during September 7 is of interest. A sun-spot with an area of 2,250 millionths of the sun's visible hemisphere on September 6 was crossing the disc during September 5–18. Some flare activity connected with this large spot was observed during the period of interest but insufficient information is available at present to decide the precise relationship between this and the display.

Acknowledgements.—Thanks are due to the ships' officers for the observations which started this study, and to the Director of the Irish Meteorological Service for auroral observations from meteorological stations in Ireland. The radio echo and radio-star-scintillation data were kindly supplied by Mr. C. D. Watkins of Manchester University, with the permission of Prof. A. C. B. Lovell. The sun-spot information came from the Royal Greenwich Observatory, by kind permission of the Astronomer Royal. A reproduction of the magnetogram made at Hermanus Magnetic Observatory on September 8 was kindly supplied by the Officer in Charge.

Appeal.—Further relevant data will be welcomed by the writer at the Balfour Stewart Auroral Laboratory, University Natural Philosophy Department, Drummond Street, Edinburgh 8. In particular, it is hoped that more observations of the auroral displays in both the southern and the northern hemispheres during the 12 hr. or so following on 1400 universal time on September 8 will be forthcoming.

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A FOG-DENSITY INDICATOR

By J. R. BIBBY, B.A.

In 1950 the Ministry of Civil Aviation asked the Meteorological Office for some means of measuring the depth of a fog layer, and preferably also the variation of visibility with height up to at least 500 ft. The most practicable method appeared to be to measure the scattering of light in the air by an instrument carried on a tethered balloon.

At first it was hoped to make an instrument which could be used in daylight as well as darkness. A model was made, using a series of baffles to exclude daylight, but it proved too heavy for the 500-gm. balloons it was proposed to use. Also it appeared that there would always be doubt whether the air inside was representative of that outside. A much simpler instrument was therefore designed for use in darkness only. Its dimensions are approximately $24 \times 20 \times 3$ cm., and weight, without batteries, about 750 gm.

Description.—A simplified drawing of the instrument is shown in the photograph in the centre of this magazine. A "sandwich" is formed from two sheets of perspex, each with a rectangular hole in the centre. Between them, 24 selenium barrier-layer photo-electric cells are arranged in a double layer facing outwards, with a strip of rubber separating the two layers, and strips of copper foil making connexion with the cells. The inner and outer edges of the sheets are then cemented together with strips of perspex, and the whole made waterproof with a solution of perspex in chloroform. A pair of leads is fitted to allow electrical connexion to the photo-electric cells, which are all in parallel. In the central hole are placed three 6 v., 12 w. filament lamps. No lamp holders are used for lack of space, the lamps being fixed in a wire frame with soldered electrical connexions. Around the lamp is a metal strip, just wide enough to prevent any light reaching the photo-electric cells directly.

Provided the instrument is mounted so that there are no objects within about 50 ft. of it, except in its own plane, and there is no fog or mist, no light from the lamp can reach the photo-electric cells, and the current from the cells is very low, less than $0 \cdot 2\mu$ amp. If fog is present, however, light from the lamps is reflected by the fog particles and a current is generated by the photo-electric cells. This current should be roughly proportional to the scattering coefficient of the air, i.e. inversely proportional to the visibility.

Method of Use.—As stated above, it can only be used in darkness, and must be mounted well away from any other object, which implies, for best results, at least 50 ft. above the ground. Normally it is fixed at one edge to the flying cable of a tethered balloon, at least 20 ft. below the balloon. A battery to supply the lamps (6 amp. at 6 v.) must also be carried, though for restricted heights a transformer fed by a length of mains cable could possibly be used. In any case some means of switching the lamps on and off is needed, not only to reduce the drain on the battery, but also to be able to allow for any photo-electric cell current generated by moonlight or other external lights. If a remotely controlled switch presents difficulties, an automatic switch controlled by clockwork, or a heated bimetal system, can be used to switch the lamps on for, perhaps 5 sec. every 30 sec. The photo-electric cell current is carried by a pair of wires to a galvanometer on the ground. The wires can be quite light but should be very well insulated in view of the small current they carry, and the damp conditions in which they are used. The galvanometer should have a full-scale deflection of about 5 μ amp. and its resistance should be not more than a few hundred ohms. A mirror galvanometer is therefore necessary.

Results obtained.—Calibration was carried out at Cardington by mounting the fog-density indicator at the top of a 60-ft. tower and comparing its readings with those of a photo-electric visibility meter operating over a 150-yd. path at the same height. As expected, the photo-electric cell current was found to be inversely proportional to the visibility, the approximate relationship being:

Current $\times$ visibility $= 300\ \mu$ amp. yd.

For comparison, the following approximate figures may be quoted:

Current in clear air $= 0 \cdot 2\ \mu$ amp. or less
Extra current due to moonlight $= 0 \cdot 5\ \mu$ amp.
Extra current if instrument is mounted only 7 ft. above the ground $= 3\ \mu$ amp.

After calibration the instrument has been used for investigation of fog structure at Cardington, mounted on the cable of the barrage balloon used for "Balthum" ascents. It has been chiefly useful in finding the height of the base or top of a clearly defined layer of cloud or fog. Some indication is also given of the variation of visibility with height, but sampling errors are to be expected as most of the light reaching the photo-electric cells comes from the fog within about 50 cm. of them. It has not been used to give routine information for aviation, as originally envisaged, chiefly because of the difficulty of operating a large tethered balloon on an airfield.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

The Annual Report of the Director of the Meteorological Office, presented by the Meteorological Committee to the Secretary of State for Air, for the year April 1, 1955 to March 31, 1956.

This Report is an account of the year's activities of the Meteorological Office as the State Meteorological Service. It appears this year with a new cover of modern design, and the contents have been prepared largely as continuous narratives replacing the numerous brief paragraphs of earlier Reports. Illustrations showing some of the more interesting aspects of the work of the Meteorological Office are included for the first time.

Meteorological services have been provided for civil and military aviation, for shipping and directly for the general public by telephone, television, radio and through the Press, and indirectly by special forecasts for electricity and gas undertakings, farmers and River Board and Road Engineers. Information regarding climate at home and abroad has been supplied to meet many enquiries connected with industry, commerce, agriculture, public utilities and shipping. An interesting development was the completion, in collaboration with the General Post Office, of arrangements to provide in the London area an automatic dialling telephone service for the issue of forecasts to the public. The Report also records the installation, in London, of a radar storm-warning set, to test its usefulness for short-period but very precise forecasts of rainfall.

The Meteorological Research Programme again covered a very wide field. Increased effort and staff were devoted to the study of numerical forecasting—the process whereby forecast pressure maps are produced by calculation—and approval was obtained for the installation of an advanced type of electronic computor for this work and other problems involving long and complex calculations. Work continued on a long series of carefully controlled trials on the possibility of increasing rainfall by cloud seeding. In addition, the Meteorological Research Flight has continued its high-altitude research and much effort has been directed at the problems which result from the increasing heights at which aircraft now operate.

The Meteorological Office has continued to take a leading part in international meteorology, not only through the World Meteorological Organization, but by exchange with and secondment of staff to other countries. The Report includes financial and staff details, and indicates both the continuing shortage of scientific staff and the difficulties still produced by the high rate of turnover of Assistants.

Weather map, 4th edition.

The "Weather map" has been a Meteorological Office "best seller" ever since it was first published as a 5 in. × 6 in. paper-covered pamphlet at 4d. a copy forty years ago. It was rewritten in 1930 to take account of the great strides which had been made in synoptic meteorology during the intervening years, and some further alterations were made for the 3rd edition in 1939.

Changes both in practice and emphasis in weather forecasting have since become so pronounced that it has been necessary to rewrite large parts of the book for this latest edition. The causes of our most frequently experienced weather phenomena have been given greater attention than formerly; a new set of weather maps plotted in the up-to-date manner and showing typical pressure distributions has been included, and modern forecasting techniques are described.

This 4th edition of the "Weather map" is a reasonably comprehensive introduction to weather forecasting, as described by the new sub-title and on that account it should appeal to many whose curiosity about weather forecasting may have been stimulated by the daily presentation of weather maps on television screens, and to teachers and pupils in secondary schools.

M.O.593. *Meteorology for Mariners.*

Meteorology for Mariners has been prepared in the Marine Division of the Meteorological Office to meet the specific need of an up-to-date book on this subject for ships' officers.

It is a companion volume to *The Marine Observer's Handbook* and aims to present the elementary theory of modern meteorology and the basic climatology of the oceans in a straightforward manner for the benefit of seamen and to show how this knowledge can be used by ships' officers in the course of their duties. Included in the book is a section on Oceanography, as it is a subject allied to meteorology, and because it forms part of the syllabus for the Extra Master's

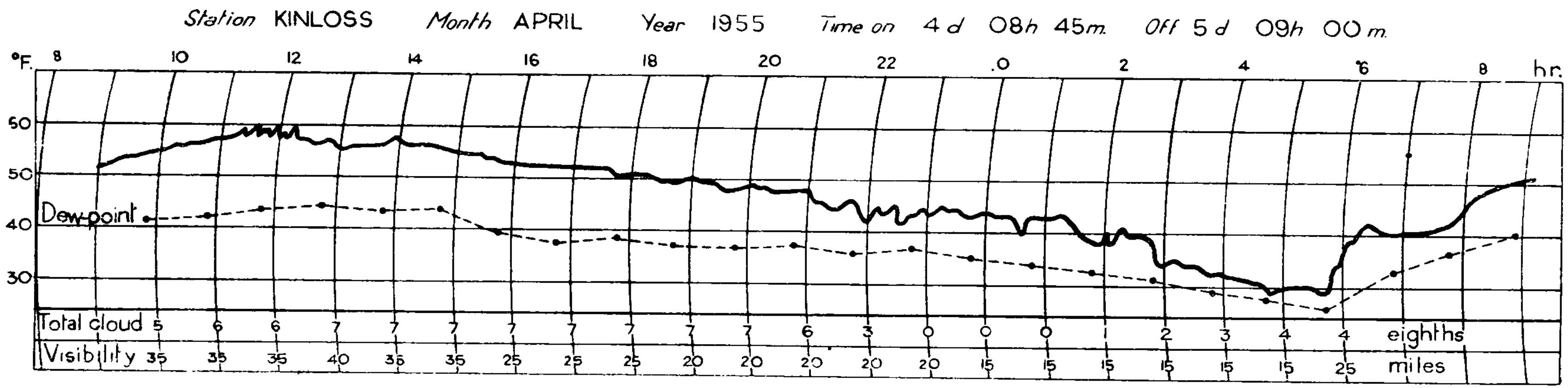


FIG. 1—THERMOGRAM SHOWING AMOUNT OF CLOUD AND VISIBILITY FOR KINLOSS, APRIL 4–5, 1953

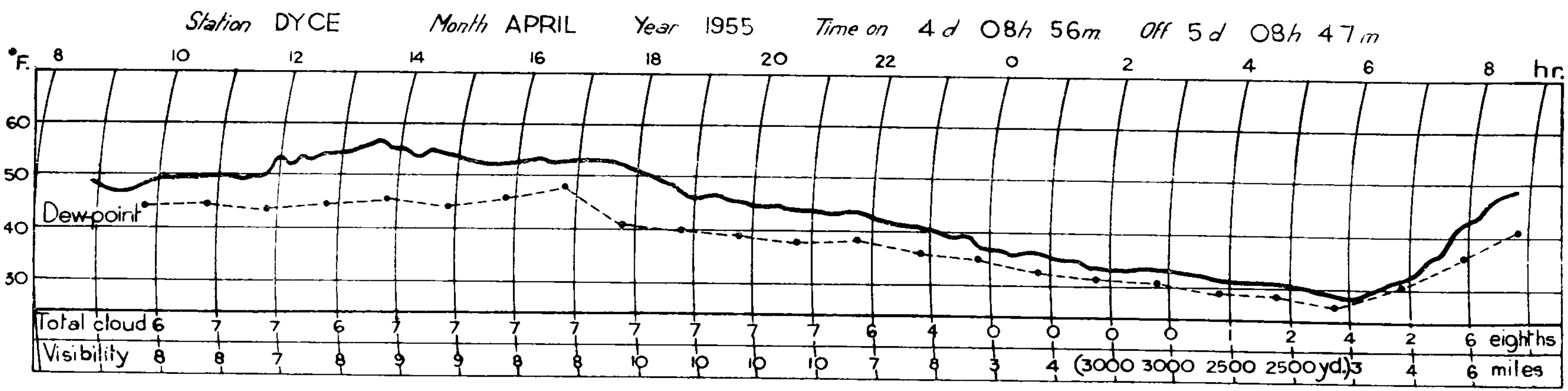


FIG. 2—THERMOGRAM SHOWING AMOUNT OF CLOUD AND VISIBILITY FOR DYCE, APRIL 4–5, 1953

Examination. All candidates for the Ministry of Transport and Civil Aviation masters' and mates' examinations will find the meteorological section of the syllabus covered in this book.

The book will be of value to yachtsmen and anyone interested in weather at sea as well as to the professional seaman.

NOTES AND NEWS

An example of freedom from fog, and an unexpected frost, at Kinloss and Dyce

On April 4, 1955, an occlusion passed Kinloss at 1200 G.M.T. and Dyce at 1400 G.M.T. At 1500 G.M.T. the temperature at Kinloss was 55°F., with a dew-point of 44°F., the gradient wind was 20 kt. from south-west and the surface wind 15 kt. Kinloss observed 3 oktas or less of low cloud and 7 oktas total cloud until 2000 G.M.T.; the cloud then began to break and had dispersed completely by 2300 G.M.T. The gradient wind slackened during the night to become 10 kt. by midnight, the surface wind falling calm.

With a dew-point of 44°F. at 1500 G.M.T. it might be expected that radiation would lead to fog formation and that thereafter temperature would fall only slowly. In fact the temperature at Kinloss fell unsteadily during the night, the minimum temperature being 28°F. (see Fig. 1). The dew-point remained fairly constant from 1700 to 2300 G.M.T. and then fell steadily to a minimum of 26°F. Saunders's investigations into night cooling under clear skies in southern England show a discontinuity in the rate of cooling which in early April occurs at about 2000 G.M.T., but no such discontinuity is apparent at Kinloss on this occasion, perhaps because of the cloud changes that were taking place. The lowest visibility reported was 15 miles.

At Dyce also the temperature fell progressively to a minimum of 28°F., and the dew-point fell fairly steadily from 1800 G.M.T. to reach a minumim of 26°F. (see Fig. 1). Visibility decreased to 3,000 yd. at 0200 G.M.T. and to a minimum of 2,500 yd. at 0400 G.M.T. In this case there is a suggestion of a Saunders's discontinuity at 1900 G.M.T. Mackenzie's formula for minimum temperatures at Dyce, $T = \frac{1}{2}(T_1 + D) - C$, where T_1 and D are the maximum temperature and the corresponding dew-point, respectively, and C a constant depending on wind and cloud, gives a minimum value of 36°F. for this night, assuming the wind to be calm and the sky free from cloud.

The hydrolapse at 1400 G.M.T. was 15·3 mg. per Kg., per mb. at Leuchars and 16·0 mg. per Kg., per mb. at Stornoway. Swinbank's diagrams[1], using these values of hydrolapse and a wind-shear value of 10 kt., give a forecast of no fog but apply to south-east and north-east England in October and November and might not be applicable to north Scotland in April. Briggs's method[2] gives a potential dew-point of 37°F. and 32°F. respectively for Leuchars and Stornoway. However, temperature fell to 28°F. at both Kinloss and Dyce without fog formation.

The north-east of Scotland is known to be comparatively free from radiation fog, largely because the atmosphere is clean and the air from the south-west is dried by subsidence. In the present case it seems likely that the absence of fog was due to an abnormally low number of condensation nuclei.

W. G. RITCHIE

REFERENCES

1. SWINBANK, W. C.; Prediction diagrams for radiation fog. *Prof. Notes, met. Off., London*, **6**, No. 100, 1949.

2. BRIGGS, J.; Notes on the temperature at which radiation fog forms. *Met. Mag., London*, **79**, 1950, p. 343.

Weather charts by radio

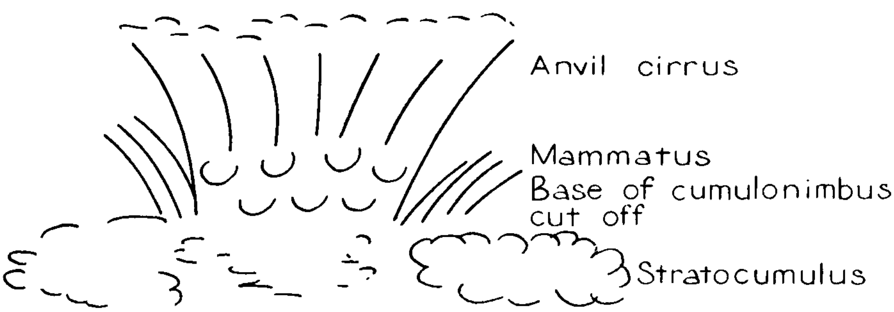
A Mufax Chart Recorder, for displaying facsimile-picture transmissions of weather charts, is now on exhibition in the Science Museum.

The recorder, which has been lent by the makers, Muirhead & Co. Ltd., reproduces a whole chart in thirty-five minutes or less depending on the speed setting, and, throughout the recording, the progressively growing chart is visible on a flat platen.

The exhibit can be shown in operation and will normally be used to record the transmissions broadcast from the Central Forecast Office at 1210 G.M.T. and 1650 G.M.T. The recorder will remain on exhibition for a period of about six months. Hours of opening:—Weekdays, 10 a.m. to 6 p.m.; Sundays, 2.30 to 6 p.m. Admission free.

Unusual cloud formation

The sketch and following notes have been received from Mr. W. J. Bruce.



"On Saturday August 25, 1956, at 1840 G.M.T. this cloud formation was seen at London Airport.

The cloud gave the appearance of 'mammatus' formed from anvil cirrus. The base of the cumulonimbus had been sheared off leaving the anvil top and stratification was rapidly taking place. At 1800 G.M.T. a filling depression was centred over northern England and an unstable westerly air stream covered the area. Showers, frequent at times, with local thunderstorms had occurred during the afternoon".

Funnel cloud off Ramsgate on August 5, 1956

We are indebted to Mr. R. T. Nicholas of 609 High Road, Tottenham, London, N.17, for the following description of the formation of a funnel cloud at the base of a cumulonimbus cloud off Ramsgate at 1210 G.M.T. on August 5, 1956.

"As I looked at the cloud (Fig. 1*a*) I saw a rounded bulge (Fig. 1*b*) appear at the base of it. The bulge developed quite quickly into a triangle as black and well defined as the main body above it. The triangle grew until it looked rather like a parsnip with the tail swinging to the right and then returning to the vertical (Fig. 1*c*). Suddenly the tail lengthened and, after swinging upwards towards the black cloud in a regular loop (Fig. 1*d*), darted away to the right (Fig. 1*e*). During this process the loop flattened out slightly

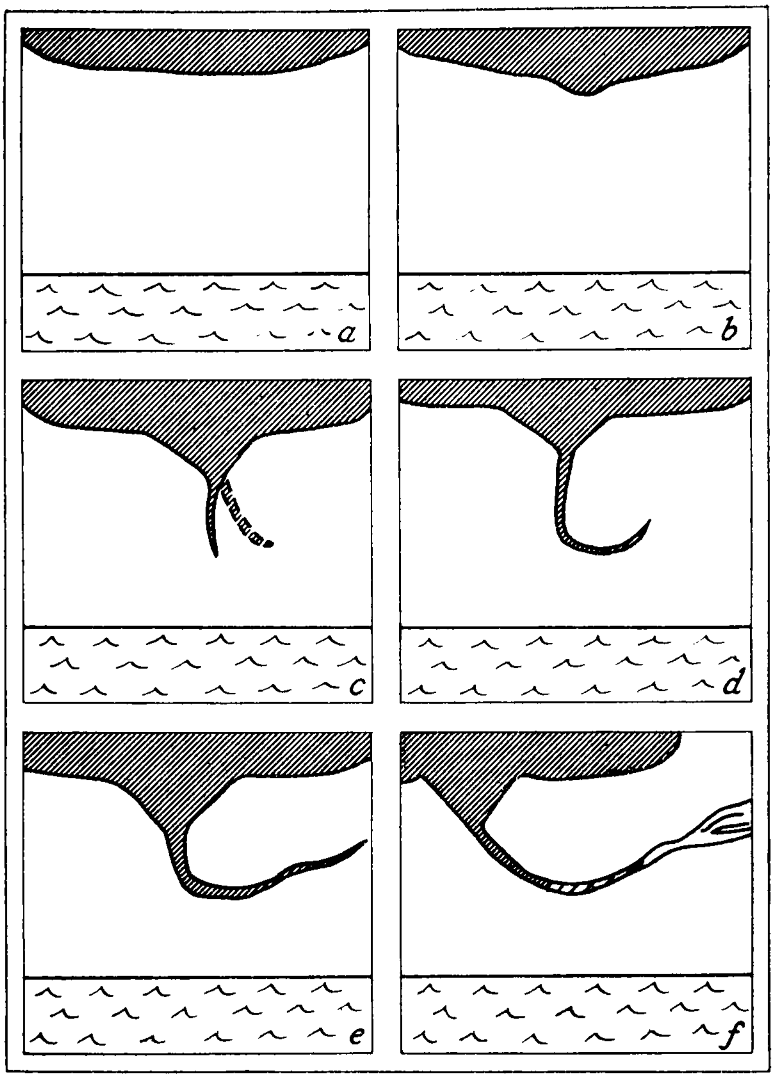


FIG. 1

and the tail lightened in colour from a grey to near transparency. The extreme end seemed to feather out like a frayed rope (Fig. 1*f*) and the tail flailed round for a short time. At about 1220 G.M.T., as the cloud began to move away in a westerly direction, the tail descended slightly but remained roughly horizontal."

On August 5, 1956 large cumulus and cumulonimbus clouds developed quickly over south-east England and thunderstorms occurred before midday. At 1200 G.M.T. an extensive polar depression was centred over south-west England. At about 1500 G.M.T. the value of the 1000–500-mb. thickness reached the minimum recorded for August during the five-year period 1949–53.

REVIEW

Introduction to dynamic meteorology. By H. F. Panofsky. 9 in. × 6 in., pp. viii + 243, *Illus.*, Pennsylvania State University, 1956. Price: $3.50.

Since the end of the Second World War a great deal of progress has been made in numerical forecasting. This has been both due to the advent of high-speed electronic computing machines and to a greater understanding of the mathematics and physics of dynamic meteorology. Numerous papers have been published on numerical forecasting and associated topics, and it is therefore very gratifying to find a textbook which contains an introduction to this subject.

This book is intended for two groups of people, forecasters who are well acquainted with problems of practical meteorology and who would like to review dynamic meteorology with special emphasis on the physical basis of numerical forecasting, and college students. It is very well written for that purpose and it assumes no prior knowledge of mathematics and physics beyond Intermediate B.Sc. It is therefore rather elementary for the specialists; indeed some college students will find the first chapter superfluous. However, a large amount of material is collected together in a convenient form for reference, and it may well be that even specialists in this field would find the book useful for reference purposes.

The book is divided into seven chapters and there are three appendices. There is also a very adequate index. Derivations are generally not given in detail and this makes for easy reading. Nevertheless, derivations of the vector form of the equation of motion and of the equation of continuity are given in one of the appendices. Diagrams are frequently used to illustrate points which the beginner may find difficult. The author does give wherever possible a physical interpretation of the mathematics and this is another reason why the non-specialist will find this book easy to understand.

The first chapter is intended only for readers whose knowledge of mathematics and physics is elementary. It explains many basic mathematical concepts, such as derivatives, integrals and vector notation. It also explains some basic meteorological concepts such as divergence, circulation and vorticity.

Although many people who read the book will omit Chapter 1, I think this chapter makes the book of value. This is primarily a book intended for the beginner, and a chapter on fundamental mathematical and physical ideas makes it very easy for the beginner in dynamical meteorology to understand the ideas which follow.

The two chapters dealing with the fundamental meteorological equations and simple manipulations of those equations are clearly set out. The derivations of the vector equation of motion and of the equation of continuity are not given in these chapters but are given in one of the appendices. A summary of the seven scalar equations in hydrodynamic form is given at the end of Chapter 2 and this is a useful feature for reference purposes. The Sutcliffe development ideas are explained, but the development equation is not derived. Constant absolute-vorticity trajectories and the Rossby wave formula are also dealt with.

The use of perturbation theory to obtain approximate solutions to non-linear equations is dealt with adequately. The properties of some important waves derived by perturbation theory are given. The absence of mathematical derivations does make this chapter easily readable; the results quoted can be derived quite straightforwardly if the reader so desires.

The chapter on dynamic forecasting is excellent. The first part of this chapter is devoted to the various techniques used in work on numerical prediction, while the second part describes the use of these techniques in specific models. The final two chapters are on turbulence and the general circulation.

I recommend this book as being very useful to the beginner in numerical forecasting and as being possibly useful to the more advanced worker in the field for reference purposes. It should be remembered that it is an elementary treatise on the subject, but that is what is intended and I think it very worth while.

F. H. BUSHBY

HONOUR

Dr. R. C. Sutcliffe, Deputy Director (Research) of the Meteorological Office, was elected a Fellow of the Royal Society on March 21, 1957.

METEOROLOGICAL OFFICE NEWS

Academic successes.—In addition to the list published in the March number the following members have also been successful in their examinations:

General Certificate of Education (Advanced Level): J. B. McNeill and A. B. Turner.

Meteorological "THUM" ascents.—On February 27, 1957 the 2,000th routine THUM ascent was made by Spitfire aircraft flown by the civilian contractors Messrs. Short and Harland. This daily ascent, which is normally performed over Worcester, was first undertaken by Messrs. Short and Harland on May 1, 1951. Spitfire aircraft supplied by the Royal Air Force Home Command are used for these flights. Despite the fact that this type of aircraft dates from the Second World War, the ascents have been made with very high regularity. A most satisfactory standard of meteorological observing has been maintained throughout, very largely as a result of the enthusiasm of Flt Lt J. Formby, R.A.F.R.O., who has been associated with the flight from the start. The Spitfire aircraft are shortly to be replaced by twin-engined Mosquito aircraft.

Ocean Weather Ships.—The following are extracts from the Radio Observer's report of Voyage 73 of the *Weather Watcher:*

"*Communications.*—While on station (Ocean Station 'India') difficulty was experienced on several occasions in establishing communications with Dunstable during the change from daylight to dark, although changes of frequency were made to try to overcome the difficulties. Long periods of squalls of rain, hail, snow and sleet did not help matters. One period of complete radio fadeout was experienced on January 21–22 between 1600 and 0300 approximately. As often happens this fadeout coincided with an unusually brilliant display of aurora.

Aircraft.—A total of 188 aircraft contacted the ship during the period on station. Meteorological information was provided for 178 of these and 173 radar fixes were given. Included in the above was a Canberra aircraft equipped only with VH/F; besides giving this aircraft the usual Weather Ship services, i.e. upper winds, radar fixes, continuous M/F beacon operation, etc. the ship acted as a link in relaying from Iceland meteorological information in that area including landing forecasts, etc. The pilot expressed his thanks for the ship's help and co-operation."

R.A.F.V.R. (Meteorological Section).—*Awards.*—It was announced in Air Ministry Orders dated February 13, 1957 that the undermentioned officers in the Meteorological Section of the Royal Air Force Volunteer Reserve had been granted the Air Efficiency Award. We offer them our congratulations.

Flight Lieutenants

E. Atkins	M. J. Merrick
H. W. Bitton	J. J. Parker
E. Chambers	A. A. Penny
C. G. Hawes	D. C. Pool
R. E. Hearn	R. S. Sowter
D. J. Hinds	D. V. Tamblin
F. M. Laughton	J. W. Thomas
A. Lonsdale	G. S. Wallace-Williams

Flying Officer W. J. R. Price.

In addition Flt Lt D. J. Hinds has been awarded a clasp to the Award.

WEATHER OF FEBRUARY 1957

The "Icelandic" depression was again much deeper than normal but unlike the preceding months of this winter the lowest monthly mean pressure in February (990 mb. at 55°N., 30°W.) was much displaced, actually well to the south-east of the normal position near Cape Farewell. In consequence, pressures were 14 mb. below normal over a considerable area (50°–55°N., 20°–30°W.). This situation gave a continuance of the mild, prevailing south-westerly winds over Europe but in many other parts of the northern hemisphere there was a radical change from the weather of the earlier part of the winter.

The Siberian high, which became weakened in January, recovered to well above normal intensity and the great extension of this system over the Arctic which had been a feature of December also reappeared in February. Pressures were 17 mb. or more above normal over much of northern and north-eastern Siberia, where the highest monthly mean pressure was about 1044 mb.

Mean temperatures in Europe for February were almost everywhere above normal, the excesses being greatest (3°–4°C.) in France and central Europe, least in Britain and northern Scandinavia, where a few stations on the north-west fringe were very slightly below normal. Unlike December and January, the month was less cold than normal in the Mediterranean and over most of the United States and eastern Canada. The lowest surface temperatures in February 1957 were over a wide area of north-east Asia, where the month was colder than average (greatest known anomaly −12°C.).

The month gave much above normal precipitation in many areas of great extent: the Plains States and western Gulf of Mexico, most of north-west Canada east of the Rockies, northern Iceland and east Greenland, also Labrador, all Europe between the Alps and Lapland, also northern Egypt and Mesopotamia. The whole Mediterranean, however, had a dry month, also most of India.

In the British Isles the first half of the month was changeable but mild with considerable rain at times. The third week was rather cold with light northerly winds, but weather became changeable again from the 21st to 24th. The last three or four days of the month were sunny and mild.

During the first few days winds were mainly south-westerly and weather unusually mild with occasional rain in most districts; afternoon temperatures exceeded 50°F. from the south coast to south-west Scotland and reached 57°F. at Mildenhall on the 1st and 4th. A vigorous depression skirted the western coasts of Ireland and Scotland on the 4th and 5th giving considerable rain and widespread gales; gusts of over 90 kt. were recorded in the Hebrides, while in western Ireland extensive damage occurred in Galway as the River Corrib overflowed its banks and flood-water in the city centre was 4–6 ft. deep. On the 7th a narrow warm sector moved across the country giving heavy rain in the west and south-west; many stations in Breconshire and Monmouthshire recorded more than 2 in. in 24 hr. A similar system on the 11th brought a renewal of heavy rain in southern England and by this time rainfall at many places had exceeded the February normal. There was considerable flooding in the Thames valley. On the 14th winds veered to the north over the British Isles and there were frequent snow showers in Scotland and northern England with keen or hard frost at night, temperature falling below 24°F, at many places. During the next few days snow showers extended as far south as the Midlands. At Leicester there was an unusual fall over a small area on the night of the 18th–19th as a small polar depression near the Scilly Isles moved eastwards; snow lay over 8 in. deep in and to the east of the city and 4–8 in. deep over most of Leicestershire, but ground remained largely clear of any but a light covering of snow in the surrounding counties. On the 21st mild south-westerly winds brought rain to southern England and two days later mild Atlantic air spread to the whole country preceded by widespread rain and some snow. By the 25th temperatures in England and Wales again exceeded 50°F. at many places and 57°F. was reached at Hurn. There was a general rise of pressure over the British Isles on the 26th and southerly winds spread to the whole country giving generally fine sunny weather until the end of the month.

It was the wettest February in England and Wales since 1951. More than 150 per cent. of the average rainfall was recorded generally south-east of a line Bristol Channel to the Wash; more than twice the average fell over most of Kent and Sussex. Temperature was about average in Scotland, but well above the average in England and Wales. At Kew it was the first February since 1946 with mean temperature more than the 1921–50 average. The mild weather has brought most crops well forward and the premature bud burst on some top and bush fruits is causing concern. A spell of hard weather during the next month would cause a serious set-back. Ground conditions are mostly very wet and even waterlogged in places: ground must dry out before any real progress can be made with spring ploughing and cultivating.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	59	3	+1·9	153	+3	118
Scotland	57	9	+0·5	103	−1	125
Northern Ireland ...	54	20	−0·3	92	+1	148

RAINFALL OF FEBRUARY 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	3·11	186	*Glam.*	Cardiff, Penylan ...	5·31	181
Kent	Dover	4·54	236	*Pemb.*	Tenby	4·30	148
,,	Edenbridge, Falconhurst	5·14	233	*Radnor*	Tyrmynydd	7·50	143
Sussex	Compton, Compton Ho.	6·10	231	*Mont.*	Lake Vyrnwy	5·36	118
,,	Worthing, Beach Ho. Pk.	4·26	215	*Mer.*	Blaenau Festiniog ...	5·77	70
Hants.	St. Catherine's L'thouse	3·78	186	,,	Aberdovey	3·21	107
,,	Southampton (East Pk.)	4·03	175	*Carn.*	Llandudno	2·21	113
,,	South Farnborough ...	3·52	187	*Angl.*	Llanerchymedd ...	4·16	165
Herts.	Harpenden, Rothamsted	3·04	159	*I. Man*	Douglas, Borough Cem.	4·26	134
Bucks.	Slough, Upton	2·89	170	*Wigtown*	Newton Stewart ...	2·97	79
Oxford	Oxford, Radcliffe ...	2·83	173	*Dumf.*	Dumfries, Crichton R.I.	4·61	141
N'hants.	Wellingboro' Swanspool	2·20	137	,,	Eskdalemuir Obsy. ...	5·32	107
Essex	Southend, W. W. ...	1·95	144	*Roxb.*	Crailing...	2·48	134
Suffolk	Felixstowe	2·05	163	*Peebles*	Stobo Castle	3·36	122
,,	Lowestoft Sec. School...	2·24	160	*Berwick*	Marchmont House ...	3·23	155
,,	Bury St. Ed., Westley H.	2·27	151	*E. Loth.*	North Berwick Gas Wks.	3·16	203
Norfolk	Sandringham Ho. Gdns.	3·38	205	*Midl'n.*	Edinburgh, Blackf'd. H.	2·31	139
Wilts.	Aldbourne	4·21	186	*Lanark*	Hamilton W. W., T'nhill	2·80	97
Dorset	Creech Grange... ...	4·37	153	*Ayr*	Prestwick	2·13	89
,,	Beaminster, East St. ...	5·35	177	,,	Glen Afton, Ayr San. ...	5·59	127
Devon	Teignmouth, Den Gdns.	5·71	215	*Renfrew*	Greenock, Prospect Hill	4·30	81
,,	Ilfracombe	5·26	190	*Bute*	Rothesay, Ardencraig ...	3·56	89
,,	Princetown	12·21	162	*Argyll*	Morven, Drimnin ...	4·49	85
Cornwall	Bude	3·71	148	,,	Poltalloch	4·11	95
,,	Penzance	5·35	160	,,	Inveraray Castle ...	4·58	68
,,	St. Austell	5·94	155	,,	Islay, Eallabus	3·60	86
,,	Scilly, Tresco Abbey ...	3·97	142	,,	Tiree	3·21	93
Somerset	Taunton	3·99	192	*Kinross*	Loch Leven Sluice ...	3·53	125
Glos.	Cirencester	4·07	174	*Fife*	Leuchars Airfield ...	3·37	193
Salop	Church Stretton ...	2·71	116	*Perth*	Loch Dhu	6·85	92
,,	Shrewsbury, Monkmore	1·82	116	,,	Crieff, Strathearn Hyd.	3·92	111
Worcs.	Malvern, Free Library...	2·78	154	,,	Pitlochry, Fincastle ...	3·56	121
Warwick	Birmingham, Edgbaston	2·93	158	*Angus*	Montrose Hospital ...	2·57	140
Leics.	Thornton Reservoir ...	2·64	158	*Aberd.*	Braemar	2·93	103
Lincs.	Boston, Skirbeck ...	3·28	224	,,	Dyce, Craibstone ...	2·26	99
,,	Skegness, Marine Gdns.	2·81	184	,,	New Deer School House	1·65	77
Notts.	Mansfield, Carr Bank ...	2·73	141	*Moray*	Gordon Castle	1·46	76
Derby	Buxton, Terrace Slopes	3·58	95	*Nairn*	Nairn Achareidh ...	1·52	94
Ches.	Bidston Observatory ...	1·74	104	*Inverness*	Loch Ness, Garthbeg ...	3·62	105
,,	Manchester, Ringway...	1·89	100	,,	Loch Hourn, Kinl'hourn	8·09	81
Lancs.	Stonyhurst College ...	2·98	89	,,	Fort William, Teviot ...	5·46	73
,,	Squires Gate	2·52	119	,,	Skye, Broadford ...	0·00	000
Yorks.	Wakefield, Clarence Pk.	2·33	136	,,	Skye, Duntulm... ...	3·79	82
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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

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DR. R. C. SUTCLIFFE, F.R.S.

By SIR GRAHAM SUTTON, C.B.E., D.Sc., F.R.S.

Dr. R. C. Sutcliffe, Deputy Director (Research) of the Meteorological Office, was elected a Fellow of the Royal Society on March 21.

This recognition of Dr. Sutcliffe's outstanding position in synoptic research is the culminating point of a career wholly devoted to professional meteorology. Dr. Sutcliffe joined the Meteorological Office in 1927, and quickly made his way to the fore as a leading forecaster. His services with Bomber Command and the 2nd Tactical Air Force during the war enhanced his reputation as an exceptionally able practical meteorologist.

Although he had published some noteworthy papers and a well-known text book, "Meteorology for aviators", before the war, it was when active operations had ceased, and he had taken up the post of Assistant Director (Forecasting Research), that Dr. Sutcliffe's gifts as a mathematician began to make his reputation in the field of synoptic research. In 1947 he published his best-known paper "A contribution to the theory of development". This paper, and its successor, "The theory and use of upper-air thickness patterns in forecasting", written jointly with Dr. Forsdyke, have had a considerable influence on meteorological thinking, especially in the rapidly developing field of numerical forecasting, much of which, to quote a well known American worker in this field, is "in the spirit of Sutcliffe's work". These papers were quickly followed by other notable contributions, but in recent years Dr. Sutcliffe has turned his attention more to the problems of the largest-scale movements of the atmosphere, especially the general circulation. It is the hope and expectation of meteorologists that his work in this field, that of dynamical climatology, will also prove significant.

The F.R.S. is usually awarded for individual research, but it also reflects, in some measure, the esteem in which a particular study is held in the world of science generally. Dr. Sutcliffe's achievements have been almost entirely in the field of synoptic meteorology and it is, I think, not unreasonable to regard his election as evidence that the forecasting of weather is now generally regarded as a true science, taxing the utmost skill of the mathematician and the physicist, and thus worthy to be ranked with any other branch of geophysics.

The Meteorological Office now has a strong and well-equipped research side, and with the direction of the work in the hands of one who so happily combines great technical ability with a lively imagination and a long record of practical experience, the further outlook is good.

METEOROLOGICAL OFFICE DISCUSSION

Synoptic meteorology of the polar regions

The discussion, which was held at the Royal Society of Arts on Monday, December 17, 1956, was opened by Mr. R. A. Hamilton and Mr. H. H. Lamb.

Mr. Hamilton introduced the subject with a description of the salient geographical characteristics of the northern polar regions and main features of the annual heat budget within them. Mr. Lamb dealt mainly with the Antarctic and with comparisons between Arctic and Antarctic.

The total solar radiation reaching the outer atmosphere over the equator in any year is about two and a half times that over the pole. Over the equator the quantity varies only 5 per cent. in different months. Over the pole no radiation is received in the long winter night, whereas at the summer solstice, with 24 hr. of daylight, the daily quantity somewhat exceeds that for anywhere else and is actually greatest of all at the South Pole about the December solstice. The amount of energy actually received to heat the earth's surface depends on absorption, reflection, re-radiation and scattering during transmission through the atmosphere, which are particularly affected by cloudiness, and finally depends upon the characteristics of the surface itself. The albedo (reflection coefficient) of snow is very great.

The over-all difference of incident radiation between equator and pole is greatest about the equinoxes, but in the northern hemisphere the greatest meridional contrast of effective heating occurs in winter when the high-albedo snow surface acquires a great extent over the continents outside the region of polar night.

Meteorological data available for study of the Arctic pack-ice region and of the Greenland ice sheet are confined to expedition data starting about 1888–90 with Nansen's expeditions across Greenland and in the s.s. *Fram* drifting in the polar pack. Interpretation[1, 2] is complicated by significant warming of the Arctic, particularly between 1920 and 1938. Only since 1954 have permanent stations been established on the ice, actually by the Russians; interception of their synoptic reports has so far proved difficult. There is a useful network of stations on islands and around the Greenland coast.

The main channel for advection of warm air and warm ocean water and for the escape of drift ice is between Greenland and Norway. High mountains largely insulate the polar basin from the Pacific. Cold air has several preferred outlets.

Depressions penetrate the Arctic most frequently from the Atlantic. The further part of the polar basin is least disturbed. This is where the ice is most permanent and where anticyclonic conditions are relatively frequent. Extremes of surface pressure so far observed over the pack-ice, range from about 960 to 1060 mb.

Over the ice there is nearly always a temperature inversion at the surface or in the lowest 100–200 m. In summer, surface-air temperature is mainly about 0°C. but occasionally rises two or three degrees above, precipitation often falling as rain, leaving pools of water lying about on the ice-floes. In winter the lowest air temperatures reach −40° to −50°C. over the pack-ice, −60°C. or below in Greenland and Siberia.

Strong winds are rare over the pack-ice in the polar basin; gales occur perhaps once a year near the North Pole.[3] Greenland is most important as a 2,000 to 3,000-m. high barrier in the atmospheric circulation. Other complications are introduced by the very high frequency of a katabatic surface wind system over all the sloping parts of the inland ice and by the strong topographical influences in the coastal strip where the regular observing stations are.

It is impossible to reduce pressures observed at expedition stations on the ice-cap to sea level, because no reasonable temperature can be assigned to the missing air column and because accurate determination of station height is wellnigh impossible. There is a need for the use of 700-mb. charts for tracking winds and weather systems over Greenland.

Antarctica is a continent of estimated area about five and a half to six million square miles, much larger than Europe or Australia, several times larger than the area of permanent ice in the Arctic Ocean and about seven times the size of Greenland. With a probable mean height of 2,500 m., Antarctica is also the most elevated continent in the world. Further, Antarctica must differ from Greenland in having much vaster extents of almost level ice, the high plateau and the shelf-ice near sea level. Another difference in the Antarctic is the absence of oceanic advection of any great meridional currents of warm water equivalent to the Gulf Stream.

Prevailing mean-sea-level pressures in the Antarctic and sub-Antarctic are 20–25 mb. lower than in the corresponding parts of the northern hemisphere. Extreme mean-sea-level pressures so far observed in Antarctica are 927 and 1035 mb. There is no corresponding difference in the intensities of the sub-tropical, high-pressure systems of northern and southern hemispheres. Thus, the prevailing westerlies of the Southern Ocean are both more prevalent and on average stronger than their northern counterparts.

Former theoretical ideas accorded a permanent existence to the climatological mean pattern of brave west winds, the sub-Antarctic depression belt, polar easterlies and the ice-cap anticyclone. These have proved fallacious. Depressions do occasionally wander on unusual tracks and do sometimes penetrate well south over Antarctica. Two centres below 950 mb. passed south of Admiral Byrd in 80°S. on the Ross Ice Barrier during the 1934 winter. Pressures down to 950 mb. occur over the Southern Ocean even in summer, and centres of 960 mb. occasionally have an extensive central region with light winds.

"Dumb-bell" rotations are common near the fringe of Antarctica, when old decaying depression centres and their occlusions are swung westwards by the circulation around more vigorous cyclonic systems over the ocean to the north. This appears to be specially common in the Ross Sea and the occlusions are liable to pass over the sector of Antarctica between 100 and 170°E. These sequences appear to be the real mechanism of the repeated pressure oscillations

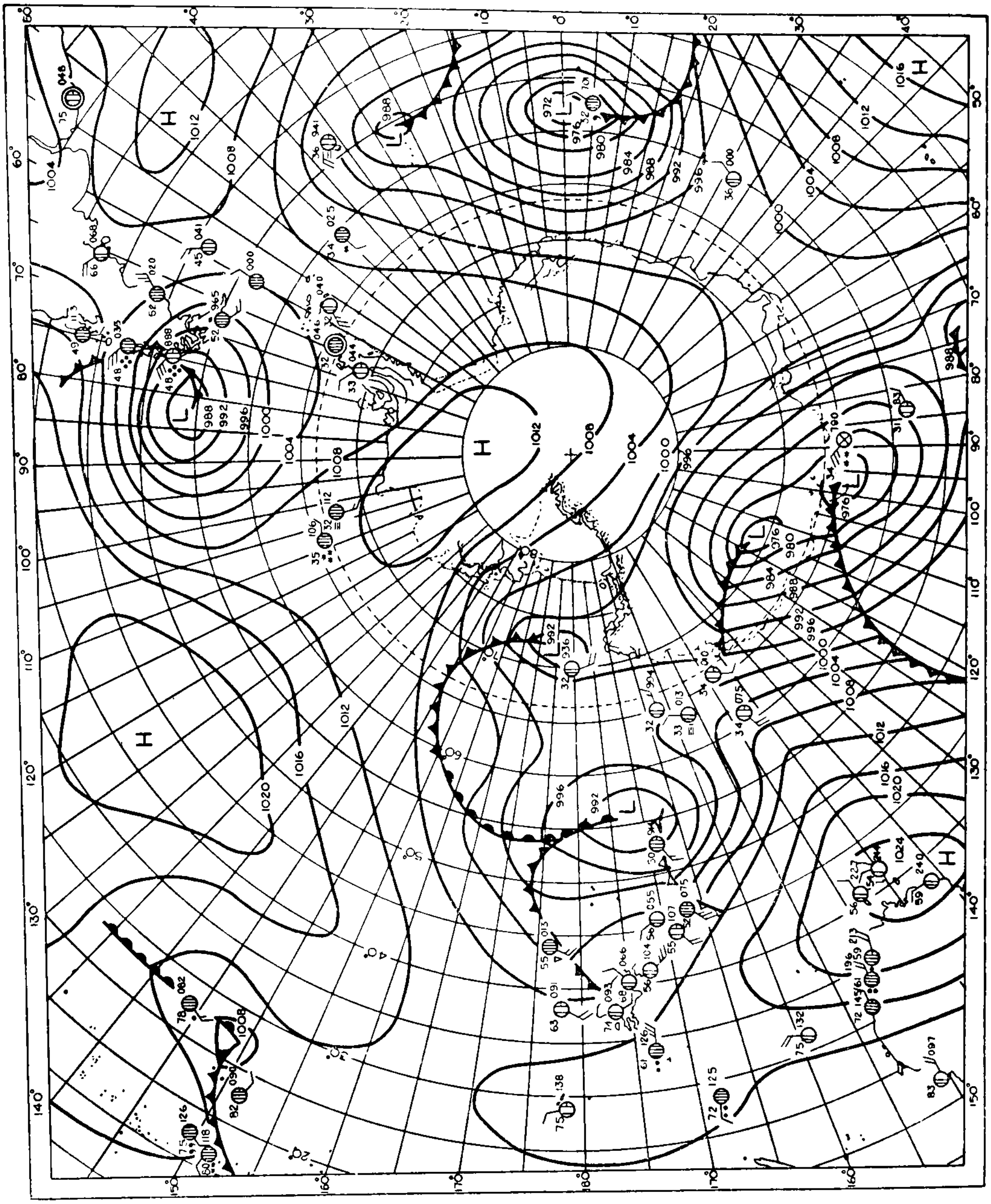

FIG. I—SYNOPTIC CHART FOR 0001 G.M.T., JANUARY 4, 1947

(After the chart in "Naval Weather Service Circular No. 13/51—Synoptic weather sequences for the southern oceans 1946–47" published in 1951.)

passing east to west and north-west across the Ross Sea, which Simpson[4] considered to be surges of a permanent Antarctic anticyclone radiating from the point 80°S., 120°W. Anticyclones are sometimes present over Antarctica for months on end, but at other times there is no room for any anticyclone between the surrounding lows. Occasionally, too, the high is pushed right out over the sea ice; but it is now clear that positions in the heart of east Antarctica near 80°S., 60°E., preponderate.

The convention generally adopted in Antarctic analysis as over Greenland at present is to extend mean-sea-level isobars over the ice-cap. There is some justification in that most depressions and anticyclones affecting Antarctica have circulations developed at least up to ice-cap level and winds on the plateau, when these are known, bear some reasonable relation to the isobars; but pressures observed on the plateau could not be formally reduced to sea level. Mean-sea-level pressures in Antarctic anticyclones are never very high, as shown by observations typically about 1000 to 1010 mb. when the systems come out over the coastal bases. All pressures over 1025 mb. so far observed in Antarctica have been at the outer coast in blocking anticyclones temporarily thrusting south from the subtropical belt. Linkages with meridional ridges from the subtropical belt seem to be the mechanism of renewal of the Antarctic continental anticyclone after periods without one. Fig. 1 shows this happening in the Pacific sector, the only sector where it is believed to be common. These pressure waves pass into Antarctica over Simpson's point, 80°S., 120°W.

The seasonal pressure variation in the Ross Sea sector of Antarctica, including the furthest south stations near 80°S., may be described as anti-monsoonal, pressure being highest in summer and lowest in late winter, June–October. This resembles the seasonal trend between south Greenland and the Barents Sea near the Atlantic depression track, where pressures are lowest in January. In the sub-Antarctic and the Antarctic fringe, especially on the coast between Grahamland and 140°E., average pressure has maxima in midsummer and midwinter, but shares the regular and remarkably low minimum of October on the Ross Ice Barrier.

There is no evidence of much climatic variation within the past 50 yr. in the Antarctic, but individual good and bad years occur as in the Arctic. Long spells of given weather type, sometimes of anomalous character, are a feature of both polar regions. Prolonged quiet or anticyclonic conditions, extending beyond the coast, must encourage increased production of sea ice in the sector affected.

The geographical distribution of gale frequencies indicates broad maxima over the open oceans where cyclonic activity is commonest and narrower concentrations associated with intense gales, commonly reaching force 12, where appropriate topographical effects operate[5]. The topographical cases include an important class of so-called frontal funnel effect gales, in which fast moving cold air is constrained to flow in a narrow channel between a mountainous coast and an approaching warm-type front. Such gales can easily be lethal to parties near mountainous sections of the coasts of Greenland and Antarctica; more open exposures, as on the Ross Ice Barrier well away from the mountains, are often safer. Fig. 2 illustrates the effect near Cape Farewell at the south tip of Greenland. Gales and strong winds constitute a greater hazard to expeditions than the low temperatures which can be more easily guarded against. Strong winds in polar environments generally reduce or destroy the surface inversion and raise the surface temperature, though unpleasantly low temperatures can occur with winds of gale force. Blizzards accompany any winds of force 5 or more where loose snow surfaces exist.

Surface-air temperatures in the interior of Antarctica probably fall to extremes of −60° to −70°C. in most winters, figures about equal to the

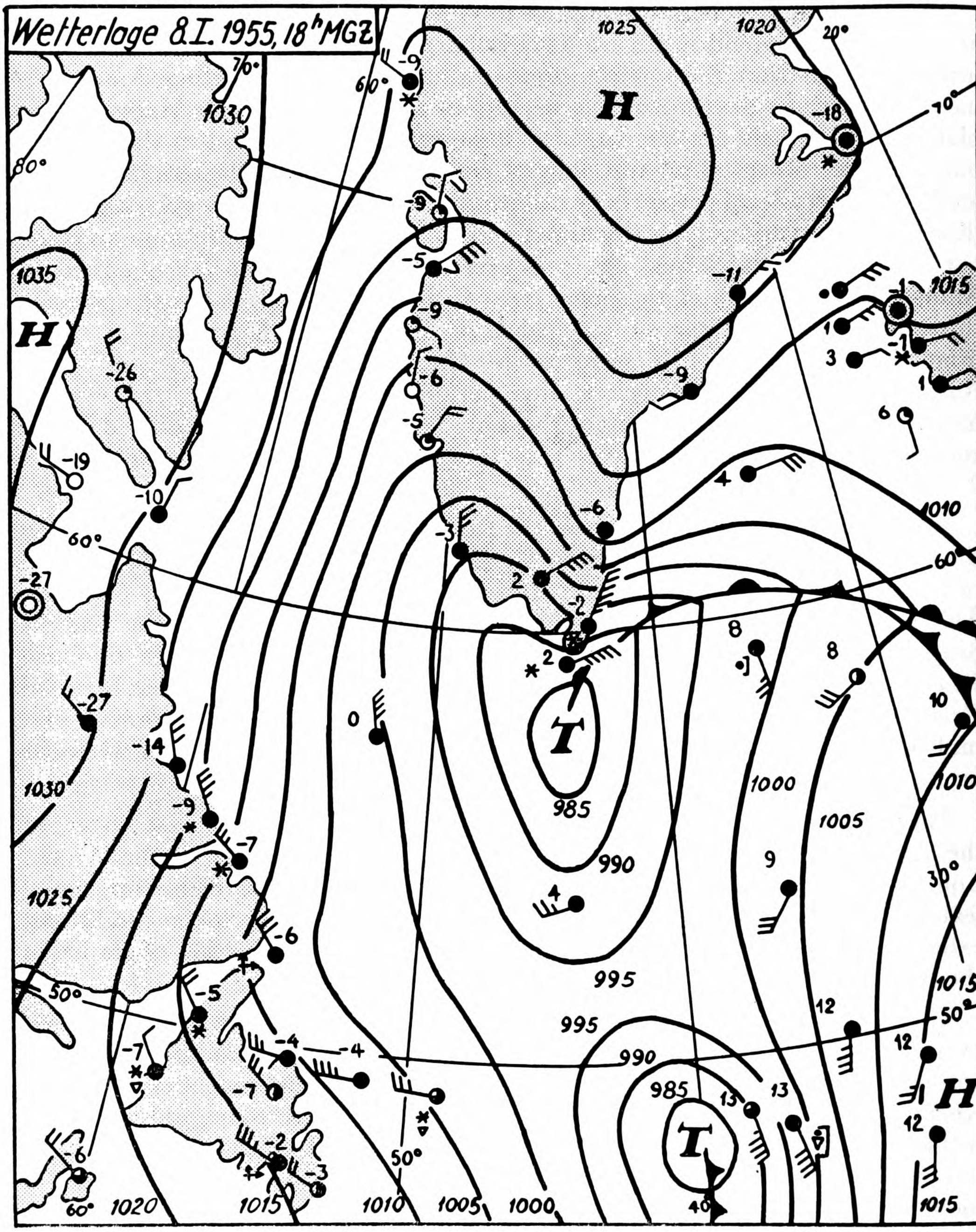

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FIG. 2—"FRONTAL FUNNEL" GALES BETWEEN THE MOUNTAINS OF SOUTH GREENLAND AND AN APPROACHING OCCLUSION

(After Klima und Wetter der Fischereigebiete West-und Südgrönland)

absolute extreme minima in Greenland, the Yukon and north-east Siberia. Maximum summer temperatures in Antarctica are about 0°C. near the coast and −5° to −15°C. at different heights on the inland ice. Points on the coast of Grahamland near open water and where föhn effects operate, as in south-west Greenland, occasionally record +10° to +12°C. at any time of year.

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CUMULONIMBUS MAMMATUS

This photograph was taken at 1830 G.M.T., August 25, 1956, from Hayes, Middlesex. The cloud was over Southall, Middlesex. The evening was one of moderate to heavy showers with local thunderstorms.

Reproduced by courtesy of C. B. Wilberforce

ALTOCUMULUS WITH RIPPLES IN TWO DIRECTIONS AT RIGHT ANGLES

This photograph was taken looking south-west from Harrow at 1830 G.M.T. on September 12, 1956. The cloud was at an estimated height of 12,000 ft. and so far as could be seen the two sets of ripples were at the same height. The 1500 G.M.T. synoptic chart showed a warm front from north to south over western England and a ridge of high pressure over eastern England. It appears likely that the ripples, vertical in the photograph, in a south-west–north-east direction, were formed first as they are broken in places by the other set.

C. B. WILBERFORCE

Although surface inversions are the general rule over the polar ice, there is probably nowhere where an adiabatic lapse rate from the surface up to great heights cannot sometimes be found: such cases appear in 4 per cent. of the available ascents in Arctic and Antarctic. They are probably connected with cold cyclones[6, 7].

Preliminary impressions of the upper westerlies in the southern hemisphere[8] show that there are no such large-amplitude semi-permanent troughs and ridges as in the northern hemisphere. The main trough in latitudes south of 40°S. is in the Indian Ocean sector and the main warm ridge seems to be in the western Pacific where the Antarctic coast is well south of 70°S. Both features appear thermal in origin; they accord with the remarkable glaciation of the islands in 50°–55°S. between Bouvet Island, 3°E., and Heard Island, 73°E. South Georgia, 36°W., is less heavily glaciated. The less hilly Macquarie Island, 54°S., 159°E., loses all its snow in summer. Between Mauritius, 20°S., and Kerguelen, 49°S., in the southern Indian Ocean one finds the whole range of climates from tropical to ice-age. The corresponding belt of upper winds has a mean annual strength of about 50 kt. at 500 mb. and is surely the broadest stream of such strength in the world.

In the northern hemisphere when the zonal index at 500 mb., about 55°N., exceeds 23 kt. over a wide sector the flow generally breaks down into large-amplitude waves leading to stationary blocking patterns. Over the Southern Ocean, in spite of much stronger mean zonal flow any great meridional ridges which form are usually quickly severed by a renewal of the westerlies.

Prof. Gordon Manley wondered if the change in frequency of gales at Jan Mayen could be due to the changed position of the observing station since the war. Mr. Lamb pointed out in reply that the frequency had decreased substantially in the area as far as Spitsbergen where the effects of changes of observing site had been eliminated and this appeared also from the marine data. Prof. Manley then remarked that South Georgia was much more heavily glaciated, with a specially low *firn* line, at its western end than elsewhere: there might be a marked diminution of precipitation from west to east. Heard Island is more uniformly glaciated, and this might be due to its shape being rounder than South Georgia. Mr. Lamb replied that the information about the heavier glaciation of the western end of South Georgia was particularly interesting, because without knowledge of this the difference in glaciation between South Georgia and Heard Island appeared greater than could be fully explained by their relative positions in the zone of strong thermal gradient; however Heard Island is believed to be more or less completely glaciated and the round contour may be chiefly due to the ice. Professor Manley further asked whether the opening up of water channels amongst the Arctic pack-ice could affect the general atmospheric circulation; might there be some critical point beyond which more open water would lead to great changes. Mr. Lamb thought that the heat exchange between the atmosphere and the Arctic Ocean would show a continuous, gradual change if the amount of open water amongst the ice were increased.

Mr. A. Elliot asked about the strength of the katabatic winds over Greenland and how they modified the general flow of the atmosphere. Mr. Hamilton replied that katabatic flow was dominant over most of the inland ice, its persistence and strength increased where the downward slope of the ice increased and in certain coastal fjords and valleys the funnelling of this katabatic flow produced violent gales, sometimes exceeding 100 kt. These gales were often characteristically localized; in side valleys only a short distance out of the main channel only light airs might be found. There were also occasional lulls at points in the main path of the gale when intervals of complete calm or a light contrary breeze might be experienced.

Mr. Peters interposed to direct attention to Mr. H. H. Lamb's work in 1936–39[9] on synoptic analysis over Greenland and the interpretation of observations reported by the coastal stations. These stations were still operating in 1956.

Dr. Stagg took up the question of the spasmodic nature of the katabatic winds off ice-caps and referred to Hobbs's theory of the permanent glacial anticyclone. Hobbs considered that pressure gradually built up in an accumulating reservoir of cold air over the ice-cap till it could be held no longer; the cold air then rushed out with gale force, followed by a period of comparative calm in which the skin of cold air built up again. These successive pulses of activity were given the name of "strophs" of the anticyclone. In more recent years, as observations around the coastal fringe became more plentiful, Hobbs seemed to have become discredited. We were now told of depressions going straight across Greenland. Could this be really right? In what sense could a depression pass right across Greenland? Mr. Lamb replied that Hobbs's theory really was regarded as exploded nowadays, because the idea of a permanent anticyclone over the inland ice was in direct conflict with the observations. Nansen, on his first crossing of Greenland in 1888, had sixteen days with normal snowfall out of forty days spent on the ice. The Wegener expedition's Eismitte station near 71°N. 40°W., manned by Georgii from August 1930 to August 1931, showed frequent long, stormy periods, usually with snow and strong winds from between SE. and SSW., whereas the briefer periods of good weather came usually with light winds from between NW. and NE. At Eismitte, where the slope of the ice plateau, nearly 3,000 m. above sea level, is almost imperceptible, the katabatic wind only occurred intermittently when fine weather permitted[2, 10, 11]. Of course, only the upper part of a depression can pass more or less unchanged over a barrier of this height; the circulation in the lower levels must be re-developed in the air masses on the further side. Very many depressions are held up in the Davis Strait and Baffin Bay and fail to pass Greenland; nevertheless the associated warm sectors generally continue east over the Atlantic and commonly a new low develops south-east of Greenland in association with these fronts. Mr. Hamilton added that in cases where the occlusion passed right across Greenland he had found that 700-mb. charts explained very well the sequence of wind veers and snowfall over the ice plateau. In north-east Greenland a front was commonly preceded by light south-easterly breezes; the katabatic wind returned abruptly as the front passed.

Prof. Manley remarked on an authenticated case in which a depression crossing northern Greenland in July gave rain on the ice cap at 8,000 ft.

Mr. Lamb added that the manner in which many depressions cross Greenland, following situations originally dominated on the east side by a north-east Greenland anticyclone, has been well described in a useful study of Greenland by Rodewald[12]. Often a sustained fall of pressure sets in, even in the region of northerly winds east of the Greenland ridge and a new depression soon dominates the situation east of Greenland.

Mr. McNaughton said that, as in the case of Greenland, depressions from the west sometimes passed across Grahamland, leaving a residual centre west of the peninsula. Alternatively new centres developed east of Grahamland. Similar sequences occurred across South America.

Mr. Peters asked Mr. Hamilton about adequacy of data for his 700-mb. analyses over Greenland. Mr. Hamilton pointed to the radio-sonde stations in the Canadian Arctic to 82°N. and all around the fringe of Greenland: the rest depended upon tracking the fronts across Greenland from their passage over stations in the south-west until they turned up at the British North Greenland Expeditition's ice-cap station, Northice.

Mr. Harding regretted the sparseness of the network of upper air observations in the Pacific sector of the Southern Ocean and Antarctica, even in the network proposed for the International Geophysical Year. Long distance flights have already been undertaken by American aircraft from New Zealand to the Antarctic. Royal Air Force or British civil aircraft which might be employed in the future on similar flights would probably fly at great heights, possibly as high as 50,000 ft. Reliable mapping of the belt of particularly strong upper westerlies over the Southern Ocean would be vital to the safety of such flights.

Finally, Mr. Lamb showed a dozen lantern slides illustrating typical synoptic situations over the Arctic and Antarctic.

Dr. Farquharson asked about the adequacy of the observational coverage in the southern hemisphere for hemispherical surface analyses of the type shown. This is an important question, deserving more consideration than could be given in a few minutes at the end of the meeting. Upon the adequacy of the network, especially over the Southern Ocean, depends the validity of interpretations which it may be possible to derive from the synoptic work undertaken in Antarctica during the International Geophysical Year. The network between 40° and 65°S. is for the most part limited to eight or ten island observing stations broadly spaced between 60°W. and 170°E. plus stations in the Grahamland peninsula, Tasmania and New Zealand, and an average of about ten ships a day. The shipping is largely confined to whaling fleets and expedition ships operating during the summer half-year, November–April. This network is far sparser than over the North Atlantic, but there are indications that it is sufficient to settle the main features of the general circulation over the Southern Ocean (see, for instance,[13, 14]). In Mr. Lamb's opinion the only gap in the network which is often unbridgeable is in the South Pacific, especially between latitudes 35° and 70°S. In all sectors, however, it is noticeable that the statistical indications of the various available series of daily synoptic analyses which have been attempted[14, 15, 16, 17, 18] in terms of the geographical distribution of anticyclone and depression populations have confirmed each other in considerable detail as the observation network has improved; most of the island stations in the Southern Ocean have been opened since the earliest chart series referred to. Their observations have made synoptic analysis easier and more precise, but have not changed the general picture.

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ACCURACY OF GEOSTROPHIC TRAJECTORIES

By C. S. DURST, B.A. and N. E. DAVIS, M.A.

Since the following of air tracks by geostrophic trajectories is frequently practised and in some cases the trajectories are pursued for long periods, it is perhaps well that these notes should be published, which give the degree of inaccuracy to which geostrophic trajectories are subject owing to the failure of the measured geostrophic wind to represent truly the path of individual air particles.

The accuracy of measurement of wind from isobars.—In a paper on convergence and divergence in the atmosphere[1], estimates have been made of

(i) the magnitude of the ageostrophic wind, and

(ii) the magnitude of the error that is likely to be made in measuring a pressure gradient.

These magnitudes were obtained for a height of about 1,500 ft. over south-east England. At that height in that locality the ageostrophic winds are probably on the high side and the errors in measurement are certainly far lower than at greater heights and in less accurately surveyed areas.

The root-mean-square value of the ageostrophic wind in January 1938 was about 9 kt., and thus, taking account that the ageostrophic wind is probably less in summer and possibly less at higher levels, we may expect the probable value of the ageostrophic wind during the year as a whole to be of the order of 5 kt.; a magnitude of 10 kt. was found by Bannon[2] for the ageostrophic winds at 10,000 ft., so we can say that 5 kt. is a conservative estimate*. We may, moreover, expect that the average duration of such ageostrophic winds is 6 hr. in view of their being usually associated with the passage of depressions and fronts.

The probable error in measurement of the geostrophic wind was found to be 2 miles/hr. along and across the isobars, i.e. a probable vector error of about $2\frac{1}{2}$ kt. This will certainly rise to 3 or 4 kt. at greater heights and may well be 10 kt. or more over the less well known areas of the globe. On the average let us assume an error of 5 kt. in the measurement of the geostrophic wind. (Murray[3] found errors of 5, 7, 8 and 6 kt. at 700 mb., 500 mb., 300 mb. and 200 mb. respectively.)

The departure of the geostrophic trajectory from the true trajectory.—Combining the two we can assume that the vector error involved in assuming the geostrophic wind to be the true wind is of the order of 7 kt. This means that in 6 hr. the end of the geostrophic trajectory is likely to be 40 nautical miles away from the true position of the air parcel to which it is supposed to refer.

It is reasonable to suppose that the departures will increase as the square root of the duration of the trajectory, and on this basis we get in Table I the probable departures from true position of the ends of the geostrophic trajectories after different intervals of time.

TABLE I—ESTIMATED DEPARTURES FROM TRUE POSITION OF ENDS OF GEOSTROPHIC TRAJECTORIES AFTER SPECIFIED TIMES

Time	6 hr.	24 hr.	2 days	4 days	8 days
			miles		
Probable departure	50	100	130	200	260

The dispersion of air masses due to eddies.—It is well known through the work of Richardson[4] and others that two parcels of air initially near together will drift apart owing to the operation of the eddies. This effect was investigated by tracking air from 4 points over the British Isles and measuring their distance apart after 6, 12, 18, 24, 30 and 36 hr. The points chosen were London, and points 50, 150 and 350 miles due north of London and the tracks were followed at a height of 700 mb. during the month of February 1948, one set of tracks beginning at midnight each day for a period of 20 days. The results are shown in Table II.

*This may be compared with estimates of the mean-square ageostrophic wind by Murray[3] He gives values of 6 kt. at 700 mb., 9 kt. at 500 mb., 13 kt. at 300 mb. and 8 kt. at 200 mb.

TABLE II—MEAN DISTANCE $\bar{l}$ MILES APART AFTER A TIME t HR. OF PAIRS OF PARCELS INITIALLY AT A DISTANCE OF l_0 MILES

l_0	6 hr.	12 hr.	18 hr.	t 24 hr.	30 hr.	36 hr.
miles				*miles*		
50	74	118	131	148	169	200
100	138	159	220	279	313	332
150	198	259	319	391	439	484
200	255	320	397	484	581	653
300	371	428	589	729	837	926
350	438	549	671	820	956	1070

If we consider the relation between $\bar{l}-l_0$ and t for each l_0 we find a linear regression of the form

$$\bar{l}-l_0 = A(l_0).t$$

with highly significant correlations $\geqslant 0{\cdot}99$ (see Fig. 1). Further, if we consider the relation between l_0 and $A(l_0)$ we find a linear regression between $\log l_0$ and $\log A(l_0)$ with highly significant correlation $> 0{\cdot}995$ (see Fig. 2) leading to the relation

$$A(l_0) = 0{\cdot}13 l_0^{0{\cdot}86}.$$

Hence the dispersion of pairs of parcels is carried out according to the law

$$\bar{l}-l_0 = 0{\cdot}13 l_0^{0{\cdot}86}.t.$$

Table III uses this relation.

TABLE III—MEAN DISTANCE APART AFTER t' DAYS OF TWO PARCELS INITIALLY l_0 MILES APART

l_0	1 day	2 days	3 days	t' 4 days	5 days	6 days	7 days	Increase per day
miles				*miles*				
50	143	236	328	421	514	607	700	+ 97
100	268	437	605	774	942	1111	1279	+168
200	506	812	1117	1423	1729	2035	2341	+306
300	733	1167	1600	2033	2467	2900	3334	+433

The magnitude of the errors in plotted trajectories.—The figures given in Tables I and III may be looked on in this way. The inherent inaccuracy of geostrophic trajectories will lead to a small departure of the plotted trajectory from the true trajectory. This departure will be enhanced rapidly by the eddy effect and one can surmise that the order of departure of the plotted trajectory from the true after a week will be 1,000 miles, after 10 days 2,000 miles, and after a fortnight 3,000 miles. It must moreover be remembered that these values are the radii of the 50 per cent. circles, and on half the occasions the errors will be greater.

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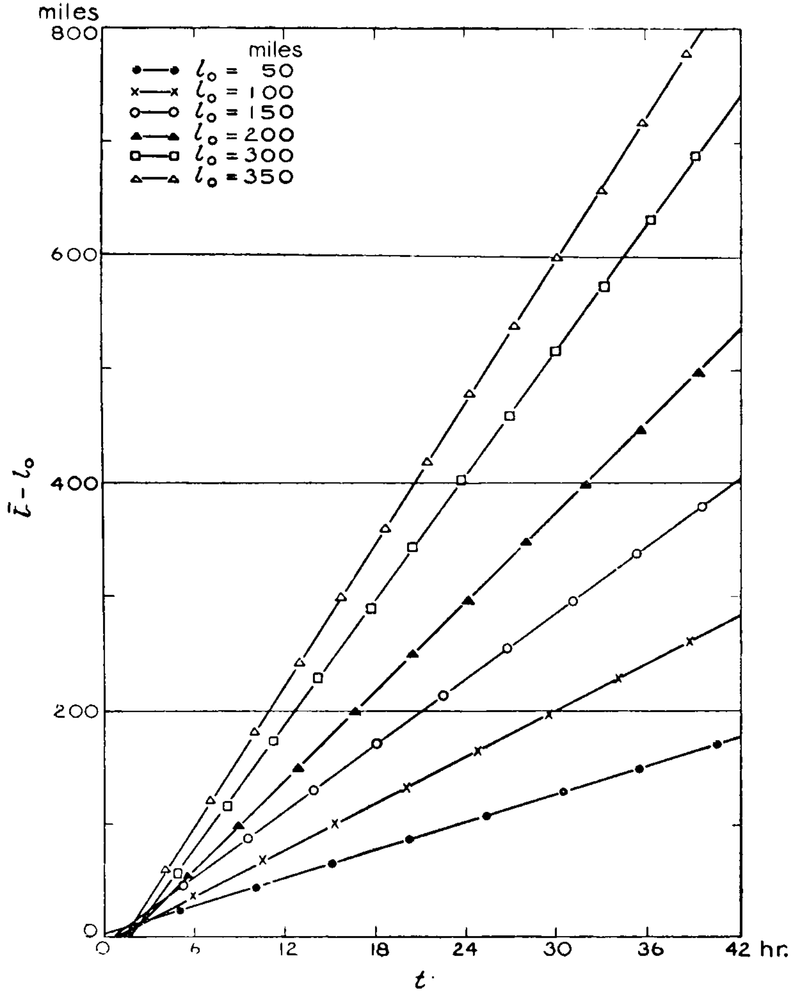

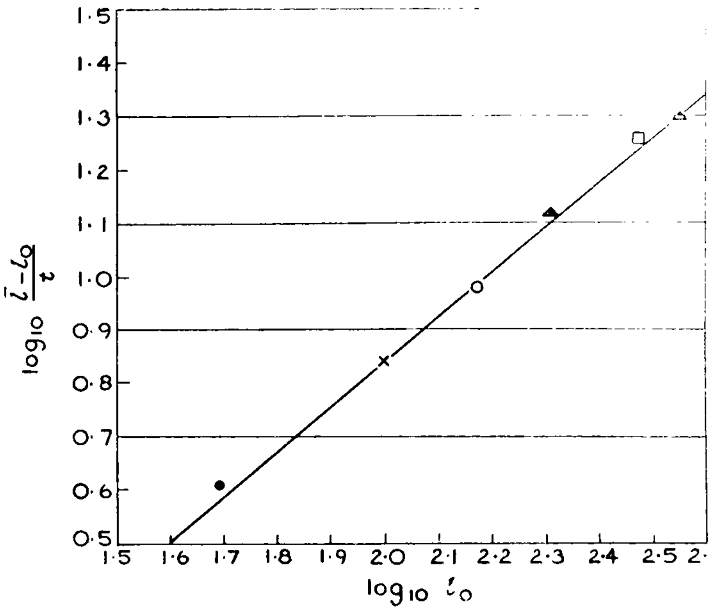

FIG. 2—RELATION BETWEEN SLOPE OF REGRESSION $(\overline{l}-l_0)/t$ AND l_0

FIG. 1 (*left*)—RELATION BETWEEN TIME AND INCREASE OF DISTANCE APART OF PAIRS OF PARCELS OF AIR FOR VARIOUS INITIAL DISTANCES

SOME INTERESTING PROPERTIES OF THE "NULLSCHICHT" OR MAXIMUM-WIND LAYER

By H. H. LAMB, M.A.

British meteorologists may like to be made aware of a growing body of work in the German literature of recent years on the "Nullschicht"[1-7]. This is the name adopted in German by Faust and others for that level in the uppermost part of the troposphere where the mean vertical motion is approximately zero —hence "zero layer" (Nullschicht). This is the level towards which resultant tropospheric and stratospheric vertical circulation components are both directed in deep depressions, and it is the level of corresponding vertical divergence in high reaching anticyclones.

Statistical comparisons of the generality of cases over two years in central Europe show that the mean level of the "Nullschicht", which is found at about 10 Km. above mean sea level, is the same as the level of maximum wind. Moreover, it is logical that this should be so in most individual cases also: below the "Nullschicht" upward motion prevails in depressions and downward motion in anticyclones; depressions are therefore normally colder than anticyclones at all heights up to this; consequently the thermal gradient should produce the maximum wind at, or quite near, the "Nullschicht."

Small discrepancies of height between the two levels may arise, partly because the "Nullschicht" itself tends to be a little higher in anticyclones than in depressions,moving up and down with about half the amplitude of the corresponding changes of level of the tropopause. Also localized vertical motions are to be found in the "Nullschicht", where it is penetrated by convection cells and by various forms of mechanical turbulence including the important clear-air turbulence near jet streams[8]. These are details which do not affect the proper definition of the layer as one in which the mean broad-scale vertical motion is zero.

The maximum-wind layer—perhaps the more obvious name to adopt for it—is inevitably the level at which the air is subjected to the strongest accelerations and decelerations in the course of its flow through the pressure field; consequently one should expect to find the strongest developmental effects of inertia and changes of momentum to correspond to the flow patterns in this layer. The simplest ideal cases of these inertia effects arise at the entrance to and exit from straight westerly jet streams, as illustrated in Fig. 1. Air at A entering the zone of strong pressure gradient associated with the jet stream is

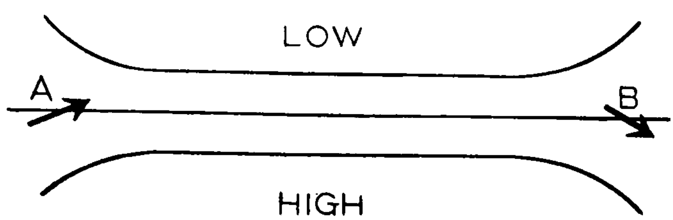

FIG. 1—INERTIA EFFECTS AT ENTRANCE TO AND EXIT FROM WESTERLY JET STREAM

moving too slowly for the increased pressure gradient and, as in the case of air in the surface friction layer, is deflected towards the low-pressure side (deflexion exaggerated in diagram). Usually there is some lateral shear between air entering the jet and slower moving air on either side, which undergoes less acceleration. The ageostrophic deflexion of air at A therefore gives rise to convergence and rising pressure at the left of the entrance to the jet (in the sense of the wind stream) and to divergence and falling pressure at the right of the entrance. Air at the jet exit, leaving the zone of strongest pressure gradient, is moving too fast for balance with the actual pressure gradient at B and experiences a deflexion towards the higher pressure side: given the required lateral shear, this effect should give rising pressure at the right and falling pressure at the left of the delta of the jet. The reality of occurrence of these ageostrophic motions at jet-stream level has been demonstrated by Murray and Daniels[9].

The maximum-wind level would deserve special attention for these inertia effects alone. Interest in the "Nullschicht" has grown further however as other, more unexpected, properties of this layer have come to light. These properties relate to the layer as a whole and not just to the jet streams within it.

In a number of carefully devised statistical approaches, making use, *inter alia*, of the interdiurnal (day-to-day) temperature changes observed in moving air parcels at many different levels in order to detect the exact height ranges within which general vertical motion goes on and in a considerable variety of defined situations, Faust has discovered:

(i) In cases where there is a well defined maximum in the vertical distribution of horizontal wind speed—i.e. cases of strong vertical shear above and below the strongest winds in the air column—the maximum wind is above gradient strength both on average and in a considerable majority of the individual cases measurable. This appears to hold true whether the maximum wind is at 225 or 500 mb. in the material examined (or any other level in the upper troposphere). In cases where the maximum winds over Germany were at 225 mb. and exceeded twice the strength of the winds at 175 and 275 mb., the 225-mb. wind was on average 10 per cent. above gradient strength and in nearly one case in six over 50 per cent. above gradient strength. (Scherhag[10] has reported a mean excess of actual wind over gradient wind of 1·6 kt. in the layers between 500 and 225 mb. which commonly contain the maximum wind.) Further tests removed all ground for supposing that these systematic departures could be just a result of the difficulty of drawing the contours or isobars in cases of strong winds.

(ii) In cases of a well defined level of maximum wind, there is on average an ageostrophic flow towards higher pressure in the maximum-wind level. This was confirmed by statistical studies both of 24-hr. thickness changes and of pressure changes at the surface and in the upper troposphere. (Reineke[11] found a mean deviation of actual wind from gradient-wind direction of 7° towards the higher pressure side between the 500- and 225-mb. levels. A recent paper[12] has confirmed the existence on average of a maximum ageostrophic wind over England at about 300 mb. with a component directed towards higher pressure.)

(iii) The "Nullschicht" effects noted in (i) and (ii) are found to be quasi-proportional to the speed of the maximum wind and to the magnitude of the vertical shear above and below the maximum-wind level.

(iv) The tropopause is found on average about 1 Km. above the maximum-wind level. Sorting of cases reveals an average tropopause height of 2 Km. above the maximum winds in anticyclones and at the south side of jet streams, and an average of less than 0·5 Km. above the maximum-wind level in depressions and at the north side of jet streams in 55°N. Geographical distribution showed the tropopause on average 1·3 Km. above the "Nullschicht" in 40°N. and just 0·5 Km. above in 70°N.; since, however, the change in the vertical distance between the levels of tropopause and maximum wind on either side of the jet stream is greater than the normal difference between 40° and 70°N., the events near the jet stream must be at least partly attributable to vertical motion and not purely due to advection from either side. Faust suggests that the main height variations of the tropopause are themselves to be attributed to the upward and downward "pumping", corresponding to vertical divergence and convergence, associated with the "Nullschicht" phenomena, including those brought about by inertia and momentum changes in and near the level of maximum wind.

(v) In cases where there is no sharp upper-wind maximum, there tends to be an ageostrophic flow from higher towards lower pressure even at the levels where the strongest winds exist.

The empirically discovered "Nullschicht" phenomena are by no means all readily amenable as yet to theoretical explanation. Nevertheless there is a logical necessity for the normal existence of over gradient winds in various upper levels, to compensate the continual flow from high to low pressure associated with under gradient winds in the layers affected by surface friction. Otherwise no pressure differences could be maintained, far less strong circulations be built up.

It is much less easy to suggest how a mean excess over gradient-wind strength can in fact arise in the free atmosphere. Hollmann's suggestion is that kinetic energy is built up close underneath the tropopause because convection mixing may be found to carry more energy upwards in the strong-wind regions in depressions than is transported downwards in anticyclones, where the pressure gradients are weaker and convection is discouraged by more stable stratification.

The maximum-wind layer and the layers near the ground must be thought of as the loci of maxima of ageostrophic motion in the horizontal wind field. Since the departures from gradient wind are in opposite senses in the upper and lower troposphere, one would expect to find some intermediate level at which the actual winds came close to the gradient wind. This theoretical level of non-divergence or equivalent barotropic level has been commonly assumed to be about 600 mb. A recent investigation[13] however suggests that in reality no level of strict non-divergence exists: the points in the atmosphere at which horizontal divergence is at a minimum tend to arrange themselves on coherent quasi-horizontal surfaces recognizable as continuous over limited areas and periods of time; their height is actually between 6,000 and 10,000 ft. in most cases.

Faust's measurements[2], from which the discoveries here listed emerged, were largely made outside the actual jet streams, for various reasons associated with amenability to reliable and, where possible, accurate measurement. He quotes Murray and Daniels'[9] figures from measurements made near the midway point of the length of straight jet streams, where no confluence or diffluence effects could be working, as providing confirmation of a net ageostrophic flow from lower to higher pressure within the jet-stream systems themselves.

A further point to note is that Faust's "Nullschicht" effect, normal ageostrophic flow towards higher pressure, works against the developmental pattern of the confluence (point A on the diagram, Fig. 1) and tends to strengthen the developmental pattern of the deltas.

In a statistical study of rainfall amounts and frequencies in relation to straight jet streams at four British and Irish stations over a 3-yr. period, with care taken to eliminate local effects, Johnson and Daniels[14] found rain maxima at the right of the entrance and left of the exit of the jet. This distribution agrees with the distribution of net vertical components of air circulation to be expected from inertia effects, as illustrated in our diagram. It is interesting to note that the rain distribution was more definite at the jet exit than at the entrance, as the "Nullschicht" effect would suggest. The rain-distribution data were however inadequate to decide whether there was any preferred vertical motion near the middle of the jet stream.

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STANDING WAVES IN THE VALE OF YORK

By F. P. U. CROKER

Ground observations at Dishforth and air observations over the Vale of York suggest that on December 5 and 6, 1955, a system of standing waves lay over the area. It is thought that this system may have extended along the line parallel to and in the lee of the Pennines, but information outside the Dishforth area is lacking. It may be of interest to describe briefly the circumstances, since these corroborate the conclusions reached by Pilsbury about the conditions required for the formation of standing waves[1]. Moreover, the liability of airfields to be affected by a standing-wave system carries implications which, it is felt, may justify further study.

At 1500 G.M.T. on December 5 pressure was high to the south and low to the north of the British Isles. A warm front had recently cleared Dishforth and was moving rapidly away eastward. A cold front lay east and west across Scotland. This moved slowly south but paused in about 57°N. latitude on December 6 while a wave depression moved quickly along it from west to east across Scotland. The strong westerly gradient wind over northern England increased during the night of December 5–6 but eased again the following day. Dry-bulb temperature curves and upper winds from the Liverpool radio-sonde ascents from 1400 G.M.T., December 5 to 1400 G.M.T., December 6, inclusive, are reproduced in Fig. 1. It will be seen that the first two ascents show a steep lapse rate to about 5,000 ft. followed by a marked inversion. Wind directions are fairly constant up to 700 mb., well above the top of the inversion; wind speeds are well over 20 kt. and increase with height. These are precisely the conditions formulated by Pilsbury for standing-wave development. The third ascent shows the inversion in the process of breaking down and an evening out in the wind-velocity profile with height.

Pilots flying on the night of December 5–6 state that they experienced strong and prolonged up-and-down draughts in addition to turbulence. One instructor flying in the approaches to Topcliffe, five miles north of Dishforth, between 2000 and 2200 G.M.T. approximately, states that in the area there were constant up-draughts during the first hour of a strength which caused him to throttle back his engines and maintain a shallow dive in order to avoid gaining height. After a slack interval, the up-draughts were replaced during the second hour by down-draughts of sufficient strength to make it necessary for him to climb on full power in order to maintain height. These down-draughts, unlike the up-draughts, were accompanied by heavy turbulence. Similar conditions were experienced the following day, but of lesser intensity. They seem to have died out at some time during the afternoon, i.e. during the time when the upper air conditions were changing. One pilot flying during the morning of December 6 states that the lower cloud displayed a wave-like appearance, the distance between wave crests being estimated at 15 miles.

At 1300 G.M.T. on December 6, the surface wind at Dishforth, which had been blowing fairly consistently from the south-west at some 15 kt., began to ease and eventually, at 1500 G.M.T., the pointer of the wind-direction indicator in the Meteorological Office began to rotate; a somewhat disconcerting event in view of the gradient wind of some 35 kt. Immediate steps were taken to check the veracity of the reading and it was confirmed by Air Traffic Control, near which the anemometer is sited, that the wind vane itself was rotating and that

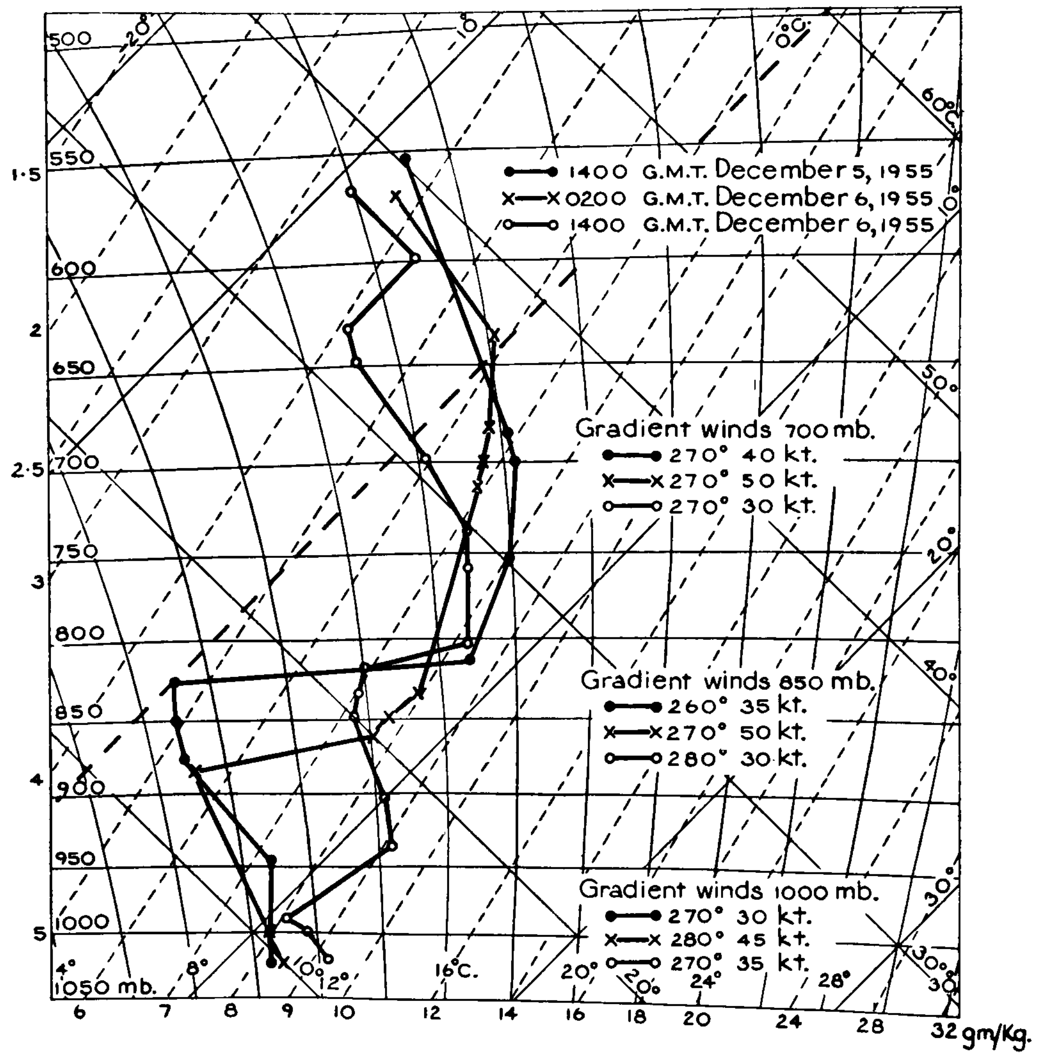

FIG. 1—DRY-BULB TEMPERATURE CURVES AND UPPER WINDS FROM LIVERPOOL RADIO-SONDE ASCENTS DECEMBER 5–6, 1955

there were no disturbing influences in the vicinity, such as aircraft running up their engines, which might account for its behaviour. By 1530 G.M.T. the surface wind had recovered its former velocity and, in fact, showed a tendency to increase. It will be appreciated that this phenomenon, also, occurred about the time that the upper air conditions were changing and could reasonably be connected with the collapse of the wave system, or, perhaps, an alteration in the position of a wave in relation to Dishforth, for, while strong surface winds are expected under a wave trough, those under a wave crest should be lighter.

As far as Dishforth and other airfields in the lee of the Pennines are concerned it would seem that for the formation of standing waves a synoptic situation is required of the same general nature as that existing on December 5 and 6, with an anticyclone to the south but close enough to provide a subsidence inversion, and low pressure to the north, giving, in conjunction with the anticyclone, a vigorous westerly air stream, reasonably constant in direction to the height of the inversion top. It is possible that standing waves might also be produced immediately ahead of a warm front approaching from a west or north-westerly direction. In this case the inversion would occur at the frontal boundary and it is thought that the wind veer with increasing height normally associated with approaching warm fronts might be too insignificant below the inversion to act as a prohibiting factor.

In standing-wave conditions an aircraft flying along a wave may experience continuous up- or down-draughts, depending on whether its position is to windward or leeward of the wave crest. An aircraft flying up wind or down wind through the waves will experience alternating periods of up-draughts and down-draughts. In addition, it will encounter variations in the strength of the horizontal wind as it passes successive crests and troughs. It is suggested that these may be sufficient in themselves to cause variations in the lift. It will be appreciated that in the case of an aircraft flying at or near trough level such variations would aggravate the effect of the up- or down-draughts, thus an aircraft landing or taking off into wind would appear to be particularly vulnerable.

It is for consideration whether or not such effects can be sufficiently powerful to constitute a hazard to air navigation in general, and in particular to the operation of aircraft from airfields over which a standing-wave system is in existence.

It may be of interest to record that on September 12, 1956, when standing wave conditions were again present in the Vale of York, the author was taken in a Pioneer aircraft to investigate them. Near the airfield and level with the cloud plume marking the crest of a wave between 5,000 and 6,000 ft., up-draughts of 1,000 ft./min. were encountered on the up wind side of the cloud and down-draughts of 800 ft./min. on the down wind side of the cloud. There was no turbulence.

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[The variation in the horizontal wind can, on Scorer's theory, be of the order of 10–20 kt. The horizontal component of wind due to the wave motion is given by $u = -\partial(U\zeta)/\partial z$ in which U is the basic wind and ζ the vertical displacement of a stream-line from its mean position. If the variation of U with height is neglected u is given by $-U\partial\zeta/\partial z$ which shows that if ζ is increasing with height, as it is up to the inversion, u is negative below crests and positive below troughs so that below the inversion the troughs are regions of increased wind. Above the inversion where the amplitude decreases with height the situation is reversed.—Ed., *M.M.*]

WINTER TEMPERATURES IN LONG AND SHORT GRASS

By M. J. T. NORMAN, Ph.D., Mrs. A. W. KEMP, B.Sc. and Mrs. J. E. TAYLER, B.Sc.
(The Grassland Research Institute, Hurley, Berkshire)

At the Grassland Research Institute, Hurley, the effect of microclimate upon the growth and death of herbage in winter and early spring is being studied. As part of the investigation, continuous records of temperature at 1 in. above soil level were obtained during two winters on two types of sward.

The swards were:

(i) long herbage, 12–18 in. tall, uncut throughout the preceding growing season

(ii) short herbage, 1 in. tall, cut frequently in early autumn prior to the recording of temperature.

The two sites at which temperatures were recorded lay within 5 yd. of each other, in permanent pasture on the slope of a chalk escarpment facing north-north-west and overlooking the Thames valley. The sites were 200 ft. above mean sea level and 100 ft. above the valley floor. Conditions were not conducive to the local ponding of cold air at night.

Temperatures were measured with mercury-in-steel thermographs. The bulbs were 6·5 in. long and 0·75 in. in diameter, shielded from direct radiation by half cylinders of "white acetate" plastic 9 in. long and 2 in. in diameter. Records were obtained during 1953–54 from November 4 to March 23, and during 1954–55 from November 8 to March 13. On account of the failure of a thermograph clock, records for the week January 10–16 were incomplete and were not included in the data. For convenience, the two series of records were divided into periods, normally of four-weeks duration (Table I).

TABLE I—PERIODS DURING WHICH RECORDS WERE OBTAINED

Period	1953–1954	Period	1954–1955
A	November 4–December 1	F	November 8–December 7
B	December 2–December 29	G	December 8–January 8
C	December 30–January 26	H	January 17–February 13
D	January 27–February 23	I	February 14–March 13
E	February 24–March 23		

Table II shows the period means and aggregates of certain temperature characteristics. Accumulated temperatures were computed directly from the thermograph traces by measurement of area above or below the trace to the chosen base line. Mean temperatures were derived from values read at every 2-hr. division on the trace.

TABLE II—TEMPERATURE CHARACTERISTICS IN LONG AND SHORT GRASS

Period	Mean daily temperature (°F.)		Mean daily maximum (°F.)		Mean daily minimum (°F.)		Accumulated temperature above 42°F. (day–°F.)		Accumulated temperature below 32°F. (day–°F.)		No. of frosts (min.<32°F.)*	
	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass	Short grass	Long grass
A	43·0	44·8	49·4	47·7	38·0	41·9	78·2	89·2	1·2	...	3	...
B	42·1	44·0	46·3	46·1	38·1	41·9	58·5	80·1	1·8	...	6	...
C	34·2	36·2	40·2	39·6	29·8	33·5	19·1	13·9	45·3	10·4	20	11
D	30·6	32·1	40·3	35·4	25·4	29·8	8·2	1·8	105·2	60·0	20	18
E	39·2	38·6	51·7	43·4	32·6	35·4	56·2	21·3	11·8	0·9	13	7
1953–54	37·8	39·1	45·6	42·4	32·8	36·5	220·2	206·3	165·3	71·3	62	36
F	41·8	42·4	47·4	46·4	36·6	38·5	61·0	50·8	0·5	...	4	...
G	38·6	39·0	42·4	41·5	35·1	36·8	47·0	32·1	9·4	3·0	15	4
H	36·8	36·5	42·4	39·4	31·9	33·9	23·9	21·9	32·6	14·5	15	10
I	31·1	31·1	37·8	34·9	26·7	29·5	2·0	...	62·4	34·9	26	27
1954–55	37·1	37·5	42·5	40·6	32·6	34·6	133·9	104·8	104·9	52·4	60	41

[*Note.—This definition is not in agreement with meteorological terminology in which "ground frost" is applied to occasions of temperature 30·4°F. and below.—Ed., *M.M.*]

In 1953–54, mean temperature in long herbage exceeded that in short herbage by 1·3°F. This was due almost entirely to differences in night temperature. However, though day temperatures in the two swards were similar, the maximum was 3·2°F. higher in short herbage and the minimum 3·7°F. lower. In 1954–55, temperature contrasts between the two swards were smaller. Maxima differed by only 1·9°F. and minima by 2·0°F., while mean temperatures were close to each other.

The aggregate effect of the difference in herbage cover upon growing and killing conditions may be approximately estimated by comparing accumulated temperatures. In 1953–54, accumulated temperatures above 42°F. differed little, but accumulated temperatures below 32°F. were more than twice as great in short herbage. Values below 32°F. in 1954–55 showed a similar relationship, but values above 42°F. in short herbage were about 28 per cent greater than those in long herbage. Frosts were recorded more frequently in the short sward; there were 26 additional frosts in 1953–54 and 19 in 1954–55.

Night temperatures in short and long herbage (t_s and t_l respectively) were of further interest. Good correlations were obtained between individual values of the general night temperature, expressed here as the mean of night temperature in the two swards, $(t_s + t_l)/2 = m$, and the difference between them, $t_l - t_s = d$, when the comparison was made over a relatively short time. The correlation coefficients between m and d for the nine periods are given in Table III.

TABLE III—CORRELATION COEFFICIENTS FOR m AND d

Period	Correlation coefficient	Period	Correlation coefficient
A	−0·93	F	−0·83
B	−0·81	G	−0·82
C	−0·74	H	−0·85
D	−0·86	I	−0·89
E	−0·85		

Thus, on cool nights, temperatures in the short sward were well below those in the long sward. As the general night temperature rose, differences between the two swards became smaller. On very warm nights, temperatures were frequently a little higher in the short herbage. Some extreme values are given in Table IV.

TABLE IV—SOME EXTREME TEMPERATURES

	Short herbage	Long herbage		Short herbage	Long herbage
	°F.	°F.		°F.	°F.
November 8, 1953	50·5	49·4	January 31, 1954	17·1	25·3
December 2, 1954	52·3	50·8	January 19, 1955	20·6	27·5

However, the general night temperature at which a particular difference could be expected varied between periods and between years at the corresponding period. Examples are shown in Table V.

TABLE V—HIGHEST GENERAL TEMPERATURE m AT WHICH A DIFFERENCE d OF MORE THAN 2°F. COULD BE EXPECTED

Period	°F.	Period	°F.
A	44	F	38
B	44	G	33
C	36	H	32
D	31	I	29
E	35		

These relationships are expressed graphically in Figs. 1 and 2. In constructing these graphs, individual values of general night temperature, m, were grouped within each period into 5° classes. Differences in night temperature, d, between the two swards were then plotted period by period for each class. The points vary considerably in accuracy in accordance with the number of observations they represent.

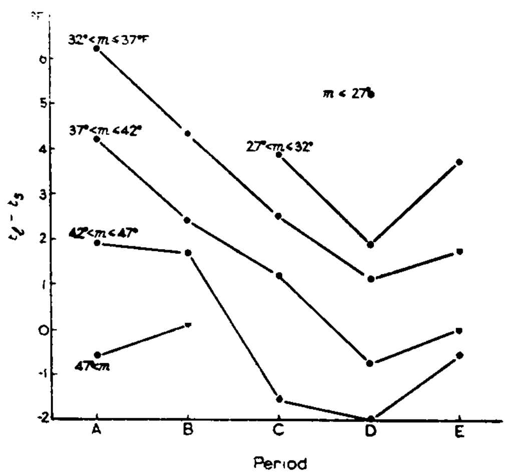


FIG. 1—NIGHT TEMPERATURES IN SHORT AND LONG GRASS, WINTER 1953–54

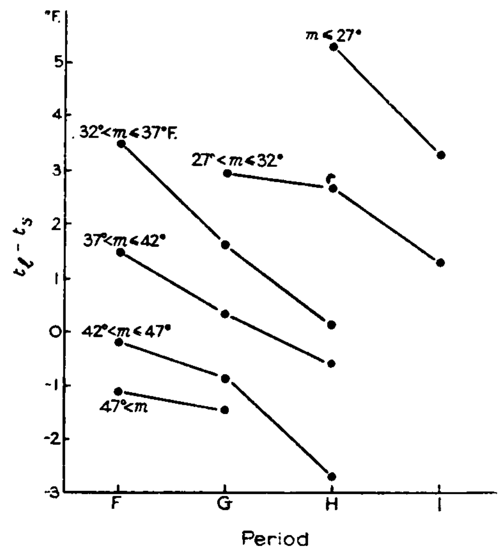


FIG. 2—NIGHT TEMPERATURES IN SHORT AND LONG GRASS, WINTER 1954–55

The clear separation of the lines for each class reflects the relationship indicated by the correlation coefficients. The approximate parallelism of the lines suggests a constant rate of change of d with respect to m over the period of recording. The general slope downwards to the right indicates the shift on the relationship with time.

This shift may be attributed either to changes in the magnitude of incoming and outgoing radiation, or to changes in the height and density of the long herbage. With the advance of winter, the herbage gradually decayed and collapsed, and the protective effect of the cover in comparison with the short sward declined.

There are two exceptions to the general angle of slope. The first is the $>47°$ class between periods A and B. Since this class was represented by only 4 values in period A and 3 in period B, little emphasis can be laid on the apparent divergence. The second is the upward shift common to all classes between periods D and E, i.e. in March 1954. This could be attributed to changes in the balance of radiation with the advance of spring, or to regrowth of the long herbage and a consequent increase in the relative protective effect. Regrowth in the long sward would be expected to start earlier and to proceed more rapidly than in the short sward, since the vigour of individual plants in the latter was reduced by repeated cutting in the previous autumn.

This reversal was not recorded in 1954–55. Records in 1953–54 did not end until March 23, while in 1954–55 they ended on March 13. Moreover, general night temperatures were increasing rapidly towards the end of the period of recording in 1953–54, while in 1954–55 the normal spring rise in temperature had barely begun by mid-March.

Considering all periods together for each winter, and introducing a variable x, where x represents the date and is measured in days from January 13, these relationships may be summarized in regression equations as follows:

1953–54

$d = 13 - 0{\cdot}29m - 0{\cdot}035x + 0{\cdot}00023x^2$. Standard error of estimate $\pm 1{\cdot}5$

1954–55

$d = 12 - 0{\cdot}32m - 0{\cdot}030x$. Standard error of estimate $\pm 1{\cdot}1$

where d and m are in °F. The values for the standard errors are probably underestimates, as no allowance has been made for the effects of day-to-day auto-correlations.

The records demonstrate that the protective influence of a dense herbage cover against extremes of night temperature in winter may be of considerable magnitude. The degree of protection was greater in early winter and when night temperatures were generally low. The observed temperature differences are likely to be of importance in connexion with herbage growth and death, particularly with reference to the losses sustained by standing herbage saved as winter keep for cattle, and to the recovery of such herbage in early spring after winter grazing.

WORLD METEOROLOGICAL ORGANIZATION

Second Conference of the Commission for Maritime Meteorology

The Commission for Maritime Meteorology of the World Meteorological Organization held its Second Session at Hamburg in October 1956. Although this was only its Second Session under the auspices of the World Meteorological Organization, the Commission was previously a technical body of the International Meteorological Organization and it held its first Conference as early as 1907. The Hamburg conference took place at the Seewetteramt, maritime headquarters of the West German Meteorological Service. This Office is situated not far from the site of the former Deutsche Seewarte which was always such an active organization in maritime meteorology until it was destroyed during the last war. The impression one gathers is that the Seewetteramt is similarly making every effort to meet the meteorological needs of the mariner.

The arrangements for this Conference were admirable. From the main conference room one had a fine view of the River Elbe with its busy docks and shipyards. There were 23 nations represented at the Conference and no less than 18 of the delegates had seen considerable sea service either as meteorologists or as oceanographers. Two of the delegates were Port Meteorological Officers, from Cape Town and Hong Kong respectively. A nautical atmosphere was therefore much in evidence.

The conference lasted a fortnight and the discussions covered the whole field of maritime meteorology. Probably the most important question was that of the voluntary observing ships; evidence was produced that the total number of such ships in the world has increased since the last conference of the Commission for Maritime Meteorology in 1952, from about 2,400 to about 2,800. All meteorological services seem to agree that there is, nevertheless, a need for more reports from ships at sea, particularly from those areas where shipping is sparse. The Commission therefore recommended that a special effort be made to increase the number of "auxiliary" ships to make "non-instrumental" observations with the addition of pressure and temperature readings when in these particular oceanic areas. The intention is that the ships' own instruments will be used, provided their accuracy has been checked by the Port Meteorological Officer. Such ships will indicate that the barometric pressure reading is only accurate to the nearest millibar, by using the code group PPXTT. A recommendation was made about recruiting voluntary observing ships flying the "flags of convenience" of Panama, Honduras, Liberia and Costa Rica, in view of the large number of such ships which are now trading in all oceans. It was also recommended that all meteorological services encourage shipowners to supply their ships with good quality barometers and thermometers. The Commission recommended that all countries be urged to increase their number of "selected ships" and that ships should be encouraged to continue sending radio weather messages when they are in coastal waters. It was recommended that a simplified uniform address be used for ships' radio weather messages addressed to the shore; there is at present a multitude of such addresses in use, many of which are lengthy and thus not only lengthen the message but cost money.

The Commission recommended ways and means by which voluntary observing ships could best contribute to the programme of the International Geophysical Year. For example, in addition to the continuance of the "selected ship" scheme, Port Meteorological Officers in all ports are to visit as many ships as possible with the object of ensuring that meteorological observations of one kind or another are made during the International Geophysical Year in the relevantly unfrequented waters of the Southern Ocean, South Pacific, Indian Ocean and central Southern Atlantic. Special forms for recording the observations aboard "auxiliary" ships have been drawn up and detailed instructions as to the type and quality of the observations which are required will be promulgated. The Commission also provided for a special form on which observations from ships during the International Geophysical Year can be tabulated in a uniform manner and forwarded to World Meteorological Organization Headquarters for international scientific purposes.

For the application of meteorology to a seaman's duties, a working party of the Commission has, since 1952, been compiling an international booklet *Meteorological care of cargo*. This booklet is intended to explain to ships' officers in simple terms how best to apply meteorological principles to the care of the cargo in the hold of a ship and it has now been recommended by the Commission for publication. A representative of the British Chamber of Shipping who attended the Conference by invitation inferred that such a booklet would be welcomed by the shipping industry. To assist meteorological services in providing the best possible radio weather service for seamen, the Conference recommended the use of a short and simple forecast code for use by those countries which are at present unable to carry out the agreed international practice of issuing forecasts in English as well as in their own language. The reason that English is selected for this purpose is that it is a language generally understood by seamen.

Steps were taken at the Conference to overcome the confusion which exists at present owing to the various uses of the word storm, e.g. storm force wind as used in the Beaufort scale, storm warning, tropical storm, thunderstorm, magnetic storm, etc. Some confusion is also caused because of the use of moderate gale in the Beaufort scale for a force-7 wind, whereas gale warnings are only issued for winds of force 8 and above. After very lengthy discussion the conference decided that the best answer as a compromise solution, which does at least eliminate some of the confusion, was to make some amendments to the Beaufort scale, which has been in force since 1807, and their recommendations are as follows:—

force 7 to be "near gale" instead of "moderate gale",
force 8 to be "gale" instead of "fresh gale",
force 9 to be "strong gale" as at present,
force 10 to be "storm" instead of "whole gale"
and force 11 to be "violent storm" instead of "storm".

The Conference also recommended that the term gale warning be used with reference to winds of force 8 and 9 only and storm warning for winds of force 10 and above in temperate latitudes and that the term warnings of tropical cyclones should be used as necessary and appropriate in tropical areas.

At a conference in London in 1952 the Commission had recommended the introduction of a revised international Ice Nomenclature, and after some amendments had been made to this at the request of certain countries bordering the Baltic, this new nomenclature was adopted for international use in 1956. At the Hamburg Conference a small committee of ice experts made a selection from all the available photographs which were made available by various nations, in order to illustrate this nomenclature. Steps are being taken to publish a limited edition of these illustrations in the first instance as a matter of urgency for use during the International Geophysical Year, because of the great interest in ice observations both in the Arctic and Antarctic as part of that programme.

Many of the maritime countries, notably Germany, Holland, the United Kingdom and the United States of America, produce marine climatological atlases of oceanic areas and other information for the benefit of shipping and also for research purposes. In order to get the best out of such information, which is contributed to by the voluntary observing ships of various nations, it is necessary that some international co-operation be achieved. For example, it is sometimes desirable to use data provided by the ships of other countries in order to "complete the picture" in areas where shipping is sparse. It is also desirable to have some uniformity in the manner in which maritime data are portrayed in climatological atlases. This is particularly important now that the World Meteorological Organization is considering a project for a world climatological atlas. This question is rather complicated and although it has already been given quite a lot of consideration no definite conclusions have yet been reached. The Commission therefore referred it to a Working Group for continued study.

Other questions considered by the Commission included:—a code for reporting sea ice from ships, shore stations and aircraft; sea temperature and rainfall observations at sea; illustrations of cloud forms and the provision of blank weather maps for use by voluntary observers at sea on an international basis; and liaison with other international bodies, e.g. the Food and Agricultural Organization in connexion with the provision of meteorological information for the fishing industry.

During the course of the Conference a series of three lectures was given on the subject of meteorology as applied to the navigation of ships. All the delegates had the opportunity of thoroughly inspecting the German Fishery Research Ship *Anton Dohrn* and lectures illustrated by films were shown concerning the work of this ship and in particular the forecasting service which she provides, alternately with a similar vessel *Meerkatze*, for the German fishing trawlers operating in far northern waters. Each of these vessels carries a fully qualified meteorologist. In addition to fishery research work, the ships do a certain amount of meteorological research and they have on board a doctor and fully equipped hospital for dealing with injured trawlermen and facilities for carrying out machinery repairs etc. to trawlers if required.

Delegates were also taken on a tour of the extensive docks of Hamburg and were very hospitably entertained by their German hosts on several occasions.

The conference was presided over by Cmdr. Frankcom; the British delegation consisting of Mr. Shellard of the Meteorological Office and the Director of the Naval Weather Service. At the conclusion of the Conference Dr. H. Thomsen of Denmark was elected President. Dr. Thomsen is an oceanographer as well as a meteorologist; he was aboard the Danish research ship *Dana* during her world cruise 1928–30, and he is also a keen yachtsman.

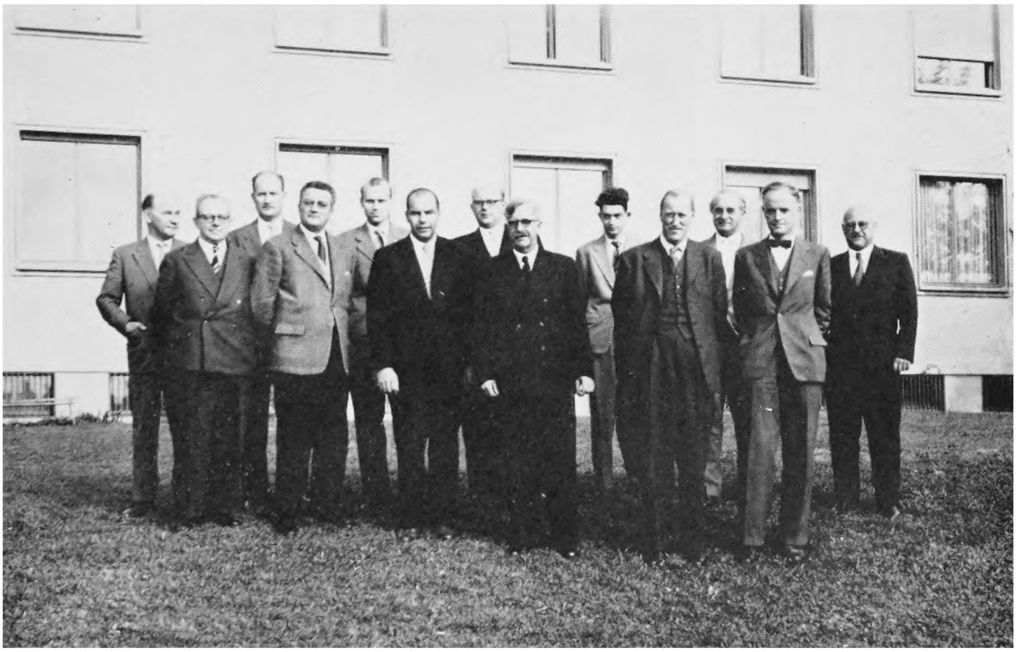
Meeting of the Working Group on Sferics and Second World Symposium on Atmospherics at Zurich 1956.

A meeting of the World Meteorological Organization Working Group on Sferics, a working group formed under a resolution of the Commission for Aerology, was held in Zurich on October 29 to 31, 1956. The working group was attended by Prof. Dr. J. Lugeon (Chairman) (Switzerland), Mr. L. A. Pick, (United States of America) and Mr. A. L. Maidens (United Kingdom). The fourth member, Mr. L. S. Mathur (India) was not able to attend.

Representatives of interested authorities in France, the United States of America and East and West Germany also attended the meeting which, in consequence was considered as forming the Second World Symposium (the first symposium was held in Zurich in 1953) on the many and varied topics embraced by the term Atmospherics. Both meteorological and radio interests were covered.

The forthcoming International Geophysical Year naturally occupied much of the discussions, and plans were made for the compilation and exchange of

MEMBERS OF THE COMMISSION FOR MARITIME METEOROLOGY OUTSIDE THE SEEWETTERAMT AT HAMBURG



MEMBERS OF THE WORKING GROUP ON SFERICS AND THE SECOND WORLD SYMPOSIUM ON ATMOSPHERICS

THE INTER TROPICAL CONVERGENCE ZONE TO THE NORTH-WEST OF SHARJAH, JULY 27, 1956

(see p. 156)

all forms of information based on measurements of the radio signals generated by lightning flashes. This included not only the location or bearings of thunderstorms but also measurements, in various forms, of atmospheric noise, direct observations of thunder heard and the study of atmospheric wave forms.

More generally, recommendations were agreed to encourage the development of sferic observations and to stimulate international co-operation of larger sferic networks than would be possible within the confines of single countries. At the request of the Commission for Aerology the meeting also reconsidered the accuracy with which thunderstorms should be located for aviation purposes, and expressed this in the form of the necessary spacing of sferic stations in the light of the Swiss, French and British trials of 1954.

The exchange, during the symposium, of views and information by experts in both the meteorological and radio fields proved most interesting and profitable. The hospitality of Prof. Dr. Lugeon and of the Swiss Meteorological Service, with most efficient secretarial services, ensured the success of the meeting.

NOTES AND NEWS

Field Studies Council.—A one-week residential course "Weather and Flight" on meteorology and aeronautics has been announced for July 3–10, 1957 at Preston Montford Hall Field Centre, near Shrewsbury.

Instructors:

Meteorology	R. S. Scorer, M.A., Ph.D.,	Imperial College
	C. E. Wallington, M.Sc.,	Meteorological Office
Aeronautics	F. G. Irving, M.Eng.,	Imperial College.

There will, in addition, be six special evening lectures by well known experts on colour photography, meteorological research flying (Mr. R. J. Murgatroyd, Meteorological Office), jets, soaring, and the flight of locust swarms and birds. Films will be shown.

The main course is intended to explain the basic principles of cloud physics and air dynamics and to interpret in terms of them the natural phenomena of weather and the artificial phenomena of flight. Knowledge of mathematics, though obviously helpful, is not essential. Opportunities for discussion will be plentiful. The current weather will be studied daily. Cameras should be brought if possible. There will be a visit on one day to the Midland Gliding Club, with opportunities for flight if the weather is suitable.

The fee for the course will be about £8.

Further enquiries should be addressed to The Warden, Preston Montford Field Centre, Montford Bridge, Near Shrewsbury.

The course has been organised jointly by the Field Studies Council and the Royal Meteorological Society, with the generous support of the Royal Aeronautical Society.

Rainfall at Sharjah, Summer 1956

The rainfall recorded at Sharjah, Oman, Persian Gulf, during the summer of 1956 is noteworthy. The details are given below. All times are in local zone time, i.e. G.M.T. plus four hours.

June		
29th	Trace	Slight rain at 0030 hr.
30th	Trace	Slight rain at 0200 hr.
July		
13th	0·6 mm.	Slight shower at 2030 hr., lightning to the south.
22nd	Trace	Slight shower at 1830 hr., thunder heard from 1600 hr.
23rd	Nil	Thunderstorm and showers to the south-east–south at 1710–1900 hr.
24th	Trace	Slight shower at 1615 hr.
25th	Trace	Slight shower at 0700 hr., slight rain at 1830–2200 hr., lightning east–south-east 2000–2100 hr.
26th	12·3 mm.	Intermittent slight rain from 0800 hr., continuing moderate 1800–1900 hr. then continuing slight to 2200 hr.
27th	2·7 mm.	Slight shower at 1230 hr., moderate shower at 1500 hr.
28th	Trace	Slight shower at 1430 hr., adjacent showers to 1730 hr.
29th	Trace	Adjacent shower 0900–1000 hr., slight rain 1700–2400hr.
30th	Trace	Slight shower at 0700 hr.
August		
	Nil	
September		
12th	5·4 mm.	Thunderstorm at 1645–1715 hr.

Total rainfall = 21 mm.

During the previous seven summers only 0·6 mm. of rain was recorded. Indeed 25 out of the 28 months, June to September, 1949 to 1955, were rainless. The monthly rainfall measured 0·3 mm. in August, 1949 with a shower on 26th, the same amount in July, 1950 with showers on the 17th, 28th and 30th, and a trace in August, 1955 with slight rain on 19th.

A Meteorological Office publication, "Weather in the Persian Gulf and Gulf of Oman", gives the rainfall for the five-year period 1933–37 as nil for the months May to October.

It is clear that the rainfall in the summer of 1956 was quite unusual. Local people say that so much rain has not been experienced in the summer months since 1939, but the amount which fell then is not known as the records are not available.

The photograph facing p. 155 was taken on July 27th, 1956, when the inter-tropical convergence zone lay along the Trucial Coast, just north-west of Sharjah.

E. W. SMITH

REVIEWS

The orientation of dunes in Britain and Denmark in relation to wind. By S. Y. Landsberg. *Geogr. J., London,* **122,** 1956, pp. 176–189. Royal Geographical Society, London.

The June number of the *Geographical Journal* contains the following article of meteorological interest.

Dr. S. Y. Landsberg studies the growth of dunes using Bagnold's result that the rate of transport of sand is proportional to $(V-10)^3$ where V is the wind speed in m.p.h. A sand-transport wind rose is built up by multiplying the frequency of winds of a given speed from a given direction by this transport factor. Good correspondence with the directions of formation of dunes in Britain and Denmark is found except for Culbin Sands (Elgin) and Fowie (near Aberdeen); it is shown that the local topography at these places renders the transport rose for the nearest wind observing station inapplicable.

G. A. BULL

Observatoire de Haute-Provence. 10 in. $\times 7\frac{1}{2}$ in., pp. 23, *Illus.*, Centre National de la Recherche Scientifique, 1956.

We are indebted to the Cultural Service of the French Embassy, London, for a copy of a pamphlet on the new astronomical observatory recently constructed by the Centre National de Recherche Scientifique.

The site of the observatory, which is at St. Michel l'Observatoire, near Forcalquier, Basses Alpes was, it is explained, selected on meteorological considerations. The major work of the Observatory is naturally astronomical and the pamphlet is mainly devoted to that subject. However, work on the optical phenomena of the upper atmosphere is being actively pursued under the direction of Prof. Dufay. The subjects are the light of the night sky and twilight illumination with a view to determine the height of the luminescent layers and to study their variations and the physics of the phenomena. The pamphlet is beautifully illustrated with photographs of the Observatory and of astronomical objects taken from the Observatory.

G. A. BULL

HONOURS AND AWARDS

Dr. J. Glasspoole, Head of the British Climatology Branch of the Meteorological Office, was on March 13, 1957 elected an Honorary Member of the Institution of Water Engineers by the Council of the Institution.

OFFICIAL PUBLICATIONS

Five-year summaries of upper air data

The prices of the forthcoming addenda described in the *Meteorological Magazine* of February 1957 will probably be between 1*s.* 0*d.* and 1*s.* 6*d.* each (exclusive of postage).

ERRATUM

The scale of the chart reproduced on pp. 68, 69 and 70 of the *Meteorological Magazine* for March 1957 is wrongly marked and is intended to represent 100 miles.

METEOROLOGICAL OFFICE NEWS

W.R.A.F.V.R. Meteorological Section.—It was announced in Air Ministry Orders dated March 20, 1957, that the undermentioned non-commissioned officers in the Women's Royal Air Force Volunteer Reserve, Meteorological Section, had been granted the Air Efficiency Award. We offer them our congratulations.

Sergeant M. H. Marsh   Sergeant P. F. Parker

WEATHER OF MARCH 1957

Pressure was 18 mb. below normal near the Azores in mid Atlantic, the "Icelandic" depression being transferred a thousand miles south to be represented by a lowest monthly mean pressure of 994 mb. about 49°N., 31°W. For the fourth successive month this represented much greater intensity of cyclonic activity than normal. It was a greater southward displacement than in February: the position in December and January had been close to normal. Frontal wave developments in March originated repeatedly well south in and near the Gulf of Mexico. For much of the month depressions failed to penetrate NE into the Barents Sea. Pressure was above normal over all the polar regions in a region of generally high pressure extending from China to the Hudson's Bay and South Greenland. There were regions of below normal pressure (anomalies −5 mb.) near the Caspian Sea and in the N. Pacific depression, which was about its normal position near the Aleutians.

Western Europe enjoyed a mild month with the persistent southerly winds, bringing anomalies of +3 to +5°C. in France and England and +6°C. at Spitsbergen. The Central Arctic and further part of polar basin is believed to have been rather colder than normal and near the northern Urals in continental air the mean temperature for the month was 7 to 10°C. below normal. As in February, most of the northern part of N. America, including the region of the Canadian cold pole, was less cold than normal (anomalies of surface temperature reached +5 to +6°C. in northern Quebec). It seems that by March the principal cold pole, though subject to erratic alternations between positions near the Canadian Archipelago and over Siberia, was mostly in the Siberian Arctic.

Temperatures were below normal over southern U.S.A. and the Middle West and probably over a wide area of the western and middle Atlantic including Iceland and South Greenland.

No remarkable features were noticed in the rainfall distribution, apart from considerable excesses in Germany, on the coast of Egypt and most inland districts of India. Unusual snowfalls were reported several times during the month in northern Texas and neighbouring regions just east of the Rockies.

In the British Isles a persistent south to south-easterly air stream maintained exceptionally mild weather for the time of year and brought a number of fronts of varying intensity across the country although depressions kept mainly to the west and north.

For the first four days weather in England and Wales was mostly dry and mild but rather foggy. Day temperatures rose well above normal on the 3rd, reaching 60°F. in places, but there was some air frost and fairly widespread ground frost that night—at Cardington temperature fell to 25°F. in the screen and to 18°F. on the grass. Fog was widespread and locally dense on the 4th and 5th, especially in the Midlands, and persisted throughout the day in many places. From the 5th until the 9th a succession of fronts from the Atlantic moved eastward across the country and weather was mostly cloudy with rain at times and early morning fog patches: the area of greatest rainfall was in the south-west, although on the 8th Eskdalemuir recorded a total of 0·83 in. in 12 hr. With the arrival of drier and sunnier weather from Spain temperatures on the 11th rose sharply into the sixties—more than 15°F. above the mid-March normal—and exceeded 65°F. locally from southern England to as far north as central Scotland. The temperature reached 71°F. at Llandudno and 69°F. at places as far apart as Mildenhall, and Cape Wrath (Sutherland) on the 12th, and on the Air Ministry Roof (London) on the 13th. Parts of England enjoyed a total of over 15 hr. sunshine on these two days. A warm front, associated with a complex Atlantic depression, brought a moister air stream over the country on the 14th with widespread rain. The mild cloudy weather lasted nearly a week; rain fell in most areas nearly every day, but substantial falls were confined mainly to Scotland; Cape Wrath had 3·27 in. in the 36 hr. ending 0900 on the 16th. A temporary influx of cooler air on the 20th brought snow to high ground in Scotland and showers to all areas. The showers were heavy locally in the north with hail and thunder. The following two days were fine and sunny with daily sunshine totals exceeding 10 hr. in some places. An active depression to the north of Scotland brought fairly widespread rain on the 25th and 26th as associated fronts moved across the country; thunderstorms developed fairly widely on the 26th. Rain areas moved across southern England on the 27th and 28th, in rather a flat pressure distribution, with temperature exceeding 60°F. in some places, but during the last three days of the month rain was mainly confined to the west of the country and temperature fell somewhat as winds backed towards the south-east.

Temperature was unusually high for March, and at many places the monthly average exceeded the April normals. Over parts of central England temperature was between six and seven degrees above normal and at Kew it was the warmest March since records began in 1871. Sunshine was below the average generally and at some places it was the dullest March on record. Whereas the mildness of the month has continued to keep the season about three weeks in advance of normal, stock and arable farmers have not been particularly fortunate; cultivation, spring sowings and plantings have been held up, and despite the fact that grass was plentiful the ground was often too soft for grazing.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	74	22	+5·6	103	−1	82
Scotland	72	19	+4·6	115	+1	62
Northern Ireland ...	64	29	+5·3	108	+4	57

RAINFALL OF MARCH 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square	1·06	58	*Glam.*	Cardiff, Penylan	...	...
Kent	Dover	1·26	60	*Pemb.*	Tenby	4·83	156
„	Edenbridge, Falconhurst	1·22	49	*Radnor*	Tyrmynydd	5·16	96
Sussex	Compton, Compton Ho.	2·53	91	*Mont.*	Lake Vyrnwy	6·73	150
„	Worthing, Beach Ho. Pk.	1·37	71	*Mer.*	Blaenau Festiniog	10·67	124
Hants.	St. Catherine's L'thouse	1·90	96	„	Aberdovey	4·80	144
„	Southampton (East Pk.)	2·06	90	*Carn.*	Llandudno	...	...
„	South Farnborough	1·31	66	*Angl.*	Llanerchymedd	3·25	109
Herts.	Harpenden, Rothamsted	1·18	57	*I. Man*	Douglas, Borough Cem.	3·78	128
Bucks.	Slough, Upton	1·07	61	*Wigtown*	Newton Stewart	4·20	122
Oxford	Oxford, Radcliffe	1·70	103	*Dumf.*	Dumfries, Crichton R.I.	2·56	86
N'hants.	Wellingboro' Swanspool	2·14	120	„	Eskdalemuir Obsy.	5·30	108
Essex	Southend, W. W.	·88	57	*Roxb.*	Crailing	1·41	66
Suffolk	Felixstowe	...	...	*Peebles*	Stobo Castle	2·54	88
„	Lowestoft Sec. School	1·68	104	*Berwick*	Marchmont House	1·84	69
„	Bury St. Ed., Westley H.	1·76	93	*E. Loth.*	North Berwick Gas Wks.	1·91	103
Norfolk	Sandringham Ho. Gdns.	2·33	123	*Midl'n.*	Edinburgh, Blackf'd. H.	...	...
Wilts.	Aldbourne	2·06	87	*Lanark*	Hamilton W. W., T'nhill	2·97	106
Dorset	Creech Grange	3·54	126	*Ayr*	Prestwick	3·94	169
„	Beaminster, East St.	3·61	123	„	Glen Afton, Ayr San.	4·76	113
Devon	Teignmouth, Den Gdns.	2·88	111	*Renfrew*	Greenock, Prospect Hill	5·95	128
„	Ilfracombe	...	...	*Bute*	Rothesay, Ardencraig	...	...
„	Princetown	10·93	160	*Argyll*	Morven, Drimnin	5·62	116
Cornwall	Bude	3·10	127	„	Poltalloch	...	...
„	Penzance	4·87	152	„	Inveraray Castle	...	...
„	St. Austell	5·66	165	„	Islay, Eallabus	4·23	111
„	Scilly, Tresco Abbey	4·42	169	„	Tiree	4·69	140
Somerset	Taunton	1·82	88	*Kinross*	Loch Leven Sluice	2·83	95
Glos.	Cirencester	2·75	115	*Fife*	Leuchars Airfield	...	...
Salop	Church Stretton	2·29	95	*Perth*	Loch Dhu	...	...
„	Shrewsbury, Monkmore	1·58	95	„	Crieff, Strathearn Hyd.	4·61	144
Worcs.	Malvern, Free Library	2·22	114	„	Pitlochry, Fincastle	3·47	126
Warwick	Birmingham, Edgbaston	2·49	118	*Angus*	Montrose Hospital	2·18	105
Leics.	Thornton Reservoir	2·29	124	*Aberd.*	Braemar	2·29	77
Lincs.	Boston, Skirbeck	1·62	104	„	Dyce, Craibstone	2·24	85
„	Skegness, Marine Gdns.	1·51	91	„	New Deer School House	2·83	109
Notts.	Mansfield, Carr Bank	...	...	*Moray*	Gordon Castle	2·74	118
Derby	Buxton, Terrace Slopes	4·50	109	*Nairn*	Nairn, Achareidh	3·31	180
Ches.	Bidston Observatory	1·74	92	*Inverness*	Loch Ness, Garthbeg	...	...
„	Manchester, Ringway	...	...	„	Loch Hourn, Kinl'hourn	8·45	92
Lancs.	Stonyhurst College	3·91	106	„	Fort William, Teviot	8·14	121
„	Squires Gate	...	...	„	Skye, Broadford	...	...
Yorks.	Wakefield, Clarence Pk.	1·29	72	„	Skye, Duntulm	5·24	119
„	Hull, Pearson Park	...	...	*R. & C.*	Tain, Mayfield	2·82	125
„	Felixkirk, Mt. St. John	1·49	76	„	Inverbroom, Glackour	...	...
„	York Museum	1·66	99	„	Achnashellach	...	...
„	Scarborough	1·13	63	*Suth.*	Lochinver, Bank Ho.	3·89	104
„	Middlesbrough	·83	53	*Caith.*	Wick Airfield	...	...
„	Baldersdale, Hury Res.	2·00	69	*Shetland*	Lerwick Observatory	...	...
Norl'd.	Newcastle, Leazes Pk.	1·15	56	*Ferm.*	Crom Castle	4·23	137
„	Bellingham, High Green	2·57	97	*Armagh*	Armagh Observatory	2·45	104
„	Lilburn Tower Gdns.	1·54	58	*Down*	Seaforde	4·43	152
Cumb.	Geltsdale	...	...	*Antrim*	Aldergrove Airfield	...	...
„	Keswick, High Hill	3·50	78	„	Ballymena, Harryville	3·07	97
„	Ravenglass, The Grove	3·12	101	*L'derry*	Garvagh, Moneydig	...	...
Mon.	A'gavenny, Plâs Derwen	...	...	„	Londonderry, Creggan	2·49	78
Glam.	Ystalyfera, Wern House	3·68	110	*Tyrone*	Omagh, Edenfel	3·61	115

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OCCURRENCE OF LOW LAYER-TYPE CLOUD OVER EASTERN ENGLAND IN RELATION TO THE SYNOPTIC SITUATION

By P. G. F. CATON, M.A., Ph.D.

Summary.—An investigation has been made of the occurrence of low layer-type cloud at four stations in East Anglia and the east Midlands, the data (amount, height of base) being related to the synoptic situation, season of the year, time of day, etc. The study has shown that frontal conditions and south-westerly tropical air streams, relative to their periods of influence, are accompanied by rather more low cloud than situations when the air flows from the North Sea. Significant differences were revealed between the average cloud height over individual stations.

Introduction.—*Cloud classification.*—The cloud layers reported in the hourly observations of Bircham Newton (220 ft. above M.S.L.), Mildenhall (15 ft. above M.S.L.), Cranfield (350 ft. above M.S.L.) and Felixstowe (10 ft. above M.S.L.) for the period January–December 1944 were classified as follows:—

CX	Sky obscured	Visibility normally less than 550 yd.
C1	Severe* stratus	9–10 tenths (7–8 oktas) layer base below 550 ft. or 4–8 tenths (3–6 oktas) layer base below 250 ft.
C2	Moderate* stratus	9–10 tenths (7–8 oktas) layer base 550–950 ft. or 4–8 tenths (3–6 oktas) layer base 250–550 ft.
C3	Slight* stratus	9–10 tenths (7–8 oktas) layer base 950–1,450 ft. or 4–8 tenths (3–6 oktas) layer base 550–950 ft. or trace—3 tenths (2 oktas) layer base below 950 ft.
C4	.. ..	9–10 tenths (7–8 oktas) layer base 1,450–1,950 ft. or 4–8 tenths (3–6 oktas) layer base 950–1,550 ft.
C5	.. ..	9–10 tenths (7–8 oktas) layer base 1,950–7,900 ft.

*These adjectives are used for convenience of description only.

If, at one hour, two layers existed satisfying different specifications, the class of lower number was assigned. No account was taken of cloud type, although the neglect of layers 8 tenths (6 oktas) or less in amount above 1,550 ft. effectively eliminated cumulus observations. Thus category C5 consisted mainly of stratocumulus, altostratus (below 8,000 ft.) and nimbostratus cloud.

During periods of fog, the cloud report assumed one of three forms:—

(i) cloud type and base stated as if no fog present

(ii) cloud amount reported as nil (Beaufort letter *b*)

(iii) sky reported as obscured (Beaufort letter *o*).

In this investigation it was decided to exclude cases of shallow radiation fog (ii), but to include cases when the vertical thickness of the fog was such that the sky was obscured (iii); the latter effectively represent stratus "on the surface". Instances of (i) were considered on their merits, ignoring the visibility.

In the discussion, reference will sometimes be made to the frequency of conditions worse than fixed limits. For convenience, abbreviations such as CX−1 will be used to describe conditions including or worse than cloud category C1, and so on.

Synoptic classification.—The synoptic situation at each hour was classified under one of the following headings. Conditions with geostrophic wind less than 15 kt. are indicated by an asterisk; the absence of an asterisk against a particular class means that only situations with geostrophic wind exceeding 15 kt. are included.

	Notation for diagrams, etc.
S1 Fronts	
(*a*) moving from south-west, west or north-west	Fw
(*b*) moving from north, north-east, east, south-east or south... ...	FE
(*c*)*moving from any direction, including quasi-stationary and complex situations...	F*
S2 Tropical maritime air	
(*a*) reaching the British Isles in a direct south-westerly air stream ...	Tsw
(*b*) arriving from west or west-north-west	Tw
S3 Polar maritime air	
(*a*) returning in a south-westerly air stream	Psw
(*b*) arriving from west or west-north-west (wind direction at 2,000 ft. 250–315°)	Pw
(*c*) arriving from north-north-west or north (wind direction at 2,000 ft. 320–25°)	PN
S4 North-easterly and easterly air streams	
(*a*) air flowing from north-east or east (wind direction at 2,000 ft. 30–105°)	NE
(*b*)*air flowing from north-east or east	NE*
S5 South-easterly and southerly air streams air flowing from south-east or south (wind direction at 2,000 ft. 110–190°)	SE
S6 Slack pressure gradients	
(*a*)*air flowing from south-east, south, south-west, west, north-west or north	*
(*b*)*conditions of light wind of no definite direction (geostrophic wind less than 6 kt.)	**

The alternatives within each heading were separate classes during the analysis, and have been grouped because this proved justifiable.

In order to determine the representativeness of the year 1944, an examination was made of the low cloud and surface wind direction summaries for Mildenhall 1944–48. In 1944, north-easterly and easterly air streams (class S4) were about 20 per cent. below average frequency in the winter, and 50 per cent. above average frequency in the summer; otherwise the year chosen appeared to be reasonably representative. The abnormalities in cloud occurrence could roughly be associated with those of wind direction. Therefore, although the subsequent discussion is based on only one year's data, it is thought that a reasonably representative picture is portrayed of average cloud conditions associated with the various synoptic classes.

Presentation of the statistics.—The overall frequencies at the individual stations of sky obscured, severe stratus, moderate and slight stratus, and of cloud categories C4 and C5, are shown in Table I.

TABLE I—OVERALL PERCENTAGE FREQUENCIES OF CLOUD CATEGORIES

	Cloud categories				
	CX	C1	C2 and C3	C4 and C5	Total
			per cent.		
Bircham Newton	3·3	4·3	13·5	20·9	42·0
Mildenhall	2·9	2·1	9·5	26·2	40·7
Cranfield	3·5	3·6	13·9	20·2	41·2
Felixstowe	1·3	1·3	6·3	27·2	36·1

Fig. 1 shows the over-all same cloud frequency for the separate synoptic classes. The abscissae are proportional to the periods of influence of the synoptic situations, whilst the ordinates represent the frequency of stratus within those situations. Thus, areas on the histograms correspond to actual numbers of observations.

Fig. 2 contains histograms showing the incidence of the various cloud categories at Cranfield for fronts moving from south-west, west or north-west with geostrophic wind exceeding 15 kt. (class S1 (*a*)). The figures beneath the columns are the average durations in hours of the conditions when they occur. The fronts are sub-divided into

(i) warm fronts moving from south-west or west

(ii) warm fronts moving from north-west

(iii) cold fronts

(iv) occluding fronts (station within 100 miles of path of point of occlusion)

(v) occlusions

(vi) frontal linkages (sections of front which approached or passed the station as a cold front and returned as a warm front without intermediately passing out of range of the station concerned).

The zone limits adopted from experience were

(i) 150 miles pre-surface front, 100 miles post-front for warm and occluding fronts

(ii) 100 miles pre-front, 100 miles post-front for occlusions

(iii) 50 miles pre-front (warm air) 100 miles post-front (cold air) for cold fronts and frontal linkages.

Fig. 3 shows the seasonal variation of cloud conditions in the various synoptic classes (winter, December–Febriary; spring, March–May; etc.). The data are for Cranfield with, in addition, diagrams for Bircham Newton in north-easterly and easterly air streams; otherwise the variations at the other stations resemble those at Cranfield. The ordinates are as in Fig. 1, but the abscissae have no frequency significance; mean ordinates have been entered when the data for two seasons did not appear to differ significantly.

Fig. 4 illustrates the diurnal variation of cloud conditions in north-easterly and easterly air streams at Bircham Newton (coastal) and Cranfield (inland). The ordinates are as in Fig. 1, and the abscissae are 3-hr. periods 0100–0300 G.M.T., 0400–0600, etc. The diagrams are compounded of conditions in

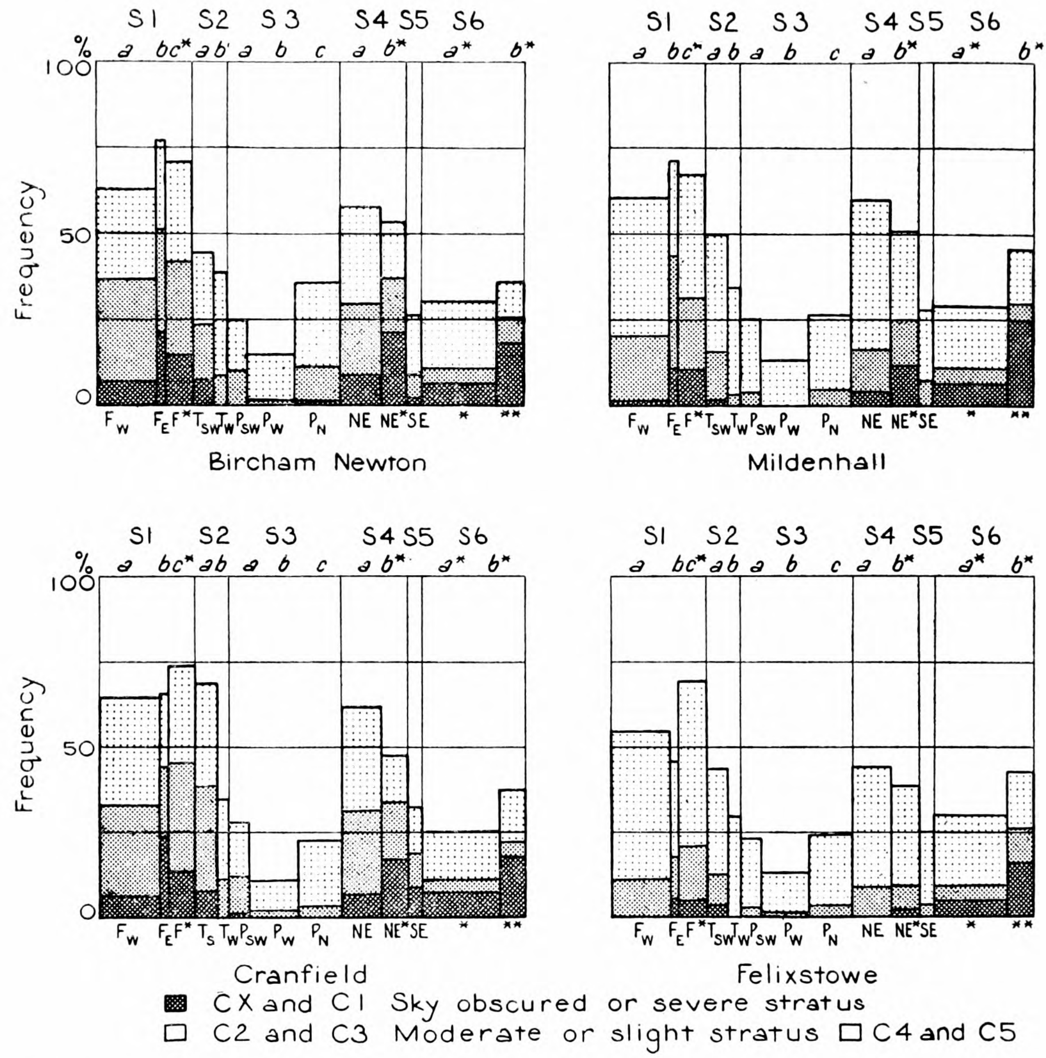

FIG. 1—AVERAGE ANNUAL FREQUENCIES OF CLOUD IN VARIOUS SYNOPTIC CLASSES

Where any ordinate is less than five per cent. shading as for the next above ordinate has been used.

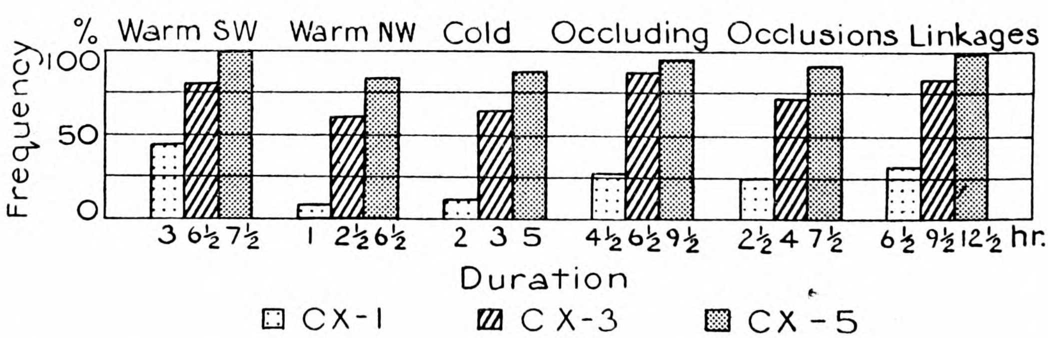

FIG. 2—FREQUENCIES OF CLOUD CONDITIONS AND AVERAGE DURATIONS WHEN OCCURRING FOR CLASS S1 (a) (F_W) SYNOPTIC SITUATIONS AT CRANFIELD

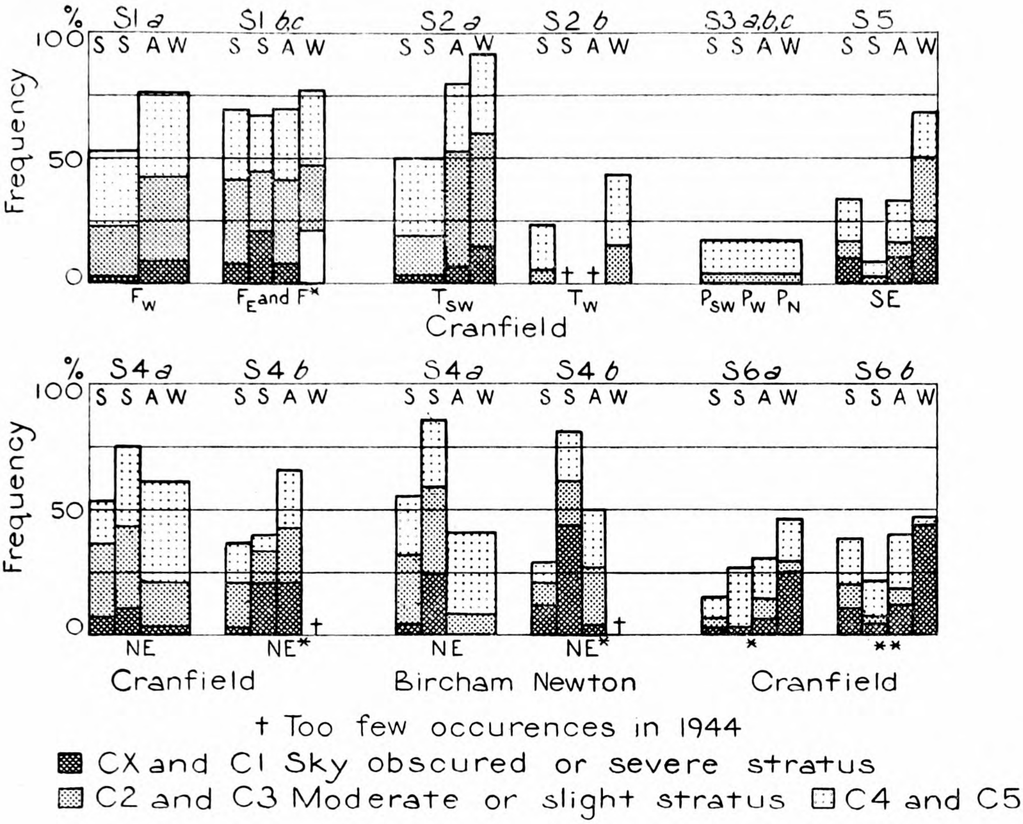

FIG. 3—SEASONAL VARIATIONS OF CLOUD SEVERITY

Where any ordinate is less than five per cent. shading as for the next above has been used.

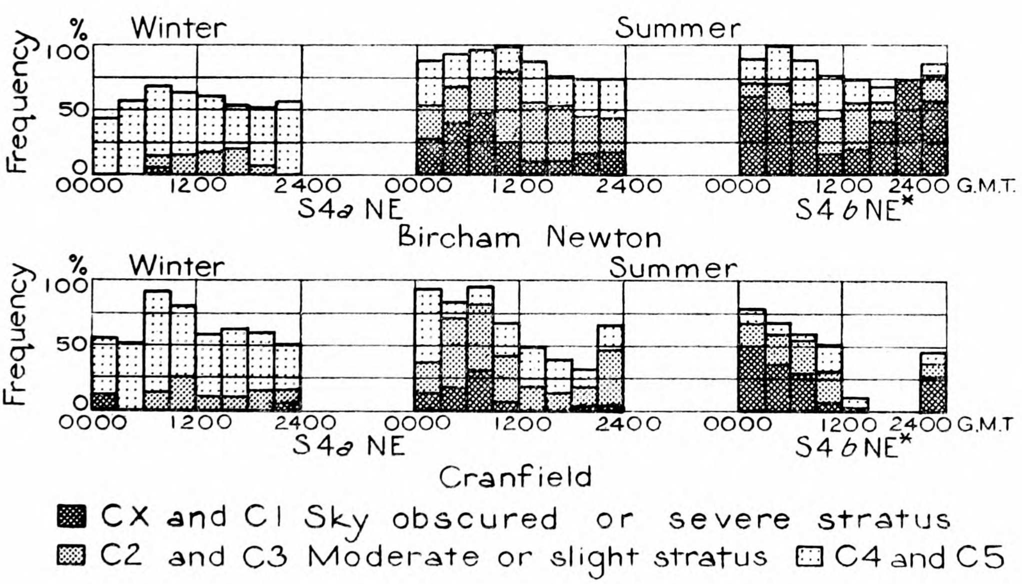

FIG. 4—DIURNAL VARIATIONS OF CLOUD SEVERITY IN NORTH-EASTERLY AND EASTERLY AIR STREAMS

Where any ordinate is less than five per cent. shading as for the next above ordinate has been used.

several periods of varying duration, usually less than a complete 24 hours; thus some irregularities in their general pattern may be expected.

The frequencies represented in Figs. 2, 3 and 4 are averages derived from limited numbers of occurrences. Although individual values may not be accurate guides to the long-period normals, the differences subsequently remarked upon are thought to be significant.

Discussion.—The main features of Table I are: (*a*) the relatively low frequency of sky obscured at Felixstowe, and of severe, moderate and slight stratus at Felixstowe and Mildenhall; (*b*) the relatively high frequency of cloud categories C4 and C5 at the above two stations, which combined with (*a*) leads to a nearly constant frequency of CX—5 conditions. However, considering the method of classification which lays emphasis on the lowest cloud layer, it is probable that the frequency of cloud actually occurring at levels 4 and 5 is approximately equal at the four stations. In 1944, winter was the most cloudy season and spring the least (Cranfield, CX—5 conditions, 49 per cent. and 31 per cent. respectively).

Sky obscured conditions were almost entirely confined to synoptic situations with geostrophic wind less than 15 kt. (those marked with an asterisk). Severe stratus occurred with roughly equal frequency (relative to the periods of influence) in north-easterly situations (NE, NE*), at fronts (F_W, F_E and F*), and in south-westerly tropical air streams (T_{SW}). However, moderate or slight stratus was rather more frequent at fronts than in north-easterly situations; whilst, especially at Cranfield, south-westerly tropical air streams were accompanied by much cloud at these levels.

At Bircham Newton and Cranfield, fronts produced the highest average frequency of CX—3 conditions, with north-easterly situations and south-westerly tropical air streams holding second and third places according to station. Mildenhall and Felixstowe, compared with the other stations, experienced a lower frequency of CX—3 conditions in each of the above synoptic situations, but a slightly higher frequency of the same conditions in situations with very light wind (**). Thus, at Mildenhall and Felixstowe, comparing the synoptic classes, situations with very light wind produced a relatively high frequency of CX—3 conditions. At all stations, CX—3 conditions were least frequent in polar maritime air from west or west-north-west (P_W).

The average cloud conditions in the main synoptic classes are considered briefly below:—

S1 *Fronts.*—Features of Fig. 2 (F_W fronts only) of particular interest are the differences between warm fronts according to direction of motion (statistically significant at the 5 per cent. level), and the prolonged periods of stratus which occurred at frontal linkages.

In each type of F_W front, the frequency of CX—1 and CX—3 conditions decreased sharply from Cranfield and Bircham Newton to Mildenhall and Felixstowe. For example, the average frequencies of CX—2 and CX—4 conditions at Mildenhall were respectively closely similar to those of CX—1 and CX—3 conditions at Bircham Newton and at Cranfield. The general level of the cloud base, measured above ground, was thus 400–500 ft. higher at Mildenhall (and, correspondingly, about 800 ft. higher at Felixstowe) than at Bircham Newton and Cranfield. As these differences substantially exceed those between the station altitudes, the data imply that the cloud base does not follow a constant height above sea level. Cranfield's altitude is probably typical of that of the east Midlands, and the rise in cloud base eastwards is presumably due to a drying of the air with increasing distance from the Atlantic. The lowering of the cloud base at Bircham Newton is possibly associated with the forced ascent and, in some cases, increased moisture content of the air after passing over the Wash.

F_W fronts produced rather worse conditions in autumn and winter than in spring and summer. However, more detailed analysis suggests that the effect was confined mainly to cold and occluding fronts and to frontal linkages. F_E and F* fronts were accompanied by worse conditions than F_W fronts, particularly as regards occurrence of sky obscured and severe stratus. The seasonal variation shows a double maximum of CX—1 conditions due to the combination of fronts moving from north-east or east, which have a cloud maximum in summer, with fronts from other directions which have worst conditions in winter.

S2 *Tropical maritime air streams.*—At Cranfield, conditions in south-westerly tropical air streams (T_{SW}) were least severe in spring and summer. Moreover, in all seasons except winter, the cloud severity decreased very considerably from Cranfield to Bircham Newton, Mildenhall and Felixstowe, the frequencies of CX—3 and CX—4 conditions at Mildenhall being comparable only with those of CX—1 and CX—2 conditions at Cranfield. In winter, the eastwards decrease of cloud severity was less marked. Study of the diurnal variation showed that conditions were worst at night and in the early morning.

Tropical air reaching the British Isles from west or west-north-west (T_W) was generally accompanied by less stratus cloud (C1—3) than air arriving direct from the south-west. The seasonal variation indicates a winter maximum.

S3 *Polar maritime air streams.*—Polar maritime air returning in a south-west air stream was also accompanied by less low cloud (C1—3) than tropical air from the south-west; the difference was marked in autumn and winter, but, except at Cranfield, was insignificant in spring and summer.

Polar maritime air arriving from west and west-north-west was the most cloud free of the synoptic classes. The frequency of CX—3 conditions averaged only 1·9 per cent. at Cranfield and Bircham Newton, and 0·6 per cent. at Mildenhall and Felixstowe, these occurrences mainly being isolated and associated with showers. Polar air arriving direct from north-north-west or north was accompanied by rather more cloud, especially at Bircham Newton where these winds are on shore.

There was no significant seasonal variation in any of these classes.

S4 *North-easterly and easterly air streams.*—S4(*a*) Air streams with geostrophic wind exceeding 15 kt. (NE). In autumn and winter 1944, severe and moderate stratus was rare, but slight stratus or cloud at levels C4 or C5 occurred on roughly 50 per cent. of occasions. The station altitude influenced the individual frequencies of CX—3, CX—4 and CX—5 conditions; thus it appeared that, on average, the cloud base was at a constant height above sea level over East Anglia, but 300–350 ft. lower at Cranfield. The effect is presumably due to the forced ascent of air over the Midland heights. There was no definite diurnal variation, except perhaps a tendency to a lower cloud base by day presumably associated with increased turbulence.

In summer, severe, moderate and slight stratus occurred frequently at Bircham Newton, Mildenhall and Cranfield. At Bircham Newton, presumably owing to the coastal position, conditions were particularly bad and, on a few occasions, the sky was obscured. The frequency of CX—5 conditions decreased with increasing distance from the coast (Bircham Newton 85 per cent., Cranfield 65 per cent.) due mainly to the greater tendency at inland stations for the cloud to break or disperse during the day. Curiously, Felixstowe is apparently sheltered from the main cloud effects of north-easterly and easterly air streams; severe stratus was rare, and CX—5 conditions covered only 40 per cent. of the time.

In spring 1944 the cloud conditions were intermediate between those of winter and summer, being roughly equal at Bircham Newton and Cranfield, and progressively less severe at Mildenhall and Felixstowe.

S4(*b*). Air streams with geostrophic wind less than 15 kt. (NE*). In winter, sky obscured and severe stratus were frequently recorded at the inland stations between 2200 and 0900 G.M.T., and everywhere the frequency of CX—3 conditions was approximately double that in class S4(*a*). In summer also, the frequencies of sky obscured and severe stratus were higher than in class S4(*a*); however, at the inland stations, the frequencies of CX—3 and CX—5 conditions were less, due, as mentioned below, to the greater likelihood of cloud dispersal during the day.

S4(*a*) and S4(*b*). At Bircham Newton in bad situations, the stratus may be expected to vary only from severe around dawn to moderate in the afternoon or early night. However, at Cranfield, the severe stratus frequently occurring between 0100 and 0900 hr. will lift during the late morning, and especially in the weak air streams (NE*) there is a very good chance of a clearance to no classifiable cloud by early afternoon; the stratus may be expected to re-form sometime after 2100, frequently suddenly at a low level. Of course, these conclusions assume that the humidity and thermal structure of the air stream remain basically constant, and this is by no means always so.

The presence beneath stratus cloud of a layer of poor visibility has been reported by several authors, particularly Bull[1] and Lamb[2]. In this investigation the visibility at ground level in north-easterly and easterly situations was correlated with the height of the cloud base. The frequency of visibilities less than $2\frac{1}{2}$ miles was found to increase from 20 per cent. to 50–70 per cent. as the cloud base lowered through a critical value, about 400 ft.; and for bases estimated at 100 ft. the median visibility was $1\frac{1}{4}$ miles. The layer of poor visibility is probably associated with an increase in size of hygroscopic condensation nuclei as the relative humidity approaches 100 per cent.

S5 *South-easterly and southerly air streams*.—These situations were accompanied by very much less cloud than north-easterly and easterly air streams, and the seasonal variation was of opposite phase (Fig. 3). Especially in winter, the conditions were worst at Cranfield, possibly due to a reduction in the average surface wind and consequent increased liability to fog to the lee of the Chiltern Hills.

S6 *Slack pressure gradients*.—These situations accounted for the majority of occurrences of sky obscured. The worst season was winter (Fig. 3) when almost one half of the periods were accompanied by fog, occasionally persisting for the entire duration of these situations. A few periods of stratus occurred in each season, and cloud at levels C4 or C5 was moderately frequent. The average conditions at the four stations were more nearly equal than in the synoptic divisions previously considered.

The preceding discussion has been concerned with the incidence of the various cloud categories in the individual synoptic classes; the frequency of occurrence of the particular class has been of no consequence. In the following table the latter factor is included. Table II gives the distribution of the occurrences of the cloud categories amongst the main synoptic divisions; the figures are means over the four stations.

TABLE II—PERCENTAGES OF ANNUAL TOTALS OF CLOUD CATEGORIES ACCOMPANYING PARTICULAR SYNOPTIC DIVISIONS

Synoptic division	Percentage time of influence	Cloud categories			
		CX	C1	C2 and C3	C4 and C5
				per cent.	
S1 Fronts	22·6	15·4	36·4	46·5	32·7
S2 Tropical air	7·8	1·0	7·6	9·2	9·5
S3 Polar air	27·0	0·3	2·0	8·7	19·0
S4 North-easterly situations	15·8	14·1	28·7	21·5	19·1
S5 South-easterly situations	3·3	1·7	0·9	1·9	2·5
S6 Slack pressure gradients	23·5	67·5	24·4	12·2	17·2

Certain of the synoptic divisions were especially important as cloud producers in certain seasons; thus, in summer 1944, north-easterly situations (probably of above average occurrence, see p. 162) accounted for substantially more severe stratus than fronts. However, over the year north-easterly and easterly air streams were accompanied by only about 25 per cent. of the total occurrences of stratus (levels C1–3), compared with approximately 40 per cent. at fronts.

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RELATIONS BETWEEN STANDARD DEVIATIONS OF DAILY, 5-DAY, 10-DAY AND 30-DAY MEAN TEMPERATURES

By A. F. JENKINSON, M.A.

Summary.—An examination of data for the months of January, April, July and October at fourteen widely spaced northern-hemisphere stations shows that the ratios σ_1/σ_{30}, σ_5/σ_{30}, σ_{10}/σ_{30}, where σ_1, σ_5, σ_{10}, σ_{30} are respectively the standard deviations of daily, 5-day, 10-day and monthly mean temperatures, vary little about the mean values of 2·03, 1·62 and 1·31. A brief theoretical discussion is given.

Data.—The stations for which data were examined are listed in Table I.

For stations 1 to 10 the daily mean temperatures were extracted for each day of the four months January, April, July and October for a 10-yr. period, and σ_1, σ_5, σ_{10}, σ_{30}, the standard deviations of mean daily, 5-day, 10-day and

TABLE I—LIST OF STATIONS AND PERIODS EXAMINED

No.	Station	Latitude	Longitude	Period for $\sigma_1, \sigma_5, \sigma_{10}$	Period for σ_{30}
1	London (Kew)	51°N.	0°	1928–37	1900–49
2	Naples	41°N.	14°E.	1919–28	1901–25
3	Alexandria	31°N.	30°E.	1931–40	1931–40
4	Odessa	46°N.	31°E.	1903–12	1896–1915
5	Leningrad	60°N.	30°E.	1901–08, 1910–11	1891–1915
6	Tomsk	56°N.	85°E.	1901–08, 1910–11	1886–1910
7	Rykovskoe	52°N.	142°E.	1894–1903	1886–1904
8	Tokyo	36°N.	139°E.	1944–53	1924–53
9	Toronto	44°N.	79°W.	1944–53	1924–53
10	New York	41°N.	74°W.	1936–45	1921–50
11	Edmonton	54°N.	113°W.	1942–51	1922–51
12	Churchill	59°N.	94°W.	1942–51	1932–54
13	Gander	49°N.	55°W.	1942–51	1942–51
14	San Francisco	35°N.	122°W.	1941–50	1921–50

30-day (monthly) temperatures were computed; for stations 11 to 14 only 5-day mean temperatures were extracted, and σ_5, σ_{30} were computed. In computing values of σ_1, σ_5 and σ_{10} only variations of temperature from the average for the time of month were considered. Variations due to the change of average temperature during the month were eliminated; for the stations examined, this change was considerable during the months of April and October.

Tabulation of results.—The computed values of σ_1, σ_5, σ_{10}, σ_{30} are set out in Table II.

The relations between σ_1, σ_5, σ_{10}, σ_{30}.— σ_5 *and* σ_{30}.—Graphs of values of σ_5 against σ_{30} for all stations are shown in Fig. 1. The estimate of σ_5 from σ_{30} is

$$\sigma_5 = 1 \cdot 62\, \sigma_{30}$$

Using this relation, values of σ_5 were estimated from σ_{30}; they are compared with observed values in Table III.

The mean error is 6 per cent. in January, 7 per cent. in April, 9 per cent. in July and 10 per cent. in October.

σ_1 *and* σ_{30}; σ_{10} *and* σ_{30}.—Fig. 2 shows the graph of σ_1 against σ_{30}; and Fig. 3 the graph of σ_{10} against σ_{30}. Estimates of σ_1 and σ_{10} in terms of σ_{30} are:

$\sigma_1 = 2 \cdot 03\, \sigma_{30}$, with a mean error of 9 per cent.

$\sigma_{10} = 1 \cdot 31\, \sigma_{30}$, with a mean error of 9 per cent.

Estimates of σ_5, σ_{10}, σ_{30} *in terms of* σ_1.—Using only stations 1 to 10, the following estimates were obtained:

$\sigma_5 = 0 \cdot 78\, \sigma_1$, with a mean error of 6 per cent.

$\sigma_{10} = 0 \cdot 64\, \sigma_1$, with a mean error of 10 per cent.

$\sigma_{30} = 0 \cdot 49\, \sigma_1$, with a mean error of 10 per cent.

Seasonal and regional variation of the ratios among σ_1, σ_5, σ_{10}, σ_{30}.—Means are given in Table IV of the various ratios, for

(i) each station with all months combined
(ii) each month with all stations combined
(iii) all stations and all months combined.

Theoretical approach.—The variance of the mean of n correlated variables $x_1, x_2, \ldots x_n$ is

$$\frac{1}{n^2}\left(s_1^2 + s_2^2 + \ldots s_n^2 + 2\sum_{i>j} r_{ij}\, s_i s_j\right), \qquad \ldots\ldots (1)$$

TABLE II—COMPUTED VALUES OF STANDARD DEVIATION OF TEMPERATURE, (°C.)

	London (Kew)				Naples				Alexandria			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
σ_1	3·13	2·40	2·28	2·60	2·48	2·33	1·86	2·60	1·73	1·96	0·73	1·37
σ_5	2·58	1·88	1·83	1·92	1·84	1·84	1·60	2·03	1·51	1·44	0·64	1·15
σ_{10}	2·22	1·50	1·59	1·47	1·62	1·59	1·45	1·84	1·39	1·05	0·58	0·88
σ_{30}	1·66	1·22	1·36	1·29	1·22	1·08	1·12	1·21	0·87	0·73	0·49	0·77

	Odessa				Leningrad				Tomsk			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
σ_1	5·29	2·67	2·50	3·70	6·50	3·51	3·29	3·45	8·17	4·51	3·43	4·17
σ_5	4·26	1·93	1·84	2·97	5·13	2·85	2·81	2·83	6·51	4·08	2·85	2·98
σ_{10}	3·28	1·56	1·28	2·50	4·61	2·51	2·41	2·32	4·87	3·21	2·26	2·23
σ_{30}	2·87	1·28	1·09	2·00	2·98	1·97	1·56	2·08	4·03	2·55	1·66	2·04

	Rykovskoe				Tokyo				Toronto			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
σ_1	6·63	3·45	3·12	3·22	2·21	2·65	2·46	2·01	5·54	3·65	2·52	3·64
σ_5	5·21	2·59	2·33	2·05	1·57	2·03	2·15	1·21	4·16	2·81	1·81	2·72
σ_{10}	4·45	1·81	1·98	1·51	1·34	1·55	1·94	0·98	3·77	2·07	1·46	2·18
σ_{30}	3·43	1·38	1·54	1·10	0·96	0·97	1·44	0·77	2·56	1·75	1·06	1·64

	New York				Edmonton				Churchill			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
σ_1	4·81	4·16	2·36	3·73	...	...	...	...	...	...	...	...
σ_5	3·71	3·17	1·67	2·61	9·08	4·45	1·79	3·94	5·96	5·21	2·72	3·61
σ_{10}	3·06	2·85	1·31	1·94	...	...	...	...	...	...	...	...
σ_{30}	2·49	1·57	0·95	1·70	5·35	2·78	0·86	2·14	3·98	3·00	1·50	2·51

	Gander				San Francisco			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
σ_5	3·92	2·39	2·24	1·86	2·26	1·50	0·99	1·49
σ_{30}	2·12	1·56	1·42	1·08	1·49	1·07	0·58	0·67

TABLE III—COMPARISON OF OBSERVED AND ESTIMATED VALUES OF σ_5, (°C.)

	January		April		July		October	
	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated
London (Kew)	2·58	2·69	1·88	1·97	1·83	2·21	1·92	2·19
Naples	1·84	1·98	1·84	1·75	1·60	1·81	2·03	1·96
Alexandria	1·51	1·41	1·44	1·39	0·64	0·80	1·15	1·25
Odessa	4·26	4·65	1·93	2·08	1·84	1·76	2·97	3·24
Leningrad	5·13	4·83	2·85	3·19	2·81	2·53	2·83	3·37
Tomsk	6·51	6·51	4·08	4·13	2·85	2·70	2·98	3·30
Rykovskoe	5·21	5·56	2·59	2·24	2·33	2·49	2·05	1·78
Tokyo	1·57	1·56	2·03	1·57	2·15	2·33	1·21	1·25
Toronto	4·16	4·25	2·81	2·84	1·81	1·72	2·72	2·65
New York	3·71	4·03	3·17	2·54	1·67	1·54	2·61	2·75
Edmonton	9·08	8·87	4·45	4·50	1·79	1·40	3·94	3·46
Churchill	5·96	6·45	5·21	4·86	2·72	2·43	3·61	4·07
Gander	3·92	3·43	2·39	2·43	2·24	2·30	1·86	1·75
San Francisco	2·26	2·41	1·50	1·73	0·99	0·94	1·49	1·09

where s_i is the standard deviation of x_i and r_{ij} is the correlation coefficient between x_i and x_j.

For n successive daily values of a meteorological element we have the relations

$$\left.\begin{aligned} s_1 &= s_2 = s_3 = \ldots = s_n \\ r_{ij} &= r_{i+m,\ j+m} = r_{i-j}, \text{ say} \end{aligned}\right\} \quad \ldots\ldots (2)$$

Thus the ratio of the variance of the mean of n daily values to that of the daily mean is

$$\frac{\sigma_n^2}{\sigma_1^2} = \frac{1}{n^2}\left(n + 2\sum_{i>j} r_{i-j}\right). \quad \ldots\ldots (3)$$

It is usually assumed for meteorological data that

$$r_k = r_1^k. \quad \ldots\ldots (4)$$

TABLE IV—SEASONAL AND REGIONAL VARIATION OF THE RATIOS AMONG σ_1, σ_5, σ_{10}, σ_{30}

		σ_5/σ_1	σ_{10}/σ_1	σ_{30}/σ_1	σ_1/σ_{30}	σ_5/σ_{30}	σ_{10}/σ_{30}	σ_5/σ_{30}
(i)	London	0·79	0·65	0·53	1·88	1·48	1·23	...
	Naples	0·79	0·70	0·50	2·00	1·58	1·40	...
	Alexandria	0·82	0·68	0·49	2·02	1·66	1·36	...
	Odessa	0·78	0·61	0·51	1·95	1·52	1·19	...
	Leningrad	0·81	0·71	0·51	1·95	1·58	1·40	...
	Tomsk	0·81	0·62	0·51	1·97	1·60	1·22	...
	Rykovskoe	0·74	0·60	0·45	2·20	1·64	1·31	..
	Tokyo	0·75	0·62	0·44	2·25	1·68	1·40	..
	Toronto	0·75	0·62	0·46	2·19	1·64	1·35	...
	New York	0·74	0·61	0·45	2·24	1·66	1·37	...
	Edmonton	...	...	...	...	1·73	...	...
	Churchill	...	...	...	...	1·60	...	...
	Gander	...	...	...	...	1·68	...	...
	San Francisco	...	...	...	...	1·61	...	...
(ii)	January	0·79	0·66	0·49	2·02	1·58	1·33	1·60
	April	0·79	0·63	0·46	2·16	1·70	1·36	1·67
	July	0·79	0·66	0·50	2·00	1·59	1·33	1·64
	October	0·74	0·58	0·48	2·09	1·61	1·22	1·59
(iii)		Stations 1 to 10						Stations 1 to 14
		0·78	0·64	0·49	2·03	1·60	1·31	1·62

NOTE.—(i) Mean ratios for each station separately with all months combined,
(ii) mean ratios for each month separately and all stations combined,
(iii) mean ratios all months combined and all stations combined.

TABLE V—THEORETICAL VALUES OF σ_n/σ_1

r_1	σ_5/σ_1	σ_{10}/σ_1	σ_{30}/σ_1
0·9	0·92	0·85	0·66
0·8	0·85	0·73	0·51
0·7	0·78	0·64	0·41
0·6	0·72	0·57	0·35
Mean values computed from data	0·78	0·64	0·49

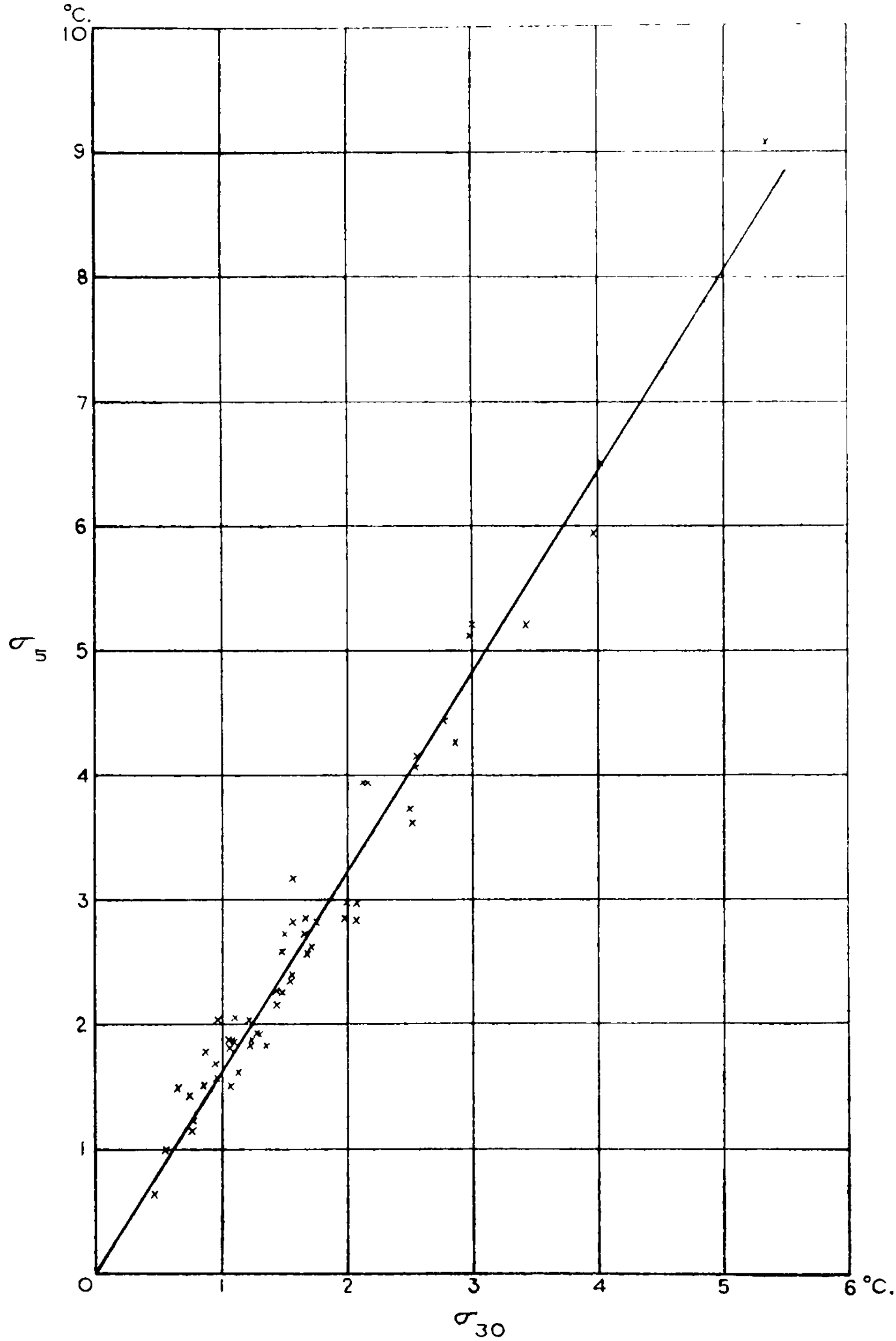

FIG. 1—RELATION BETWEEN STANDARD DEVIATIONS OF 5-DAY AND MONTHLY MEAN TEMPERATURES

This can be shown[1] to be equivalent to assuming that the series of daily values is made up of random variations combined with some degree of persistence, with an autocorrelation r_1 between successive daily values.

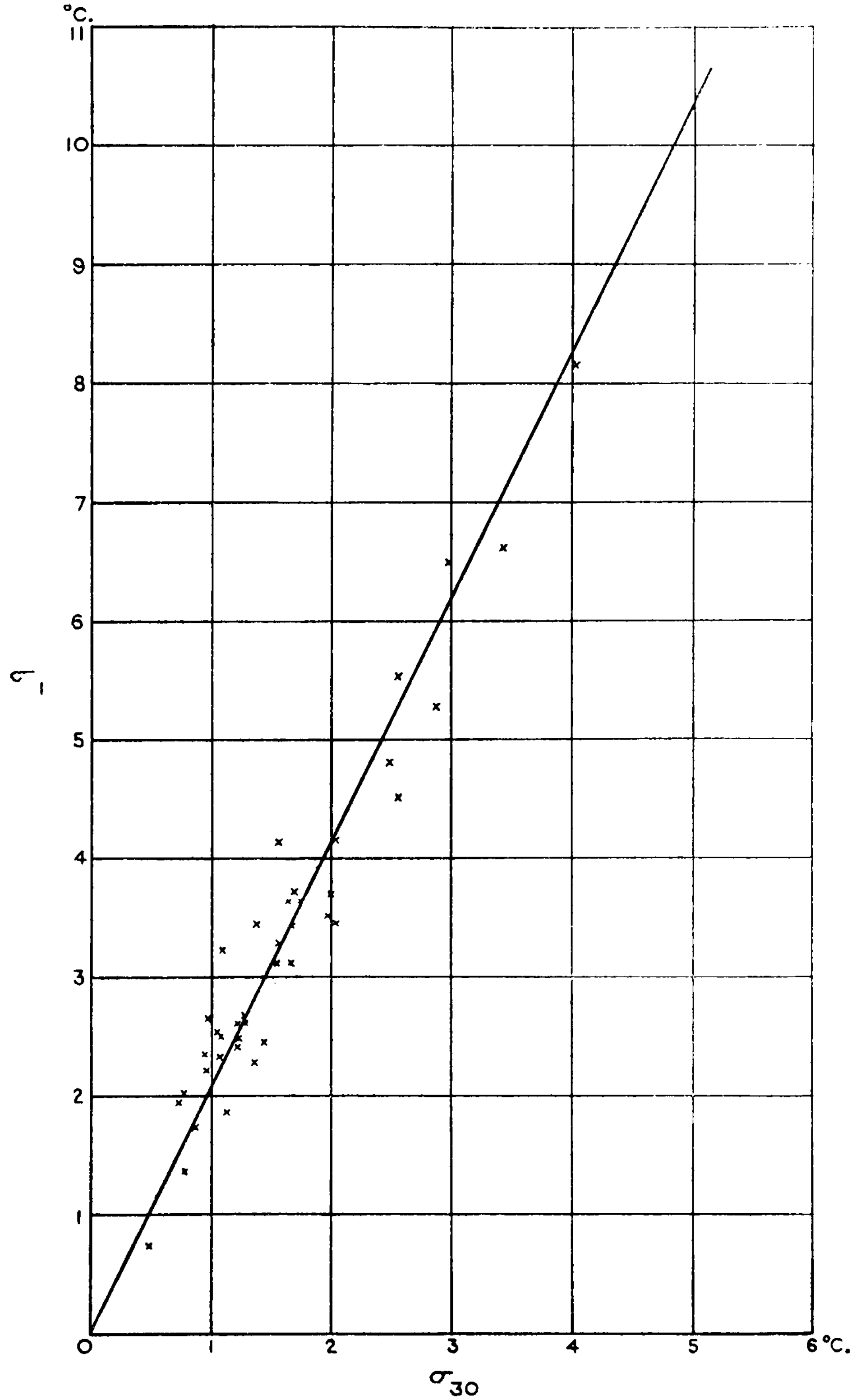

FIG. 2—RELATION BETWEEN STANDARD DEVIATIONS OF DAILY AND MONTHLY MEAN TEMPERATURES

Using the assumption (4), equation (3) can be written

$$\frac{\sigma_n^2}{\sigma_1^2} = \frac{1}{n^2}\left(n + 2\sum_{i>j} r_1^{i-j}\right)$$

$$= \frac{1}{n^2}\left[n + 2\left\{(n-1)r_1 + (n-2)r_1^2 + \ldots + 2r_1^{n-2} + r_1^{n-1}\right\}\right]$$

$$= \frac{n(1-r_1^2) - 2r_1(1-r_1^n)}{n^2(1-r_1)^2}. \qquad \ldots\ldots (5)$$

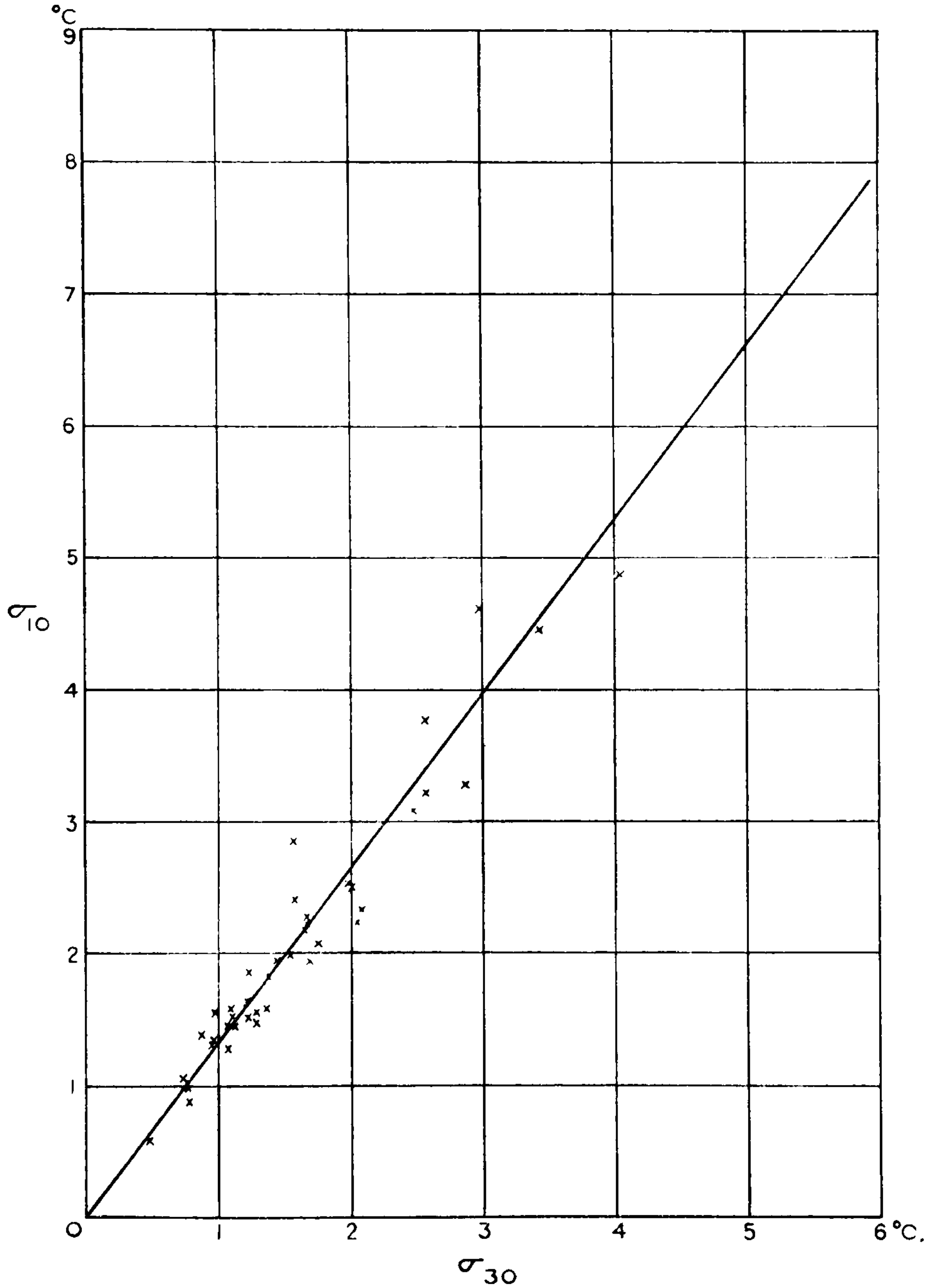

FIG. 3—RELATION BETWEEN STANDARD DEVIATIONS OF 10-DAY AND MONTHLY MEAN TEMPERATURES

Table V shows the values of σ_n/σ_1 for $n = 5, 10, 30$ and $r_1 = 0\cdot9, 0\cdot8, 0\cdot7, 0\cdot6$.

There is a reasonable correspondence between the computed ratios of σ_n/σ_1 and the theoretical ratios obtained for a value of r_1 of about 0·7.

Conclusion.—Anomalies of daily, 5-day and 10-day mean temperatures can be quite accurately referred to constant multiples of the standard deviation of monthly mean temperature, for which a large amount of data are available, for example those given by Nagao[2].

REFERENCES

1. BROOKS, C.E.P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953, p. 323.
2. NAGAO, T.; Standard deviation of monthly mean temperature. *J. met. Res., Tokyo*, **3**, 1951, p. 434.

METEOROLOGICAL OFFICE DISCUSSION

Mesoanalysis

The discussion on Monday, January 21, 1957, held at the Royal Society of Arts, was opened by Mr. W. D. S. McCaffery of The Central Forecasting Office, Dunstable, whose opening statement was based mainly on the paper by Fujita, T., Newstein, H. and Tepper, M.[1]:—"Mesoanalysis, an important scale in the analysis of weather data".

In 1953 Swingle and Rosenberg[2] published a paper with the title "Mesometeorological analysis of cold front passage using radar weather data". Since then meteorological literature has been enriched by the addition of such words as mesosystem, mesostructure, mesomap. But although the words are new and new synoptic models are being evolved, there is nothing essentially new in the method of attack. The earliest workers in the field of mesoanalysis were the Norwegians during and immediately after the First World War, and papers by Bjerknes[3] and by Bjerknes and Solberg[4] can be classed as mesometeorological studies.

Scales of synoptic analysis.—Synoptic analysis, carried out as a normal daily routine, is primarily concerned with weather systems whose dimensions are of the order of several hundreds of miles. This may be termed macroanalysis. Synoptic studies have also been carried out over limited areas[5], say 10 miles by 20, with a station spacing of about one mile and synoptic charts have been constructed at intervals of as little as one minute[6]. These are studies on a microscale.

Work in recent years, particularly by the Severe Local Storms Research Unit of the United States Weather Bureau has revealed that between the two extremes of phenomena on the micro and macro scales, there is an important third class of phenomena—too small to be detected with certainty by the coarse network of stations normally available for macroanalysis and too big for their motion to be investigated in the limited area used in micrometeorological investigations. Characteristic physical dimensions of these systems lie between 10 and 100 miles, so in an arbitrary way this defines the scale of mesoanalysis with macro and micro scales being used for atmospheric motions respectively greater than 100 and less than 10 miles in extent. The time interval used in meso studies is one hour, but very full use is made of autographic records and intermediate reports.

[To face p. 176

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THAMES FLOODING ABOVE TEDDINGTON

(See p. 189)

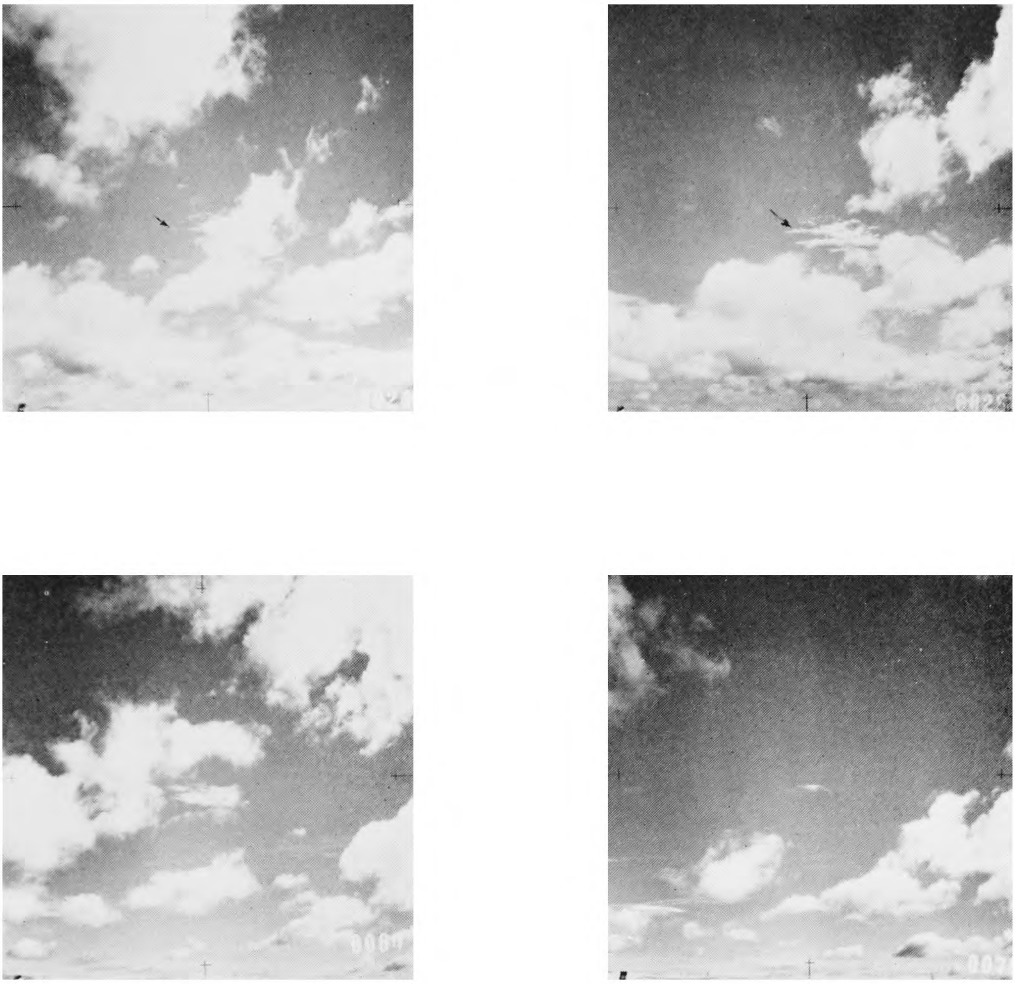
ALTOCUMULUS IN A STANDING WAVE

We are indebted to Mr. L. G. Bird of the Meteorological Office, Defford, Worcestershire for this report and the photographs reproduced above which show a patch of altocumulus which was stationary between 0914 and 0935 G.M.T. on July 24, 1956 N.E. of Defford though the wind at its level had a speed of 45 kt.

When the existence of this stationary Ac patch was realized a series of photographs was taken at fifteen-second intervals with a camera facing 030° true. The photographer was Mr. J. Dowding of the Photographic Section, Defford. The first photograph was taken at 0914 G.M.T. and the photographs reproduced are numbers 1, 20, 24, 28, 32, 36, 60 and 70 of the series.

The Ac patch is visible on all the photographs reproduced and from the vertical and horizontal register marks is seen to have remained stationary as small Cu move quickly from left to right.

The Ac patch slowly dispersed and the dispersal appeared to coincide with a temporary dispersal of the small Cu. In photographs 24, 28, 32 and 36 the



progression through the cloud of a small cloudlet can be clearly seen with fresh cloud forming upwind of it.

On July 24, 1956 a NW'ly airstream covered the Welsh hills and the Midlands of England and a warm–cold front link ran from east to west between Northern Ireland and Lincolnshire between two wave depressions, one centred on the Atlantic and one centred near Denmark. Between 0800 and 1000 G.M.T. the weather was cloudy over the Welsh mountains but to their lee the cloud was well broken with small cumulus forming between 2,000 and 3,500 ft. At Defford there was little cloud above apart from thin slowly dispersing Ac patches which were estimated to be at 13,000–15,000 ft. where the winds were 310°, 45 kt. The photographs are of one of these patches. It seems probable that the patch was formed in a stationary lee wave. Conditions were favourable for the formation of such waves as Scorer's parameter l^2 varied from 2·02 (naut. miles)^2 to 1·14 (naut. miles)^2 in the layer 1000–800 mb. and from ·84 (naut. miles)^2 to ·77 (naut. miles)^2 in the layer 700–400 mb.*

* SCORER, R. S.; Forecasting mountain and lee waves. *Met. Mag., London,* **82,** 1953, p. 232.

Photograph by P. Keeling

CONTRAIL SHADOW

Photograph taken at Defford on February 18, 1957
(See p. 187)

[IV]

Mesoanalysis in the mid-West United States of America.—In an area of the United States comprising all or part of ten mid-West States centred on Kansas, the Severe Local Storms Research Unit has set up a special network of "co-operative" stations which together with the normal synoptic network gives an average station spacing of between 20 and 30 miles over an area which is approximately a 600 mile square. In this area station heights vary from less than 1,000 ft. to over 6,000 ft. above sea level and immediately to the west the Rockies rise to over 9,000 ft. The synoptic stations are equipped with the normal complement of meteorological instruments and in addition they and the co-operative stations are equipped with high speed barographs revolving once in twelve hours. Thirty-one of the co-operative stations also have high speed hygro-thermographs. During the period of the analyses which were used to illustrate the techniques and results of mesoanalysis, data were also available from six radar stations operating in the area and about a dozen upper wind and radio-sonde stations.

Processing the data.—Before the available data could be used in the construction of mesomaps, barograms and thermograms had to be calibrated and a method found which made the best possible use of 24-hr. rainfall totals.

Pressure.—Using hourly values of pressure reduced to sea level from the synoptic reporting stations, a 24-hr. mean pressure at sea level was calculated for each synoptic station in the area and plotted on a map. Through these values, smoothed isobars were drawn. On this map 24-hr. vector mean winds were also plotted and a rough fit with the mean isobars obtained. By interpolation a 24-hr. mean pressure at sea level (which in many cases would have been difficult to compute) was read off for every station used in the analysis. A horizontal line was drawn across each barogram such that it, in effect, represented the mean value of the barogram for the 24-hr. period. As such it was given the same value as that interpolated from the mean smoothed pressure field. This procedure provided for a calibration of the barograms so that the value of sea-level pressure could then be read directly from the recorded trace for any time.

Temperature.—From the hourly values of station-level temperature at the synoptic reporting stations, 24-hr. mean temperatures were calculated which revealed at once the influence of station elevation. By plotting the 24-hr. mean temperatures on a scatter diagram of station height against station latitude, and drawing isotherms of best fit, lapse rates at various latitudes through various heights could be found. These were found to be very similar and in the interests of simplicity one mean lapse rate of 3°F. per 1,000 ft. was used to determine "sea-level" mean temperatures. Micro variations in temperature, due to patchy cloudiness, variations in surface texture, etc., were eliminated by drawing smoothed isotherms through the plotted values of sea-level mean temperatures. A smoothed mean temperature at sea level could then be interpolated for each station and the thermograms calibrated.

Precipitation.—Most of the precipitation data were available as 24-hr. rainfall totals, but a scatter of stations reported hourly values. Using the hourly values, for any particular hour the percentage of the 24-hr. total which fell during that hour could be calculated and plotted on a chart. Sufficient values were available for a reasonable pattern of iso-percentage lines to be drawn. Using this field it was then possible to calculate for each of the other stations the percentage of the 24-hr. total which fell during the hour in question. Having the 24-hr. total for these stations it was then possible to infer the hourly precipitation accumulation and unique isohyetal patterns could be drawn for each hour analysed.

Station time sections.—In order that all of the weather elements could be viewed in their proper interrelation and to assist in understanding events at any one station, individual station time sections were constructed which were, in effect, a composite of all the weather data on one chart. The time scale of the time section ran from right to left and in this way, for weather systems which moved mainly from west to east, the time section approximated to a space section through the station. The barograms and thermograms were entered across the top half of the section after calibration. An entry for clouds was made under the thermogram trace, symbols plotted roughly according to height indicating more than 9/10, 6/10 to 9/10 and nil to 5/10. Reports of precipitation appeared on the line below the cloud data and were presented in the form of a line spectrum which indicated the duration of light, moderate or heavy rain and also hail. On the next line below, shading represented thunderstorms in two categories; thunderstorm and heavy thunderstorm. The lowest entry on the chart showed wind speed and direction. Written vertically across the chart at the appropriate time were edited additional remarks giving extra information from special observations, climatological forms, reliable newspaper reports and the like.

Construction of the mesomaps.—For each hour of the period chosen for study, four basic maps were drawn:

(i) Pressure (including winds and isogon pattern)

(ii) Temperature

(iii) Precipitation (including radar data and storm reports)

(iv) Clouds (both lower and upper).

In the analysis of these charts there were three basic techniques which were applicable to all:

(i) The interpretation of time gradients as space gradients.

(ii) The adherence to the principle of continuity of pattern from hour to hour.

(iii) The smoothing of irregularities of a purely local nature.

In constructing the pressure chart, a rough analysis indicated the speed and direction of movement of the mesosystems. When this is known, and assuming that for short intervals of time the pressure field moves without very much change, it is possible to interpret the time scale of the barogram in such a way that one hour of the trace corresponds in length to the distance that the pressure system has moved in one hour on the map scale. By retracing the portion of the barogram plus or minus half an hour each side of the map time and oriented along the track of the perturbation being followed (time increasing against the motion), the pressure variation falls, more or less, in its proper spatial position on the map and clearly indicates the pressure field between the station observations. Fujita[7] in another paper describes a technique for dealing with cases of rapidly changing pressure patterns. In the analysis more weight was given to the gradient of pressure than to the numerical value of the pressure itself, and values were ignored if drawing to them meant introducing pressure gradients not supported by the barograms.

From the wind field, it was possible to delineate the isogon pattern and emphasize lines of significant wind shift.

The construction of the temperature chart was accomplished in a similar manner to that of the pressure field.

On the hourly rainfall maps, were entered in their appropriate location, the severe storm reports and also radar echo reports from stations within the analysis area.

The cloud charts showed the data divided into two categories—by height (high clouds and low-medium clouds) and by amount (1/10 to 9/10 and 10/10).

When all four charts for one hour were complete, a composite coloured chart was prepared which showed all the above features superimposed. In this way the inter-relationship between the various elements was clearly brought out.

Case of June 24–25, 1953.—The macroanalysis over this period, done in the conventional manner with charts at three-hourly intervals, shows a cold front progressing steadily south-eastwards, entering a trough of low pressure, initially in warm air, and finally both trough and front moving along together. The authors comment: "The analysis appears to represent a very orderly sequence of events, i.e. the progress of a 'classical' cold front along which precipitation is distributed prefrontally, post-frontally, and at times even along the front."

The mesoanalysis of this situation presented on ten-hourly composite charts, reveals instead of the simple cold front, eleven major mesofeatures which grow, move and decay in an orderly fashion, persisting from three or four hours to upwards of eight hours and being closely related to the areas of precipitation, overcast skies, radar echoes, wind and electrical storms, and tornadoes. Fig. 1 shows the pressure, temperature and precipitation fields taken from the last in the series of composite charts (0300 C.S.T., June 25, 1953). The central State in the diagram is Kansas with Oklahoma immediately to the south and Nebraska to the north. The macroanalysis for this time is similar to this mesomap from the low pressure area in Oklahoma south-westwards. North-eastwards the two analyses are very different without any one feature on the mesomap corresponding closely with the cold front of the macroanalysis. The mesosystems shown are: System XI, a pressure jump line, located entirely in the warm air, and at which a sudden wind shift accompanies the sharp rise of pressure, but without precipitation and with very little cloud; System VII, a well developed meso-high or thunderstorm high and trailing wake depression (Fujita[7]) with which there is associated a large rain area; System X, which started off as a pressure couplet—a small high and a low of comparable magnitude in close association—but which at this time resembles more closely the model of the thunderstorm high. Some precipitation and radar echo were associated with this system earlier, but at the time of the map, only an area of overcast skies is reported.

Meso-synoptic models.—After showing a series of slides illustrating the main features of the mesoanalysis of the case of June 24–25, 1953, Mr.

McCaffery used further slides to illustrate in greater detail the three synoptic models which seem to emerge. The pressure couplet is a new feature about which little is known except that when it appears, storminess seems to be associated with the low pressure part, which is often warm. The origin of the pressure jump line, as illustrated in the analyses discussed, has been explained by Tepper[6]. Newton[8] has proposed an alternative theory for the prefrontal squall line while Fujita[7] refers to the pressure surge line. It is not altogether clear that these three phenomena are one and the same thing and further work is obviously required.

The model of the thunderstorm high seems the most satisfactory from the forecasters' point of view, in that when it appears the chart analysis often resembles the simplified synoptic model and it often has a long enough life for a short term forecast to be successful on the basis of growth and decay over six to twelve hours. The phenomena of the thunderstorm high has been studied in

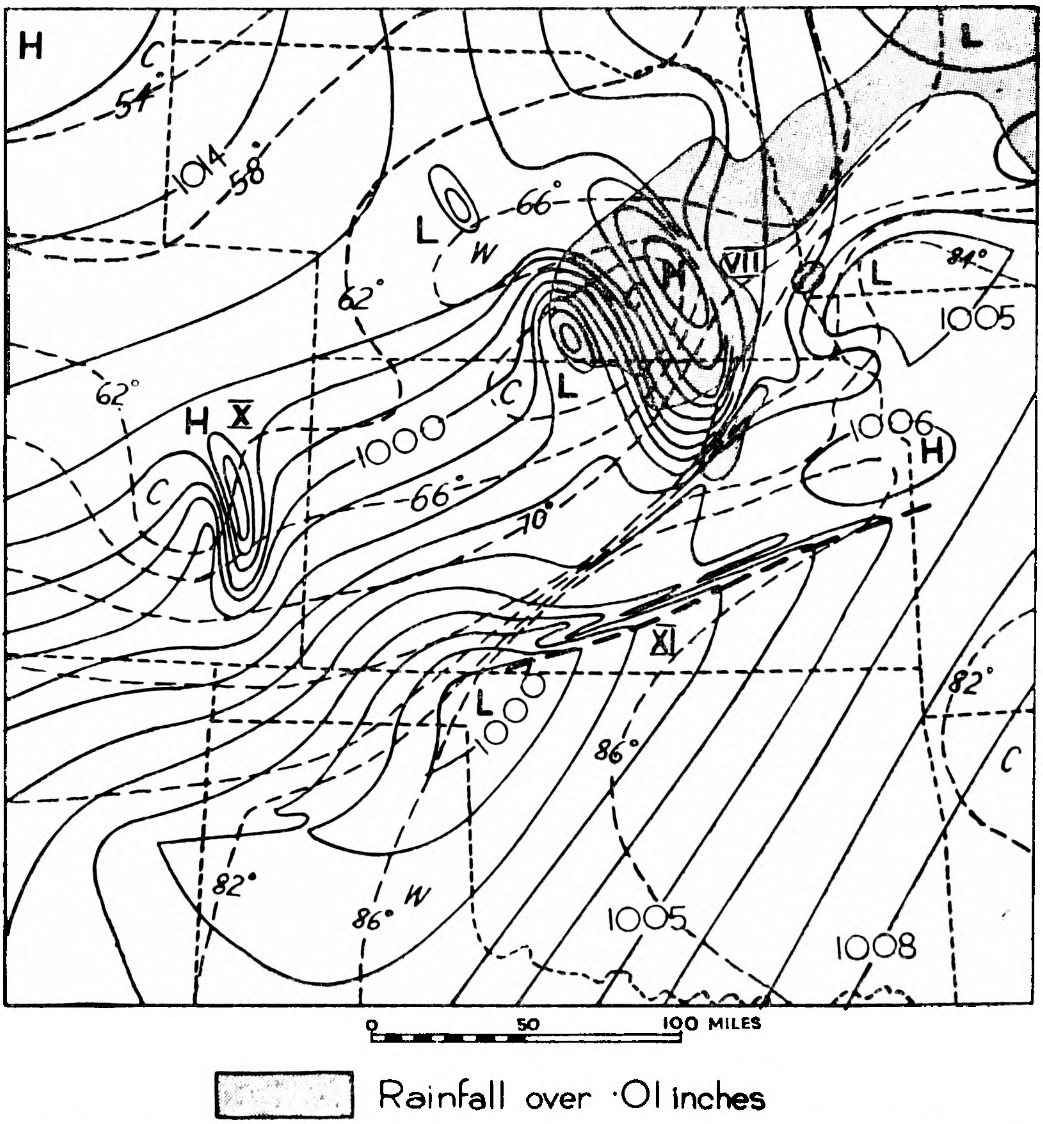


FIG. I—MESOMAP OF THE MID-WEST UNITED STATES OF AMERICA 0300 C.S.T., JUNE 25, 1953

India, Japan and elsewhere, and a synoptic study over the United Kingdom by Douglas[9] attributes the observed rise of pressure to cooling due to rain.

In concluding, Mr. McCaffery said that with the hourly observations available from the synoptic network over the United Kingdom, it was possible to do a crude form of mesoanalysis as an hourly routine. What was lacking was systematic investigation of small disturbances by which the background knowledge of the forecaster could be so increased that instead of smoothing out all irregularities, mesosystems could be confidently drawn in and some improvement in short-term local forecasting hoped for.

The Director, in opening the general discussion, asked if mesosystems were predictable or if they were minor eddies of an unpredictable variety. He did not remember anything like a pressure couplet in orthodox hydrodynamics and wished to know if there was any other evidence for them. In reply, Mr. McCaffery said that the examples studied suggested that there were mesosystems with a long enough life history to make a knowledge of them useful in short-range forecasting, but others were more ephemeral and akin to unpredictable eddies. With regard to pressure couplets it had been suggested that the initial smoothing of the average sea-level pressure data might mean that any low which then appeared on the charts would be accompanied by a corresponding high. But as the barograph trace had been calibrated without changing the shape of the barogram, and as these showed peaks and troughs above and below the main run of the trace, the pressure couplet must be accepted as a real phenomenon.

Mr. Sawyer pointed out that features similar to those described were to be observed over the United Kingdom and mentioned Pothecary's[10] description of a pressure jump line observed moving across southern England independently of the wind-fields. He went on to describe the formation of the thunderstorm high as due to cooling by precipitation falling into dry air. Although observed in this country it was thus more frequently seen in dry regions such as the mid-West United States of America and north-west India. Mr. Sawyer thought that if we could draw detailed mesomaps over this country some interesting phenomena, e.g. coastal and other orographic effects, would be observed. He was glad that a start had been made on this type of work.

Dr. Sutcliffe recalled that 25 years ago he had investigated irregularities in barogram traces during thundery weather in the Mediterranean. Pressure rises of 4 mb. or so in half an hour were observed often without any actual thunderstorms or indeed sometimes with no definite weather at all. The cooling of a mass of air by rain falling through it was important as only a 5°F. difference in the mean temperature of adjacent columns of air could account for the observed pressure changes. It was interesting to note that broadly similar synoptic situations—upper south-westerlies above lower southerlies—gave rise to mesoscale features in the United Kingdom, the United States of America and the Mediterranean. It was perhaps rather difficult to see how mesoanalysis could be used in forecasting and possibly its importance might lie more in increasing the background knowledge of the forecaster.

Mr. Harper stated that one of the features of weather radar is that many systems are seen on the screen which are not related to anything on the synoptic chart and he thought that it would be useful to study radar observations against hourly observations. A case of a well defined pattern of radar echo was that of the West London Tornado[11] of December 1954 which could be tracked back to Hayling Island where a whirlwind had occurred an hour earlier. Without radar the connexion between these two events could not have been proved.

Mr. Craddock mentioned a spectacularly successful thunderstorm forecast which had been made at The Festival of Britain by means of radar location of thunderstorms originating near the Channel Islands. With radar location of mesosystems a special forecast service for persons interested in minor-scale phenomena might be possible.

Dr. Caton referred to his study of the possibility of producing detailed forecasts of precipitation from weather radar displays—forecasts of the type: "Rain or shower expected, commencing . . . . . , ceasing . . . . . ." In conditions of instability a satisfactory standard of accuracy had been achieved for periods up to about two hours ahead.

Mr. C. V. Smith thought that the uncertainties in the evolution of the more readily identifiable synoptic systems (e.g. pressure centres and fronts) were always such as to obviate the use of analysis on the mesoscale, at least as far as the Central Forecasting Office was concerned. The difficulty of recognizing what would be a persistent meso feature and of forecasting its displacement suggested that information on this scale was probably useful only as background knowledge and for the interpretation of developments after the event.

Dr. Farquharson said that the atmosphere is not split into phenomena of special periods of say, six or 24 hours, but that we must expect all scales of motion and attempt to predict them.

Mr. Peters wanted further work on these lines and recalled that J. Bjerknes spent two periods in the United Kingdom teaching and doing research on frontal analysis over the British Isles. His published result[12] was one of the earlier works in mesoanalysis. Studies of the effects of coasts, mountains, river valleys and urban areas on the major features of weather were unco-ordinated and not in a form useable by forecasters. Little was known of the synoptic climatology of large cities or popular holiday resorts. With the extension of WEA (telephone weather service) fresh responsibilities were being laid on certain outstation forecasters, and Senior Meteorological Officers should examine the need for new synoptic reporting stations.

Mr. R. F. Jones drew attention to the fact that pressure variations of 8 mb. in 10 miles such as had been shown on the mesomaps were important to aircraft for altimeter settings.

Mr. Roberts was not satisfied that the present synoptic network was anything like good enough to catch small systems since inquiries from the general public often reveal phenomena not recorded on the synoptic chart.

Mr. Hanson, speaking of the experience in the use of radar in forecasting from Victory House, said that the radar information is additional to, but cannot replace synoptic reports. Referring to the analyses discussed by the opener, Mr. Hanson wondered if excessive smoothing in some cases had removed features associated with tornadoes. Mr. McCaffery, replying, said that tornadoes were essentially micro features and the locally intense pressure gradient associated with them might escape a meso-synoptic network. Drawing to the data actually available seemed to have been done without undue smoothing.

Mr. Gold wanted the scale of mesoanalysis extended down to about 1 mile or 1 Km. as 10 miles was too big for a lower limit. He would also like to see upper air charts on the same scale. Mr. Gold stressed the importance of the time element, as features with a life history of an hour or less were obviously unpredictable. Mesoanalysis might be most important in a "flat" situation since then such things as evaporation and radiation would have the greatest chance of producing meso phenomena. He would like to think that meso-meteorology could lead to a WEA forecast for the London area of the type "rain at Mill Hill but not at Golders Green".

Dr. Sutcliffe, taking up Mr. Gold's point about the definition of the meso scale, said that perhaps we should refer to meso-synoptic-analysis, micro-synoptic-analysis and so on, distinguishing between these scales and the limits implied by such terms as, for instance, the micro-physics and macro-physics of clouds.

Mr. Clements was of the opinion that if we were ever to forecast successfully for a local area we must do this sort of analysis. The station network had much increased since 1939, but he doubted if there had been any improvement in detailed forecasts for individual places. How does the forecaster today set about forecasting local detail?

Mr. Harley doubted if many forecasters could say exactly how they arrived at the final version of any forecast. He was much in favour of mesoanalysis being done in the United Kingdom, but thought an increased station network might be necessary. He would welcome the opportunity to take part in such work.

Mr. Bradbury described detailed short-range forecasting for fly-pasts when aircraft reconnaissances were necessary to reveal phenomena which escaped the existing network of stations.

Mr. Jacobs thought that over the past twelve years, observations from hourly reporting stations, together with climatological data, reports from railway controllers and the like, and observations from over 5,000 rainfall stations provided ample data for research in the meso-synoptic field.

The Director, closing the Discussion, said that the wider use of weather radar would depend on our establishing its usefulness in normal synoptic work. He went on to relate the circumstances in which early in the Second World War, Mr. Gold had made a brilliantly successful local forecast, in which he predicted a complete reversal of wind direction, simply by carefully noting the local topography and applying the physics of katabatic winds.

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WORLD METEOROLOGICAL ORGANIZATION

Second Session of the Commission for Climatology, Washington, January 1957

It seems rather ironic that the Commission for Climatology of the World Meteorological Organization should have had to hold its second session in Washington, D.C., United States, from January 14 to 25, 1957 when, although the city is sheltered by the Appalachians from the bitter cold of central North America, the normal monthly temperature ranges between 20°F. and 44°F. and, on the average, 6 in. of snow falls during the month! However, in these days of financial stringency, one has to be grateful that there is a Government willing to act as host—and, anyway, the weather was not too bad although the writer found the indoor climate much too cosy! Indeed, all delegates were deeply appreciative of the invitation of the United States Government and of the excellent facilities provided in the International Conference Suite. Delegates from more than 20 Members of the World Meteorological Organization, observers from the International Civil Aviation Organization, the Food and Agriculture Organization, the United Nations Educational, Scientific, and Cultural Organization and other international organizations (including the recently formed International Society of Climatology and Biometeorology), also a number of invited experts, were given a cordial welcome by Mr. Francis O. Wilcox, Assistant Secretary of State for International Organization Affairs and by Dr. F. W. Reichelderfer, Chief of the United States Weather Bureau. The meeting was presided over by the President, Dr. C. W. Thornthwaite, Director of the Laboratory of Climatology, Drexel Institute of Technology, Centerton, New Jersey, United States of America, who gave an opening address on "The task ahead in climatology"; which was reported in the World Meteorological Organization Bulletin[1]. Messages wishing the meeting success from the President and Secretary-General of the World Meteorological Organization were read by Dr. K. Langlo, Chief of the Technical Division of the World Meteorological Organization Secretariat.

Only two Working Committees were established, one under the Chairmanship of Dr. Helmut E. Landsberg, Director, Office of Climatology, United States Weather Bureau and the other under the Chairmanship of Mr. C. C. Boughner, Chief, Climatological Division, Meteorological Service, Canada. Dr. Landsberg's Committee dealt with those agenda items which related to research and applied climatology whilst Mr. Boughner's Committee dealt with agenda items relating to general climatology, requirements, regulations, rules and practices. There was an excellent spirit of co-operation among all delegates and the work of the Committees proceeded smoothly and efficiently; it was most helpful for each Committee to have the assistance of a member of the World Meteorological Organization Secretariat, i.e. Dr. K. Langlo and Mr. O. M. Ashford.

The final resolutions and recommendations covered many aspects of climatology. The resolutions related mainly to the establishment of working-groups. In view of the difficulty of conducting the business of working-groups by means of correspondence (funds, available to finance meetings, are very limited) it was decided to keep their number to a minimum. Nevertheless as many as eight were set up. One has the formidable task of preparing a system of climatic classification "based on dynamic climatological concepts". Another is called upon to study methods of determining and mapping "derived" climatic elements e.g. heat content and flux, evaporation, moisture deficit, precipitable water. A third is expected to provide an advisory service on the application of statistical methods to specific climatological problems and is required to prepare a chapter thereon for inclusion in the projected World Meteorological Organization Guide to Climatological Practices. The other working groups will be concerned with the review of World Meteorological Organization Technical Regulations relating to climatology, the machinery for the exchange of past weather data, the provision of advice and the preparation of a publication on the processing of climatological data by means of punch-cards (it was decided that there is no need for international standardization of the punch-card layout for general climatological purposes), the review and co-ordination of contributions to the Guide to Climatological Practices, the study of current work on microclimatology and the preparation of a chapter thereon for inclusion in the Guide.

The recommendations embraced many aspects of climatology. Perhaps the most important was that covering proposed amendments to the World Meteorological Organization Technical Regulations. Others dealt with the possibility of establishing national data-control authorities (it is proposed that the views of Members of the World Meteorological Organization should be sought), the use of aircraft meteorological observations for climatological purposes (Members of the World Meteorological Organization to be invited to carry out pilot studies on models and procedures for summarization), CLIMAT broadcasts and CLIMAT publication, earth-temperature measurements. In connexion with certain agenda items it was decided to seek the views or advice of other Technical Commissions or the Regional Associations. For example, the Commission considered that the maintenance of a selection of climatological stations as "reference" stations at places where the exposure could be kept unchanged over a very long period, was of great importance for the determination of "trends" and long period fluctuations in temperature, rainfall etc. and decided to invite each Regional Association to study the requirement for such key stations in its area and to urge that early action be taken to set up sufficient stations to cover all climatic régimes of the Region. In view of the need for more extensive measurements of, and for the adoption of a standard definition for, daylight illumination, the Commission decided to seek the advice of the Commission for Instruments. It was also decided to consult the latter regarding automatic climatological stations, and the measurement of the water equivalent of snow and of earth temperature.

At the request of the Executive Committee the Commission studied in detail a report of a Working Group on Climatic Atlases which the Executive Committee had itself set up. It was decided to pass certain comments to the Working Group with the suggestion that their report be revised accordingly. With regard to the proposed World Meteorological Organization Guide to Climatological Practices, the Commission considered that it should not embrace material readily available in existing textbooks but recommended that liberal use be made of references to such publications. As some chapters of the Guide would be ready for publication before others, the Commission decided to recommend that the Guide should be issued in loose-leaf form and that individual chapters should be issued separately as completed.

So much for the actual business of the Commission. It is important to mention, however, that the meeting provided an invaluable opportunity for the exchange of ideas and experience among the various delegates. Two afternoons were devoted to scientific discussions. Papers were read by Dr. M. I. Budyko, Director, Central Geophysical Observatory, Leningrad, on the "Heat balance of the surface of the Earth", by Dr. H. E. Landsberg on "Preparing climatic data for the user", by Dr. W. C. Jacobs, Director for Climatology, Air Weather Service, United States Air Force, on "Problems associated with modern requirements for data processing", by Mr. N. Rosenan, Chief, Climatological Division, Meteorological Service, Israel, on "Special problems in arid zone climatology" and by Dr. L. J. L. Deij, Director, Climatology Division, Royal Netherlands Meteorological Institute on "Evaporation in the Netherlands". In addition, one of the invited experts, Dr. F. K. Hare, Professor of Geography, McGill University, Toronto, Canada, read a paper on "The dynamic aspects of climatology".

In addition to many individual acts of hospitality on the part of members of the United States meteorological services, there were the usual social functions including receptions by our hosts, the United States Government, our American and Russian colleagues, the Microcard Corporation, and a dinner by the Bendix-Friez instrument makers. Through the courtesy of the Chief, interesting visits were made to various Offices of the Weather Bureau, including the Meteorological Office at Washington Airport. Many of the delegates accepted Dr. Reichelderfer's kind invitation to tour the United States' National Weather Records Centre at Asheville, North Carolina. This is a most impressive organization which comes under the control of Dr. Landsberg, and the Director, Mr. Leslie Smith, and his staff spared no effort to make the visit both instructive and enjoyable. The history of this centre is a story in itself, a story which might well be entitled "Automation as applied to climatology". Suffice it to say that many of the visitors, having seen the huge array of machinery, including modern electronic computers, the enormous store of cards, now 300 million and increasing at the rate of 30 million per year, the facilities for making micro-films, the highly efficient printing section, and especially the man-power at Mr. Leslie Smith's disposal, came away feeling extremely envious and, perhaps, a little ashamed of the "Stone-Age" methods in use in their own country.

All that remains to be said is that the Second Session of the Climatological Commission was very well run and quite successful. The task of distributing and publishing documents was very efficiently dealt with by the experienced staff of Mr. Hampton Davis, the capable Executive Secretary, in collaboration with Dr. Langlo and Mr. Ashford of the World Meteorological Organization Secretariat: the interpreting facilities were excellent.

At the end of the meeting the writer had the honour of being elected President of the Commission in succession to Dr. Thornthwaite and Mr. C. C. Boughner of Canada was elected Vice-President in succession to Dr. A. Ångström of Sweden.

R. G. VERYARD

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1. THORNTHWAITE, C. W.; The task ahead in climatology. *W.M.O. Bulletin, Geneva,* **6**, p. 2.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. C. S. Herbert,* Senior Experimental Officer, retired on April 30, 1957. He joined the Office in January, 1912 in the General Services Division. He was transferred to the Forecast Division in 1924 and from 1930 until 1943 he served successively at a number of aviation outstations including a tour of duty in the Middle East. Since 1943 until his retirement he served in the Instruments Division at Headquarters. He was "Mentioned in Despatches" in June 1943.

Mr. E. S. Tunstall, Senior Experimental Officer, retired on April 30, 1957. He joined the Office as a Staff Assistant in February 1920 after service in the Seaforth Highlanders (1915–17) and the Meteorological Section, Royal Engineers (1917–19) during the First World War. Apart from the period between 1928 and 1937 which was spent in the Forecast and General Services Divisions at Headquarters, Mr. Tunstall has been at aviation outstations. For the past twelve years he has been forecasting for civil aviation and since 1946 until his retirement he has been the Officer-in-Charge of the Meteorological Office at Speke Airport, Liverpool.

NOTES AND NEWS

Contrail shadow photograph

The photograph which is reproduced (see p. 177) was taken at Defford at 1030 G.M.T. on February 18, 1957. The bearing of the contrail from the Meteorological Office was 160° east of true north. The height of the contrail was estimated to be 23,000 ft.; the shadow was cast on thin but dense altostratus cloud estimated to be at 13,000 ft.

Torrential Rainfall at Royal Air Force station Tengah

A heavy fall of rain occurred in the north-west of Singapore Island at Royal Air Force station Tengah on September 16, 1956, when 118·5 mm. (4·67 in.) were recorded in a thunderstorm. On this occasion the normal shower development over the Malacca Strait during the night was intensified by a convergence zone separating the Pacific easterlies and the Indian Ocean westerlies. The zone was lying at 0730 local time (0001 G.M.T.) on September 16 just to the west of Singapore Island and extending in a north-south direction. The showers developing over the sea were carried eastwards by the general westerly flow at 10,000 and 15,000 ft.

The rain commenced at 0627 local time (2257 G.M.T.), about dawn. The rain was slight at first, but after three minutes became torrential. A solid sheet of water reduced the visibility to under 500 yd. Thunder was not heard until 40 min. after the rain had commenced, and it did not become frequent or heavy. The wind was calm at first, but later freshened to north-north-westerly about 15 kt. The large monsoon drains designed to take the normal heavy tropical rains could not cope with this torrent, and the ground was soon under water. After $1\frac{1}{2}$ hr. the rain eased slightly and the observer was able to measure the rain. In 99 min. from 0627 to 0806 (2257–0036 G.M.T.) 111·9 mm. (4·40 in.) had fallen. Heavy rain continued for a while then became slight, and finally ceased at 1050 local time (0320 G.M.T.).

This intense rainfall was fairly local, and only in a few areas were floods reported. Rainfall figures for other airfields on Singapore Island, during the same period, are given below:—

R.A.F. Seletar (north-east coast)	17·1 mm. (0·67 in.)	0843–1007 local time
Singapore Airport (north-east inland)	6·6 mm. (0·26 in.)	0745–1010 local time
R.A.F. Changi (extreme east coast)	3·0 mm. (0·12 in.)	0857–0957 local time

This is not the heaviest fall recorded at Tengah, but it is considered to be the heaviest yet measured from the early morning "rains". Other heavy falls recorded on the Island are:—

R.A.F. Changi	4·28 in. in one hour[1]	April 20, 1953
Kallang Airport	4·73 in. in one hour (1430–1530 local time)	July 28, 1951

D. C. MASON

REFERENCE

1. PALMER, W. G.; Heavy storm at Changi. *Met. Mag., London,* **82,** 1953, p. 341.

LETTERS TO THE EDITOR

Mean range in an autoregressive series

The note on "Mean range in an autoregressive series", by A. F. Jenkinson[1] is based on Exercise 370 of "Exercises in theoretical statistics" by M. G. Kendall[2]. This exercise, in turn, is based on "The distribution of extreme values in samples whose members are subject to a Markoff Chain Condition", by Benjamin Epstein[3].

But Dr. Epstein subsequently published[4] a correction:—

"In the paper mentioned . . . I claim to have proved a number of results dealing with the distribution of extreme values in samples of size n drawn at equally spaced intervals from a stationary Markoff process. As Professor W. Feller has kindly pointed out to me in personal correspondence, this is actually not the case. However, the theorems and their proofs remain completely valid in their present form if the observations are drawn from a stochastic process satisfying condition (5) of the paper. This chain condition states that the process be such that

$$\text{Prob}\ (X_n \leqslant x \mid X_1 \leqslant x, X_2 \leqslant x, \ldots X_{n-1} \leqslant x) = \text{Prob}\ (X_n \leqslant x \mid X_{n-1} \leqslant x)$$

is satisfied for all x and all positive integers n."

This restriction, therefore, applies also to the ingenious application that Mr. Jenkinson offered in his note. It requires, for example, that the probability that today's temperature will not exceed some value that also was not exceeded yesterday be completely independent of whether that value was exceeded on any of the preceding days. In other terms, it permits no correlation of lag more than one. Since few meteorological phenomena, if any, satisfy this condition, Mr. Jenkinson's result is of only academic interest.

Another approach to the distribution of the largest member of a sample from a stochastic process was taken by G. S. Watson[5]. He showed that as the sample size increases, the distribution of the largest member tends asymptotically to the distribution of the largest member in a sample from a population all of whose elements are independent. Although of theoretical interest, this result is not directly applicable to samples of size 30, used by Mr. Jenkinson. Consequently, the problem that Mr. Jenkinson posed, of the relation between mean monthly temperature range and standard deviation of daily values, has not yet been solved.

ARNOLD COURT

California Forest & Range Experiment Station,
Forest Service, U.S. Department of Agriculture,
Berkeley, California, December 26, 1956.

[The solution proposed by Kendall[2], is correct for the autoregressive series under discussion, which is a wide-sense strictly stationary Markov process[6]. For such processes, Doob (pp. 80–91, especially equation 6.1, p. 80) says: "For any integer $n \geqslant 1$, if $t_1 < \text{----} < t_n$ are parameter values, the conditional ${}^{x}t_n$ probabilities relative to ${}^{x}t_1$, ----${}^{x}t_{n-1}$ are the same as those relative to ${}^{x}t_{n-1}$ in the sense that for each λ

$$P \left\{{}^{x}t_n \leqslant \lambda \mid {}^{x}t_1 , \text{---} {}^{x}t_{n-1}\right\} = P \left\{{}^{x}t \leqslant \lambda \mid {}^{x}t_{n-1}\right\}."$$

In my opinion therefore, for the autoregressive series of my note the distribution function of the largest member is correctly given and I believe that Mr. Court is wrong in his conclusion that this distribution function would only apply to series with no correlation of lag more than one.

A. F. JENKINSON]

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3. EPSTEIN, B.; The distribution of extreme values in samples whose members are subject to a Markoff Chain Condition. *Ann. math. Statist., Ann. Arbor,* **20,** 1949, p. 590.
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5. WATSON, G. S.; Extreme values in samples from m-dependent stationary stochastic processe ; *Ann. math. Statist., Ann. Arbor,* **25,** 1954, p. 798.
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Thames flooding above Teddington, February, 1957

You may be interested in the attached photograph (facing p. 176) the best o four taken at the same time, which shows the increased flow over Teddington Weir on the afternoon of Saturday, February 16, 1957.

The normal daily flow over Teddington Weir is given by the Thames Conservancy as 2,399 million gallons per day. On this day the flow is given as about 4,300 million gallons. This was not the maximum flow recorded during this February's floods, for that occurred on the previous Saturday.

The maximum flow recorded this century at Teddington was in March, 1947, when the day's flow was 13,700 million gallons.

Harrow, March 1, 1957 KENNETH WOODLEY

BOOKS RECEIVED

Indian Journal of Meteorology and Geophysics. **8,** 1956, No. 1., *India Meteorological Department.* 9½ in. × 7¼ in., pp. ii + 126. *Manager of Publications, Delhi,* 1957. Price : *Rs.* 3*s*. or 5*s*.

Meteorologia por correspondencia. Nos. 13 and 14. 9 in. × 5¾ in., pp. 49–56. Sociedad Meteorológica, Instituto de Estudios Superiores, Montevideo, 1956.

WEATHER OF APRIL 1957

Atlantic depressional activity was largely concentrated over the north-western part of the ocean near Labrador and south Greenland, a pattern which is more usual in March and May than in April. Lowest monthly mean pressure (1003 mb.) was about 57°N. 47°W., where the value was 6 mb. below normal. The usual extension of the depression track towards the Barents Sea was present but also displaced west and north of its normal position, passing west instead of east of Iceland. The British Isles were more or less immune to cyclonic influence throughout the month and returned the highest mean pressures for the month anywhere in the Atlantic sector. The value was 1024 mb. over all Ireland and northern England. The anomaly in this region was probably the largest anywhere in the hemisphere (+12 mb. over north-east Ireland).

The polar high pressure was displaced over the Canadian North-West Territories, highest monthly mean pressure being 1026 mb. near 70°N. 110°W., i.e. 7 mb. high for this place and slightly above normal intensity for the system which is usually centred over the Arctic ice near 83°N. in April. Pressure over Siberia appears to have been generally a few millibars below normal.

These patterns showed a considerable break from March.

Monthly mean temperatures in April were above normal over all the eastern Atlantic though over the southern North Sea the excess became zero. Spitsbergen had the biggest positive anomaly (+6°C.). Most of Greenland and the western Atlantic were cold, the departure reaching −4 to −5°C. over north-western Greenland. Texas and the Plains States were again cold, as in March, and suffered very excessive rainfall; apart from this region, most of the United States and Canada from the Rockies to the Atlantic seaboard were warmer than normal (maximum anomalies +3°C. near Washington and in northern Quebec).

The most prominent feature of the rainfall pattern was above-normal falls covering most of the United States, apparently arranged about depression tracks crossing the country from California and the borders of British Columbia to converge near New England. All Europe north of the Alps was decidedly dry; falls reported in most parts of the Mediterranean were several times as great. There was some storminess in the Mediterranean.

In the British Isles, weather during the month was predominantly anticyclonic and dry in all areas; over much of England and Wales it was one of the driest Aprils of the century.

The first three days were cloudy with occasional rain as troughs associated with a deep Atlantic depression moved slowly east across the country. An anticyclone from the continent spread westward over the British Isles on the 4th giving two fine, warm days; afternoon temperatures rose into the sixties and on the 5th several places recorded 11 hours of sunshine. There was a sharp fall of temperature the following day as the anticyclone became established between Scotland and Iceland and north-easterly winds spread over the country. Cool winds from a northerly direction continued until the 13th and brought scattered showers, occasionally of snow, but there were good sunny periods. Milder weather spread in from the Atlantic on the 14th as winds backed to the south-west but pressure was generally high to the south of England and the rain associated with the weak fronts which crossed the country during the next three days was mainly slight. The 18th was dull and stormy, particularly in the north where wind reached gale force in places as a deepening depression skirted northern Scotland. Pressure rose rapidly behind the disturbance and although there were some showers in Scotland and northern England the following three days were fine and warm in most places, although on Easter Sunday a cool south-westerly air stream brought occasional rain to the north-western half of the country. Outbreaks of thundery rain associated with a small depression over northern France occurred in southern England late on Sunday night and on Easter Monday. With a ridge of high pressure extending from an anticyclone over northern Russia to the British Isles, weather was fine and warm nearly everywhere on the 23rd and 24th, temperature reaching 70°F. locally in southern districts. On the 25th a cool north-easterly air stream spread over the country as an anticyclone moved to the north of Scotland. During the last four days of the month, pressure was high to the west of Ireland and winds continued mainly from a north or north-easterly direction with dry weather and about average temperature.

Sunshine was mostly above the average for the month and, apart from the rather cold second week, so also was the temperature. With rainfall only 20 per cent of the average it was the driest April in England and Wales since 1938; it was the driest at Blackburn and Chesterfield for 70 years. In many areas there was no measurable rain from March 28th to April 11th and in places in Herefordshire the drought lasted for more than 30 days; at Ross-on-Wye there was an absolute drought throughout the month, the only other completely dry month in nearly 100 years of records being June 1925.

The dry weather and low night temperatures combined to exert a restraining influence on the growth of plants and trees. The shortage of rain caused concern to farmers and growers in all areas, as the land was so dry that spring sowing was held up, and it was feared that the prolonged drought might affect the harvest. Frosts during the month did not on the whole cause serious damage except to near ground level plants in some areas.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	71	22	+1·0	19	−8	103
Scotland	65	17	+1·9	68	−3	119
Northern Ireland ...	63	29	+1·1	57	−4	126

RAINFALL OF APRIL 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	·26	17	*Glam.*	Cardiff, Penylan ...	·23	9
Kent	Dover	·49	30	*Pemb.*	Tenby	·32	1
„	Edenbridge, Falconhurst	·20	11	*Radnor*	Tyrmynydd	·26	7
Sussex	Compton, Compton Ho.	·14	7	*Mont.*	Lake Vyrnwy	·46	15
„	Worthing, Beach Ho. Pk.	·10	6	*Mer.*	Blaenau Festiniog ...	2·04	33
Hants.	St. Catherine's L'thouse	·27	17	„	Aberdovey	·60	23
„	Southampton (East Pk.)	·09	5	*Carn.*	Llandudno	·16	9
„	South Farnborough ...	·37	24	*Angl.*	Llanerchymedd ...	·50	23
Herts.	Harpenden, Rothamsted	·29	18	*I. Man*	Douglas, Borough Cem.	1·05	43
Bucks.	Slough, Upton... ...	·24	17	*Wigtown*	Newton Stewart ...	1·59	62
Oxford	Oxford, Radcliffe ...	·39	24	*Dumf.*	Dumfries, Crichton R.I.	1·83	78
N'hants.	Wellingboro' Swanspool	·30	20	„	Eskdalemuir Obsy. ...	2·91	86
Essex	Southend, W. W. ...	·12	9	*Roxb.*	Crailing...	·28	17
Suffolk	Felixstowe	·25	21	*Peebles*	Stobo Castle	2·03	97
„	Lowestoft Sec. School...	·49	33	*Berwick*	Marchmont House ...	·83	41
„	Bury St. Ed., Westley H.	·30	20	*E. Loth.*	North Berwick Gas Wks.	1·43	104
Norfolk	Sandringham Ho. Gdns.	·38	25	*Midl'n.*	Edinburgh, Blackf'd. H.	·61	41
Wilts.	Aldbourne	·36	18	*Lanark*	Hamilton W. W., T'nhill	1·80	96
Dorset	Creech Grange... ...	·19	9	*Ayr*	Prestwick	2·23	128
„	Beaminster, East St. ...	·16	7	„	Glen Afton, Ayr San. ...	2·36	79
Devon	Teignmouth, Den Gdns.	·07	3	*Renfrew*	Greenock, Prospect Hill	2·86	83
„	Ilfracombe	·31	15	*Bute*	Rothesay, Ardencraig...	...	...
„	Princetown	·55	11	*Argyll*	Morven, Drimnin ...	2·81	77
Cornwall	Bude	·25	13	„	Poltalloch	2·02	67
„	Penzance	·75	31	„	Inveraray Castle ...	4·58	100
„	St. Austell	·51	18	„	Islay, Eallabus... ...	2·14	75
„	Scilly, Tresco Abbey ...	·66	34	„	Tiree	1·78	72
Somerset	Taunton	·03	2	*Kinross*	Loch Leven Sluice ...	1·68	87
Glos.	Cirencester	·30	15	*Fife*	Leuchars Airfield ...	·46	29
Salop	Church Stretton ...	·61	23	*Perth*	Loch Dhu	3·45	73
„	Shrewsbury, Monkmore	·44	30	„	Crieff, Strathearn Hyd.	1·58	72
Worcs.	Malvern, Free Library...	·00	00	„	Pitlochry, Fincastle ...	·89	40
Warwick	Birmingham, Edgbaston	·19	10	*Angus*	Montrose Hospital ...	·80	44
Leics.	Thornton Reservoir ...	·15	9	*Aberd.*	Braemar	1·29	54
Lincs.	Boston, Skirbeck ...	·23	17	„	Dyce, Craibstone ...	1·41	68
„	Skegness, Marine Gdns.	·35	26	„	New Deer School House	1·48	74
Notts.	Mansfield, Carr Bank...	·17	10	*Moray*	Gordon Castle	·61	35
Derby	Buxton, Terrace Slopes	·52	18	*Nairn*	Nairn Achareidh ...	·56	40
Ches.	Bidston Observatory ...	·34	21	*Inverness*	Loch Ness, Garthbeg ...	1·24	54
„	Manchester, Ringway...	·29	16	„	Loch Hourn, Kinl'hourn	4·19	67
Lancs.	Stonyhurst College ...	·75	28	„	Fort William, Teviot ...	3·13	70
„	Squires Gate	·31	17	„	Skye, Broadford ...	...	...
Yorks.	Wakefield, Clarence Pk.	·16	10	„	Skye, Duntulm... ...	2·85	88
„	Hull, Pearson Park ...	·33	21	*R. & C.*	Tain, Mayfield... ...	·68	37
„	Felixkirk, Mt. St. John...	·54	32	„	Inverbroom, Glackour...	2·08	56
„	York Museum	·20	13	„	Achnashellach	3·18	59
„	Scarborough	·73	47	*Suth.*	Lochinver, Bank Ho. ...	2·52	88
„	Middlesbrough... ...	·25	18	*Caith.*	Wick Airfield	1·03	52
„	Baldersdale, Hury Res.	·46	21	*Shtland*	Lerwick Observatory ...	2·29	100
Norl'd.	Newcastle, Leazes Pk....	·43	27	*Ferm.*	Crom Castle	2·01	79
„	Bellingham, High Green	·58	27	*Armagh*	Armagh Observatory ...	1·17	56
„	Lilburn Tower Gdns. ...	·30	15	*Down*	Seaforde	1·15	44
Cumb.	Geltsdale	1·30	61	*Antrim*	Aldergrove Airfield ...	1·14	54
„	Keswick, High Hill ...	1·06	35	„	Ballymena, Harryville...	1·60	61
„	Ravenglass, The Grove	1·30	52	*L'derry*	Garvagh, Moneydig ...	1·37	56
Mon.	A'gavenny, Plâs Derwen	·06	2	„	Londonderry, Creggan	1·17	46
Glam.	Ystalyfera, Wern House	·74	19	*Tyrone*	Omagh, Edenfel ...	1·62	62

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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 86, No. 1,021, JULY 1957

ERNEST GEORGE BILHAM, B.Sc., D.I.C.

The news of the sudden death of Mr. Bilham from coronary thrombosis on Sunday, May 5, 1957, came as a great shock and sorrow to his many friends, past and present members of the Office. It is less than four years since he retired, to enjoy, as we hoped for many years, "the small house and large garden" of Cowley's desire, where, with Marvell, he could reckon the "sweet wholesome hours with herbs and flowers". His death seems to us a premature ending of a happy time.

E. G. Bilham entered the Meteorological Office in April 1915; he served for a year as resident observer at Kew Observatory; a year with Mr. W. H. Dines at Benson; seven years as a forecaster at headquarters; six years as Superintendent of Instruments and eight years as Superintendent of Climatology both at South Kensington; fourteen years as Head of the Forecast Division. An account of the main features of his career in the Office was published in the *Meteorological Magazine* for July 1953 but there are, naturally, aspects not mentioned there. One of the earliest indications of his ability for clear exposition was his examination of the isallobars of moving depressions which disposed of the idea that isallobaric charts would solve the forecaster's problem; but at the same time indicated the conditions under which such charts could be of real assistance to the forecaster. The paper was published in the Swedish *Geografiska Annaler* 1921.

In the 1920's the French Meteorological Service pressed for the use of the "face of the sky", the *systèmes nuageux*, and the sequence of its changes as fundamental elements in the basic information of synoptic reports. They were also using series of charts of barometric change over different time intervals. Bilham was sent to Paris to gain experience in the practical application of these methods in the French Meteorological Office. This stood him in good stead many years later when it fell to him to take a leading part in preparing the "scales and specifications" for synoptic reports at the first post-war meetings of the International Meteorological Organization at Paris in 1946 and Toronto in 1947.

A small thing but worthy of mention was Bilham's introduction of the Meteorological Office tie; it certainly appealed to those who had at heart, as Bilham had, the solidarity of the Office.

Bilham was happy and fortunate in his love of music and the playing of music by Bach was an ending of hope and consolation to the simple funeral service at Headington on Thursday, May 9. How naturally right it was too, that the rain, forecast by Dunstable, was refreshing the lawns and flowers and trees of that garden of rest, and, as we were returning, cascaded from the windows of heaven in confirmation of the announced instability of the earthly atmosphere.

"Mr. Bilham was a good man." These six words, spoken simply and spontaneously by the messenger who stepped forward courteously to open the door for me as I left Dunstable to go to the funeral, live in my mind. Spoken by servant of master they rank with the prayer of the Elder Servant, number one in C. L. Hind's *100 Best Prayers*.

E. G. Bilham was born on December 1, 1891. He married in 1918, Miss R. Corrin, who survives him as do also their son and daughter, to whom goes the natural sympathy of those of the Office who knew him.

E. GOLD

ATMOSPHERIC CHEMISTRY

By B. C. V. ODDIE, B.Sc.

The atmosphere contains a wide variety of simple inorganic acids and salts in the gaseous form, as minute solid particles and as very small droplets of solution. These substances are washed into the soil by rain and, since some of them are of kinds which are essential to plant-growth, they have considerable importance in agriculture. It is for this reason that atmospheric chemistry, as it is coming to be called, is a new branch of meteorology but by no means a new branch of science: for it has been systematically studied by agricultural research workers for more than a century.

The subject entered the meteorological world as a result of collaboration between Dr. H. Egnér of the Royal Agricultural College of Sweden and Prof. C.-G. Rossby of the Institute of Meteorology (University of Stockholm). Under their energetic leadership a network of stations was inaugurated in 1954 to serve the needs of both agriculturalists and meteorologists. This network, originally Scandinavian, has since extended to Holland, Belgium, West Germany, northern France and Great Britain. The principal sampling technique consists simply of collecting the rainfall in a glass funnel for a period of one month, at the end of which a measured proportion is sent for analysis. At most stations, a sample is also taken by drawing air continuously through a very dilute solution of nitric acid and hydrogen peroxide, in which most of the common ions are absorbed: and this solution is likewise sent for analysis at the end of each month. Both rain-water and solution are analysed for sulphur (SO_3 and SO_4), chlorine, ammonia, sodium, potassium, magnesium and calcium, and in addition the rain-water is analysed for nitrate, carbonate, acidity (pH) and electrical conductivity.

It will be seen that the greater importance attaches to the rain-water analyses—the traditional technique of the agriculturalist and indeed the natural one, since he is directly interested in the rain-water as a sort of dilute chemical fertiliser. To the meteorologist, whose object is a general study of chemical processes in the atmosphere, the technique is less satisfactory, as we shall see presently. Nevertheless, it has so far proved the more rewarding, even from the meteorological standpoint, and has thrown a great deal of light on a remarkable phenomenon. Nearly all of the sodium and chlorine in the air is derived from sea-salt, which finds its way into the atmosphere as spray. One naturally expects this salt to be brought down by rain and, therefore, that the ratio of the mass of chlorine to that of sodium in rain-water will be the same as in the sea—i.e. 1·8. In fact, the ratio is nearly always less than this—at least, it is so in Scandinavia, the only region for which there is yet a substantial body of information. It is only about 1·3 even near the windward coasts, and farther to the east it often falls to about 0·6.

An obvious explanation comes at once to mind—as the salt is washed out by rain, some new sodium compound is added to the air, being derived from inland sources. Thus the Cl : Na ratio present in the air would decrease with increasing distance from the sea, and would be shown in the rain-water analyses. But there is no obvious source of the new sodium compound in the necessary quantities. The only other explanation possible seems to be that the sea-salt is somehow gradually dissociated into two parts, one containing the sodium and the other the chlorine; and that the former is more readily brought down by rain than the latter. Cauer[1] suggested that the sea-salt is oxidized by ozone to form sodium hydroxide and free chlorine, and that the latter then combines with water vapour to give hydrochloric acid. This, Cauer supposed, is not brought down by rain because it is present either as a gas or as droplets of solution too small to serve as condensation-nuclei. None of this seems very plausible at first sight, and yet some such mechanism seems necessary to explain the apparent fact that, with winds from the sea, most of the sodium is deposited within a hundred miles or so of the coast, while the chlorine is not.

What then happens to the chlorine? It is certainly not accumulating in the atmosphere, and must therefore be returning to the earth, probably in rain. Rossby and Egnér[2] followed up this idea, and sought for occasions on which the rain brought down a high proportion of chlorine: and they found that, when the winds reaching Scandinavia were southerly and had therefore been over land for several hundred miles, the Cl : Na ratio in the rain-water was in fact very high, sometimes reaching 3·5. Further studies on the same lines enabled Rossby to distinguish four zones of chemical climate, which are successively farther from the windward coast. These zones are,

(i) A coastal zone where unaltered sea-salt predominates and the Cl : Na ratio in rain-water approaches 1·8.

(ii) A zone where the salt is largely dissociated and little chloride brought down by rain: the Cl : Na ratio is low.

(iii) A zone where little sodium remains and the principal condensation-nuclei are chlorides other than sodium chloride: the Cl : Na ratio is high.

(iv) A zone where most of the ions originating in the sea have already been lost. The chlorine and sodium present are derived from the ground, where sodium is the commoner. The Cl : Na ratio is therefore low, but the amounts of both are very small.

The explanation embodied in this classification is, of course, largely hypothetical, and much more information will be needed before it can be confirmed. One may doubt, however, whether this additional information can ever be obtained with the present type of equipment for, striking as its successes have been, a little consideration shows that it has very serious limitations. The samples come to the analyst as solutions so that all the physical properties of the dissolved matter have been lost before the study begins. One cannot hope to tell whether a given ion was present in the air as a gas, a solid, or a solution-droplet, nor which ions were combined together, nor anything about the masses of the particles. Very little can be judged about the distribution of materials in the vertical, for the air samples are taken at the surface, and it is impossible to judge how far they represent conditions at the cloud level; while the rain-water samples can tell one little about the composition of the atmosphere at any level, since it is the whole point of Rossby and Egnér's results that the two are not related in any predictable manner.

One can get a hint of how much is lost by the use of these methods from the work of Junge[3]. He endeavoured to estimate the ions present in the gaseous form by sampling air after it had been drawn through a millipore filter. At the same time he collected the aerosols by means of a "cascade impactor" which separated them into two classes according to size—the "giant nuclei" of diameters between 0·8 and 8 microns, and the "large nuclei" with diameters between 0·08 and 0·8 microns. Smaller nuclei, present as a rule in greater numbers but of relatively small total mass, were not collected. Junge found that in maritime air the Cl : Na ratio in the "giant" particles was always substantially the same as in sea-water, whereas in the "large" particles it was low—about 0·5. He believes that the two classes are of quite different origin, the "giant nuclei" coming from the sea whereas "almost all the large ions are of continental origin, even over the ocean". Evidently quite considerable differences of constitution, particularly differences in the Cl : Na ratio, could be accounted for by the mere mixing of nuclei of these two different types, without any necessity to assume the dissociation of salt. Junge also found that a surprisingly large proportion of some ions was present in the gaseous form—about half the chloride and nine-tenths or more of the ammonium, sulphate and sulphite.

It is not, in general, impossible to reconcile these results with the findings of Rossby and Egnér, but they do suggest that there may be far more complex interactions than have yet been imagined, and one can hardly disagree with Junge's view that "a real step forward in the understanding of the basic processes of air chemistry can be gained only if aerosols and gases are measured simultaneously but separately and if aerosols, in turn, are separated according to size". It is not easy to judge, however, whether even Junge's technique really achieves this kind of separation. Most of the particles in the air are, in fact, minute droplets. Junge endeavours to remove these from the air by a filter; but one would imagine that they would evaporate on the filter, and that all the volatile part would then pass through, and be treated in the analysis as a gaseous constituent of the air. Again, the "cascade impactor", which Junge uses to separate his particles, has generally been found unsatisfactory for droplets smaller than about two microns in diameter, as they are apt to evaporate on their way through the instrument.

Junge might fairly have added, to the passage quoted above, that a short sampling period is also essential to a satisfactory technique. One can only hope to establish clear-cut relationships between synoptic weather and chemical climate if each sample represents a distinct synoptic type. That Junge is able to sample for a few hours only, whereas in the Scandinavian network the sampling period is a month, is in theory a great advantage of his methods. In practice, the application of his methods to an extensive network would raise very serious administrative problems: the chemical analysis of such small quantities of material is difficult, and can only be carried out in a few specialized institutions. These have already had some difficulty in absorbing the analytical work of the present network. Any considerable increase in the analysis would necessitate the building of special laboratories for the purpose, at considerable expense.

We have, then, neither a completely satisfactory sampling technique, nor even a very clear idea of what sort of technique we want. Thus, for the believers in atmospheric chemistry the only course open at present is to make the best possible use of the existing methods and network. Attention is being concentrated on the International Geophysical Year, because during that period an exceptional amount of observational material, which may be related to the chemical constitution of the atmosphere, will be collected—data on winds, precipitation, ozone-concentration, numbers of condensation nuclei and intensity of solar radiation. It is hoped that the study of atmospheric chemistry against this background will either yield valuable new information or, at least, enable the usefulness of the present sampling technique to be assessed more reliably than is now possible.

The immediate aim is to fill the more serious gaps in the network before the start of the International Geophysical Year. The largest gap is in Great Britain where there are at present only five stations—Aberdeen, Edinburgh, Leeds, Harpenden, and Newton Abbot—whereas for a satisfactory network, by Scandinavian standards, there should be about twenty-five. Last summer, therefore, Prof. Sheppard and Dr. Goody (who had already been responsible for the setting up of the five existing stations) suggested to the Meteorological Research Committee that the Meteorological Office should co-operate in the programme, at least during the International Geophysical Year[4]. The proposal was accepted, though with some reservations: to set up the twenty additional stations which were desirable was hardly practicable, because there was not time to arrange for the manufacture of the equipment by a contractor, and the Meteorological Office's own constructional resources, already engaged in other preparations for the International Geophysical Year, could not undertake so large a task. It was decided, therefore, that the Office would endeavour to set up five or six stations, at Lerwick, Stornoway, Eskdalemuir, Irvinestown, Camborne and probably one other. All the places named are so placed that they will sample the air almost straight from the Atlantic, and before it has undergone much pollution from industrial sources. They will thus be complementary to the chain organized by Prof. Sheppard and Dr. Goody, which lies mostly in the east. The sampling equipment is being constructed by the Instruments Division of the Meteorological Office at Harrow, and it is hoped to install it not later than the beginning of June.

As already indicated, the present plan of the Meteorological Office is to maintain these stations during the International Geophysical Year. It is still uncertain whether all or any of them will be retained after that. However, the whole subject of atmospheric chemistry is to be debated by the World Meteorological Organization's Commission for Aerology at a meeting to be held in Paris in June 1957, and this body will probably make recommendations as to the future of the observing network. Although one cannot anticipate these recommendations, it is almost inconceivable that the Commission will propose the abandonment of the network, for its observations are not only most intriguing in themselves but also provide an essential background for a large number of other studies. There are, for example, various special chemical studies which have hitherto been pursued only occasionally and in isolation, such as the variation in chemical constitution of the air with height above the ground, the relationship between the ozone-concentration in the lower atmosphere and the synoptic situation, the variations of the chemical constitution of rain-water with the size of the raindrop and with its location in the pattern of precipitation. In addition, there is an important group of studies concerning the physical properties of aerosols—their size-distribution, electric charges and mobilities, and especially their activity as freezing- and condensation-nuclei. All these form with atmospheric chemistry a single natural group. They all have considerable importance both in meteorological theory and in their practical applications, and they can only be studied satisfactorily if they are treated as a whole, by a unified organization based on a well designed sampling network. It is to be hoped that the Commission for Aerology will be able to make proposals which will, at least, lead towards a sampling procedure which will be sufficiently comprehensive to meet all these varying demands, without being impossibly expensive.

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AVERAGE HEIGHT OF THE STANDARD ISOBARIC SURFACES OVER THE NORTH POLAR REGIONS IN JULY

By H. HEASTIE, M.Sc.

Introduction.—In a previous article[1] the decision to start the revision of *Geophysical Memoirs No. 85—Upper winds over the world*, by constructing circumpolar charts of the standard isobaric surfaces was explained and some of the charts for January were shown. This article presents, with a brief description, some of the corresponding charts for July. The complete set of charts is given elsewhere[2].

Data.—Data for the same fixed period, 1949–53, were used: sources are listed elsewhere[3]. The labour of extraction was eased by the receipt of further micro-film data for Norwegian stations from Det Norske Meteorologiske Institut, Oslo and of manuscript data for Alaska and the Aleutians from the United States Weather Bureau.

Method of constructing the charts.—The method used was similar to that described briefly in reference 1, although there was one slight complication. For Siberia no data at all for July 1949 were available. For this month the monthly mean 500-mb. contour chart published in the monthly supplement to the *German daily weather report*[4] was accepted over Siberia and the 700–500-mb.

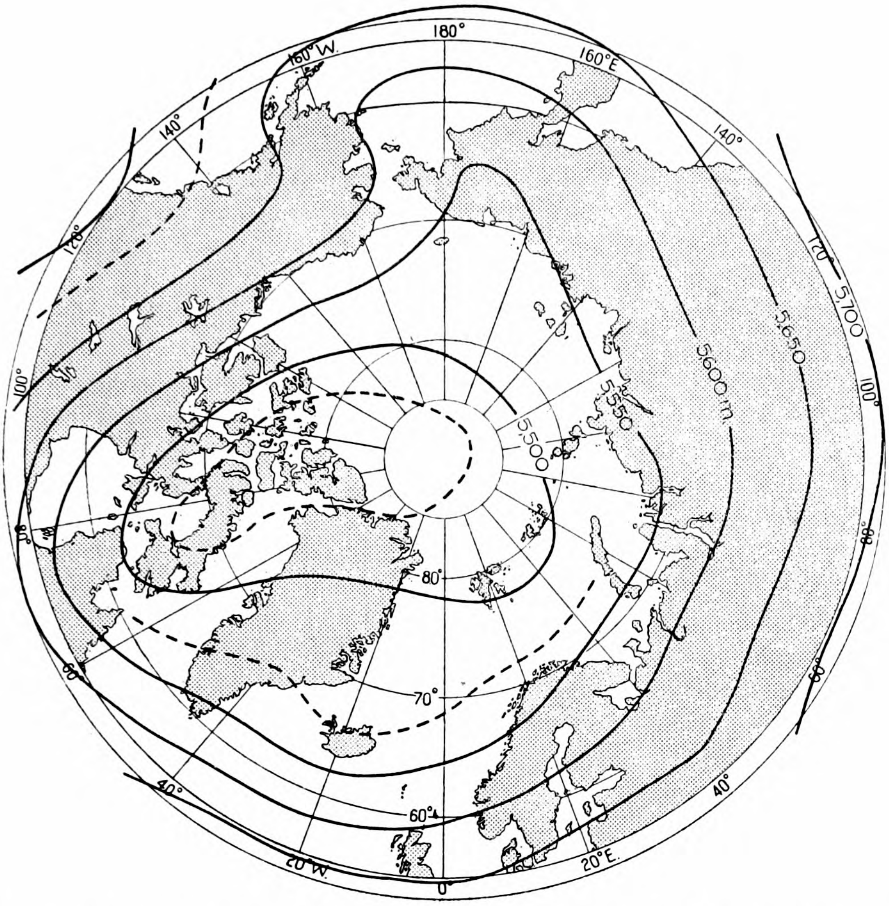

FIG. I—AVERAGE 500-MB. CONTOURS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

thickness chart constructed over this area by correlating the 700–500-mb. thickness with the 500-mb. contour height along the meridians 20°E., 40°E.... 180°E. for the four years 1950–53. As the grid values obtained fitted in reasonably well with the rest of the chart drawn from data and as the nine values obtained for the pole lay within a ten-metre range, the method was regarded as satisfactory. The 500–300-mb. thickness and the 300-mb. temperature charts were computed in a similar manner.

For a large part of the area covered by the charts no night time ascents were available and the effect of solar radiation on the various types of radiosondes used by the different countries had to be considered. In most cases, with the exception of the Union of Soviet Socialist Republics, the problem was solved more or less satisfactorily. Unfortunately the Russian ascents were made in daylight and very little is known about the characteristics of the Russian instrument.

The charts.—The July contour charts show some marked differences from those for January. In January there is mainly westerly flow in the troposphere with considerable asymmetry about the pole. The very cold arctic winter stratosphere leads to a thermal pattern which reinforces this flow so that the January charts present a picture of mainly westerly flow increasing with height

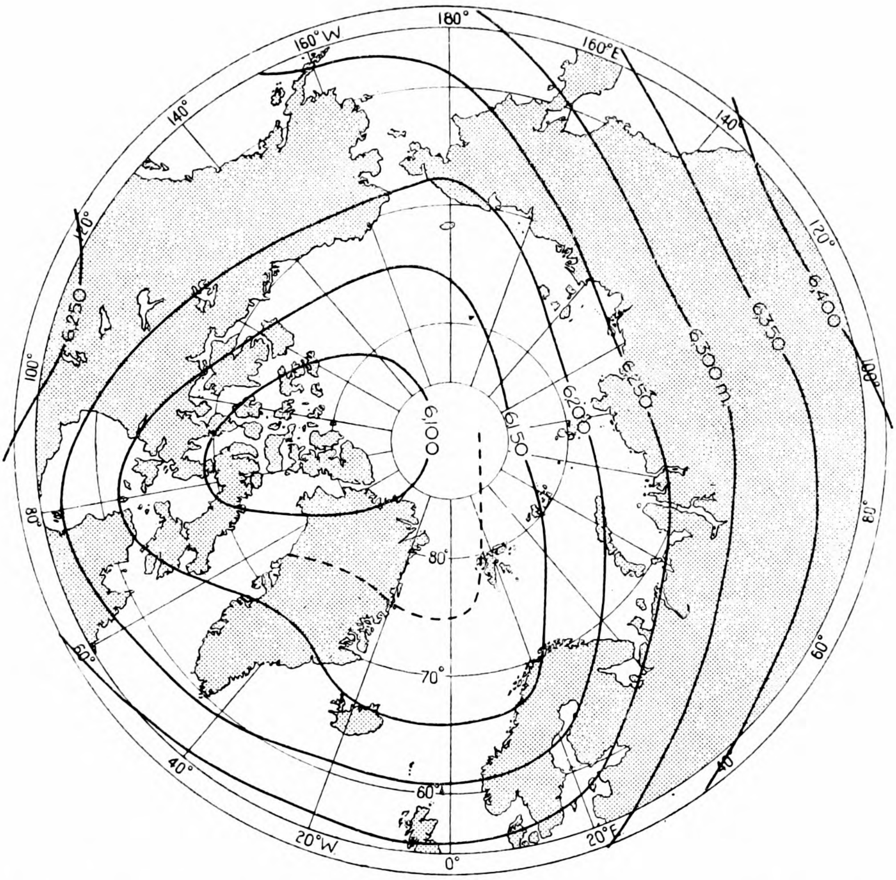

FIG. 2—AVERAGE 700–300 MB. THICKNESS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

and becoming almost symmetric about the pole at the 100-mb. level. In July there is again mainly westerly, though much weaker, flow in the troposphere (Fig. 1). The 700—300-mb. thickness chart (Fig. 2), representing the thermal pattern in the troposphere, shows a centre of low thickness over northern Canada and, as the main low centre on the 700-mb. chart lies near the pole, this causes the main axis of the tropospheric flow to tilt southwards with height along the 90°W. meridian. In the region considered the tropopause is everywhere below the 200-mb. surface and the very warm arctic summer stratosphere is reflected in the 200–100-mb. thickness chart (Fig. 3) which shows an easterly thermal centred on the pole. The resulting contour charts show a mainly westerly flow over Eurasia at all levels with a maximum at the 200-mb. level. Over the Canadian sector of the chart the centre of low contour height is transferred southward from about 87°N. at 700 mb. to about 68°N. at 100 mb. (Fig. 4) and lies between the 70°W. and 90°W. meridians. The flow round this low centre increases generally up to 300 mb. and, above 200 mb., decreases to less than 15 kt. everywhere at 100 mb. Hence, up to 100 mb., where the January charts show increasing symmetry with height, the July charts become more asymmetric with height. Temperature lapses 100–25 mb. shown on the Air Weather Service charts[5] suggest that from about 25 mb. upwards the circulation is again tending towards symmetry about the pole with a contour

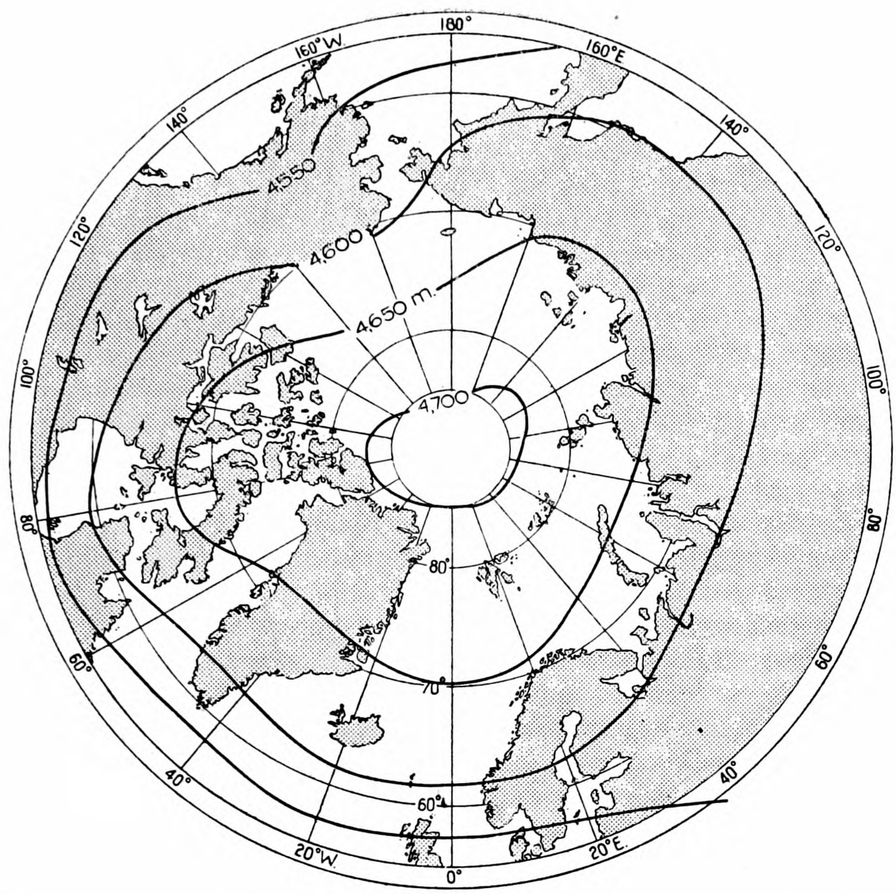

FIG. 3—AVERAGE 200–100 MB. THICKNESS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

high moving northwards over central Siberia towards the pole and the Canadian low centre moving southwards and being absorbed.

One interesting feature arising out of the symmetry of the thickness pattern and the asymmetry of the contour pattern in the stratosphere may be mentioned here. Over a large area of the chart north of the Arctic Circle the flow in the stratosphere (Fig. 4) is directly across the thickness pattern (Fig. 3). Neither the flow in the troposphere (Fig. 1) nor the tropopause pressure chart[6] suggests any appreciable vertical motion of the atmosphere in this area and the implied temperature changes are presumably due to radiative effect. For the layer 200–100 mb. the heating of the air moving poleward from 70°–75°N. appears to be of the order of 0·5°C. per day over 2–4 days. The stratosphere over this area is in continuous sunlight during the whole of July, but no attempt has been made to estimate whether variation in solar altitude or in ozone concentration could account for this heating.

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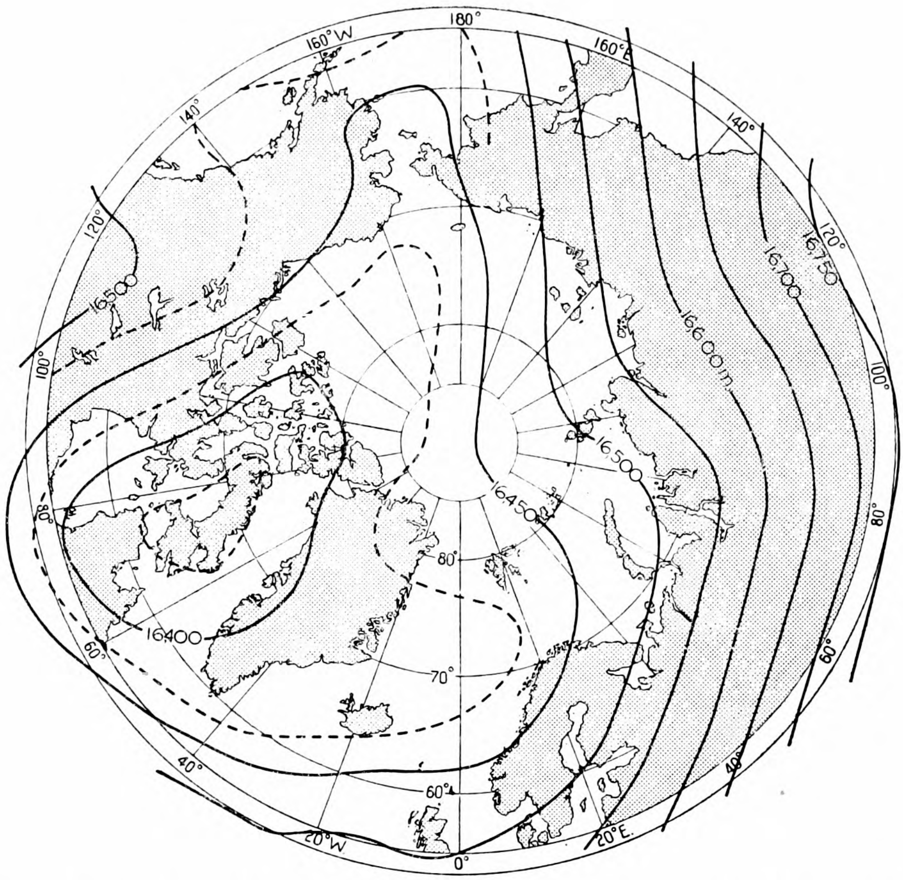

FIG. 4—AVERAGE 100-MB. CONTOURS FOR JULY 1949–53 OVER NORTH POLAR REGIONS

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THE APPLICATION OF CLIMATOLOGICAL DATA

By R. G. VERYARD, B.Sc.

In the Meteorological Office centenary issue of the *Meteorological Magazine* in June 1955 a series of articles was published under the general heading of "The Meteorological Office Faces the Future". The articles dealt with scientific research and development, services for aviation and defence, and forecasting and public services, but no reference was made to the future of climatological services. The intention of this article is to repair that omission. It is also hoped that the article will enable observers called upon to render climatological returns to appreciate the need for introducing new forms and to feel that their labour in completing these forms is worth while.

When the Meteorological Office was founded, in 1855, its primary function was to obtain climatological information for the benefit of shipping. Thus the climatological work of the Office is as old as the Office itself. As in other countries, the original aim of this work was to build up a statistical picture of general weather conditions as a contribution to meteorological knowledge. It was soon realised that climatological data could have a wider practical value. For example, over 50 years ago Sir Napier Shaw presented a paper to the Royal Society on "An apparent periodicity in the yield of wheat for eastern England 1885–1905". An apparent relation was derived between the yield of wheat and the aggregate rainfall for the three autumnal months of the preceding year. Ever since then climatological data have been applied to the problems of the grower and today there is a separate branch of the Office which makes a special study of the application of meteorological information and knowledge to farming, horticulture and forestry. Other fields in which, for many many years, important use has been made of long series of observations are those of water supply and hydro-electric power supply. Indeed, the organization of rainfall observations in this country, originally in the hands of the British Rainfall Organization and now of the Meteorological Office, is one of the finest in the world—not that it is perfect by any means. Many other examples could be given of the application of climatological data and meteorological knowledge to various fields of human endeavour—to air and sea navigation, to building and architecture, to engineering, to insurance, medical research, and so on. For a detailed account reference should be made to the report in the *Meteorological Magazine* for January 1956 of an Office discussion on the subject. From a reading of this account it will be realised that the profitable expenditure of large sums of money on capital investment may well depend on a reliable assessment of climatic risks. A forecast may be of little use if the recipient is not prepared for the type of weather that is to occur.

What are the basic requirements for the provision of an efficient climatological consultant service? Obviously, the first requirement is for an adequate supply of reliable data, i.e. observations of temperature, rainfall, wind, etc. suitably distributed in space and time. In regard to reliability, it is essential that a high standard of accuracy be maintained. Actually, the acceptable standard of accuracy will depend on the user's requirements, but it could be said that the accuracy needed for synoptic purposes is not always sufficient for climatological purposes. A comparatively small margin in the assessment of areal rainfall, e.g. in connection with the construction of dams, or the maximum wet bulb "design" temperature, e.g. in connection with the construction of cooling towers or air conditioning plant, might involve very large sums of money. To ensure that basic data are accurate involves the selection of suitable sites, regular inspection of instrumental equipment, checking of observational procedures and practices, and the scrutiny of climatological returns. Scrutiny by eye is a tedious task and calls for the sustained effort of experienced staff. The value of reliable data cannot be over-emphasized but accuracy alone is not enough. It is imperative that long period *homogeneous* data are available. This means that there must be as little change of exposure as possible at the site of observation and also no effective change in observing procedure or practice. When one considers the effect of urbanization or the growth of trees, the frequent changes in the layout of buildings at, and the siting of, airfields (whence much of our basic data are derived), the changes in methods of reporting (e.g. from tenths to eighths in respect of cloud amount), it is not surprising to learn that in the British Isles there are hardly any long period homogeneous data. Hence the reason for the recent decision, promulgated in Meteorological Office Standing Orders, to endeavour to maintain a number of "key" stations at which, it is hoped, the exposure will remain unchanged. Another reason for trying to maintain in perpetuity at least a small number of stations, is the need for a body of "representative" data. Hitherto, the Office has not suffered from a surfeit of data except perhaps in respect of the more common items of observation, e.g. temperature and rainfall, in southern England, where there are a goodly number of the non-official climatological stations which co-operate with the Meteorological Office. There are many areas for which the available data are quite inadequate, especially in respect of wind and rainfall. Moreover, most of the stations which provide climatological returns are the "co-operating" stations, at which observations are made only once a day. However, the time is coming when it will be necessary to limit the ever increasing mass of data by applying some kind of statistical sampling technique in order to determine, in the light of known and potential requirements, for how many stations observations of temperature, rainfall, wind, sunshine etc. should be made, for how many hours per day over a period of how many years. Already, the collection of basic data is being limited by restricting the returns of hourly, 3-hourly, 6-hourly or daily observations to a selection of stations only, by restricting the period for which hourly tabulations of sunshine are required, and so on. Unfortunately, before it will be possible to apply sampling techniqes it will be necessary to have adequate data—homogeneous data.

Another fundamental requirement is that data should be readily made available in the form required by the user. The processing of meteorological data, i.e. the determination of averages, frequencies, extremes, standard deviations, by manual procedures is a laborious business and even when the results have been worked out they are not always in the form required for answering an inquiry. For example, it is not possible to find from the *Climatological Atlas of the British Isles*, or other Meteorological Office data publications, the frequency distribution for a given place of the rainfall amounts, in 1, 2, 3 . . . . *n* consecutive days—yet this type of information is often wanted. It was realised a long while ago that to prepare, by hand, climatic atlases for the oceans from the data provided by ships, e.g. moving observing stations, would be a gigantic task, and a far-sighted decision was made to put the marine data on to punch cards for processing by machine methods. As a result the Marine Division of the Meteorological Office, having several million cards to work with, is now in the happy position of being able to deal effectively with many inquiries and problems relating to meteorological conditions at sea—except perhaps for those parts of the oceans which are not regularly crossed by ships and for which the available data are therefore scanty—which it would have been quite impracticable to tackle in any other way. An account of the extraction and compilation of marine meteorological data by mechanical methods was given by H. T. Smith in *The Marine Observer*, Vol. XIV, 1937. Several years ago a similar wise decision was made in respect of upper air observations and we have already seen the fruits thereof, namely, the publication in the M.O. 555 series of the machine-analysed data for our upper air stations. The application of the punch card system to upper air data was described by D. Dewar in the *Meteorological Magazine*, Vol. 78, 1949.

Now it has been decided to put surface land data also on to punch cards. Hence the introduction, with effect from January 1 this year, of new forms for climatological returns, initially from official observing stations. The fundamental reason for these new forms is that, having little or no meteorological knowledge, a machine assistant (who does the punching) cannot be expected to sort out exactly from a complicated array of data, as in the *Daily Register* or on the old climatological forms, the actual figures which have to be punched on the cards in a prescribed order. That is why the new design of climatological forms corresponds to the design of the punch cards. If it were possible, as in the United States, for the cards to be punched at the observing stations by the meteorological assistants, then the forms could be dispensed with—although they would still be required from the co-operating stations, who could hardly be expected to punch the data themselves. Maybe, the day will come when the data required from official stations can be punched (or put on to a magnetic tape) directly from the teleprinter tapes at the Central Forecasting Office. But this would raise the question of accuracy. Teleprinter messages are by no means free from mistakes. However, even this difficulty might be overcome. In fact, the National Weather Records Centre at Asheville in the United States has already dispensed with the personal scrutiny which, in this country, is regarded as such an important feature of the work. Special machine procedures have been evolved to exercise "quality control" and internal consistency checks on the observations. Data are tested for "reasonableness" and only those which are rejected as out of line (for example the machine will pick out observations of cloudiness and cloud height which are contradictory) are scrutinized by a meteorologist. Nevertheless, to ensure accuracy, all the necessary computations for upper air data are repeated at Asheville before such data are punched.

It should not be imagined, however, that the introduction of machine facilities is a simple straightforward business. There are many possible snags. In the first instance it is necessary to consider very carefully, in the light of past and foreseeable uses of climatological data, precisely how and what information is to be punched. Obviously the selection of units is important. Frequent changes in the past militate against the use of synoptic codes. The instructions for entering data on the climatological forms must be quite unambiguous. Then there is the need for tidiness and clarity in entering figures on these forms. A badly written 6 or 9 can easily be mistaken for a 0. Like all other meteorological services which have introduced punch card methods (see for example the article on introduction of punch card methods into the Australian Meteorological Service in *Weather* of February 1952) we have had our "teething troubles"—so we are proceeding very warily. When these troubles have been overcome it is hoped to introduce new forms, to go with punch cards, for use by the co-operating observers.

What are in fact the advantages of punch card methods? Perhaps the simplest answer is that sorting into categories (e.g. for the determination of frequencies), the computation of totals (e.g. for the determination of averages), the calculation of squares and products (e.g. for the determination of correlation or standard deviation), can generally be performed more accurately and more quickly by machine than by hand. Of enormous advantage is the facility for determining the frequency of simultaneous occurrence of given values of two or more elements, e.g. cloud and visibility (in connection with landing conditions at airfields), wind and rain (in connection with the problem of "driving" rain), dry bulb and wet bulb temperature (in connection with problems of air conditioning), temperature, humidity and wind (in connection with the cooling power of the air). Compound analyses of the type mentioned would be impracticable without machine methods. An important feature is the capability of the machine, known as the tabulator, for listing data in a form suitable for printing and publication. Many of the data publications of the United States Weather Bureau are produced in this way at Asheville. It is hoped that a day will come when we shall use the tabulator for the publication of the *Monthly Weather Report.* Perhaps also one of these days the machine processing of climatological data will facilitate the prediction of trends and the issue of probability forecasts based on analogues or objective procedures.

However, as far as the machine processing of surface land observations is concerned, it must be expected that future progress will not be rapid. It will be some time before sufficient data have been punched to eliminate the need for dealing with inquiries and investigations by manual methods, although it is hoped to get a "backlog" punched back to January 1, 1949 (when the last big change in synoptic code took place) for a small selection of stations. Nevertheless, we are looking hopefully ahead, and steps have already been taken to centralize machine facilities in a Machine Pool to serve the Meteorological Office as a whole. As yet, the available machines have certain limitations and some analysis must still be done by hand but, maybe in the not far distant future, when the Meteorological Office headquarters has settled down at its future home at Bracknell, we shall see the rather humble machine set-up which we have at present, developed with the support of the outstations into a really important unit of our organization, a unit capable of rendering an increasingly valuable contribution to the economic life of the country.

METEOROLOGICAL OFFICE DISCUSSION

Hydrology and British Rainfall

The fifth discussion of the 1956–57 series, held at the Royal Society of Arts on February 18, 1957, was opened by Mr. A. Bleasdale, who also repeated the opening statement in the lecture theatre of the Royal Botanic Gardens, Edinburgh, on March 28, 1957. This report includes an account of the discussions at both meetings.

Mr. Bleasdale explained that from the very wide field which the title could be taken to cover, he had chosen to restrict attention to deficiencies of knowledge on the rainfall side of hydrology. Though it was not suggested that others who wished to contribute to the discussion should feel themselves similarly restricted, he thought that it would be useful to give special attention to deficiencies of hydrological data and to methods which might be applied to overcome them.

The most accurate possible knowledge of precipitation was fundamental in nearly all hydrological investigations, and for water supply inquiries especially the need for full and precise information was of growing importance. The rate of increase in the demand for water was beginning to cause concern and even alarm, as evidenced by quotations from *The Economist* of January 26, 1957[1], and from a statement by the Minister of Housing and Local Government in November 1956[2]. In each case it was emphasized that the water supply problem is becoming a dominant factor in the development of industry, and that the future standard of living and well-being of the people are bound up with its adequate solution. In this context it was a serious responsibility to keep under review the outstanding problems of rainfall measurement, as a basic contribution to the general effort of hydrological research.

Mr. Bleasdale then dealt in turn with the problem of the areal assessment of precipitation, and with problems of measurement at a point under the five headings: exposure and shielding of rain-gauges, rainfall measurement in rugged terrain, snow, dew, and fog precipitation.

Areal assessment of precipitation.—In hydrology the accurate measurement of precipitation at a point is only a beginning. It is necessary to assess the amount of water, in any form, which reaches the ground from the atmosphere over an area. In Britain we have the advantage of one of the densest rain-gauge networks in the world (the average density being about fifteen times that in the U.S.A.[3], for example), but the distribution of rainfall stations is very irregular. Amongst the gathering grounds of overground water-supply undertakings there are probably a dozen or so throughout Britain with rain-gauge networks conforming with standards recommended in 1937[4], a notable example being the Birmingham Waterworks area in central Wales with 32 gauges covering about 71 square miles[5]. In the majority of areas there are deficiencies, and in some the networks are very sparse. The assessment of areal precipitation, as carried out in the Meteorological Office, involves at some stage the drawing of isohyetal lines, often based on a rather limited number of reliable observations. Though it is possible to develop a high degree of skill, allowing for effects of altitude, slope and aspect, the subjective factor remains—in varying degree in different areas—and in Britain objective tests of the accuracy of such methods have not been developed.

Attempts to develop tests have been made in the U.S.A.[6, 7, 8], and the superficial indications are that the standard error of estimates in the most favourable areas in Britain may be about 3 or 4 per cent. But the standard error is a function of rain-gauge density, the size of the area, the time interval covered by the rainfall data, and the type of rainfall. Bearing in mind that it is higher for thundery rainfall in summer than for widespread frontal rain, conditions in Britain may in general be more favourable than in areas studied in the U.S.A., and routine monthly estimates of general rainfall for the most favourable areas may have a standard error as low as 2 per cent. For the most difficult areas, it may be hoped that the standard error does not exceed 10 per cent. There is a need for attention to this problem to determine the margins of uncertainty inherent in the estimates.

Completely objective methods for assessing areal precipitation have been suggested, the earliest being the Thiessen polygon method[9]. By drawing the perpendicular bisectors of the lines joining adjacent gauges on the map, the area is divided into polygons, each enclosing a gauge, and such that any point within a given polygon is nearer to the gauge included than to any other gauge. Each gauge reading is then weighted in proportion to the area of the associated polygon to obtain the areal estimate. The result is better than a straightforward arithmetic mean, but includes no allowance for topographic effects, which could be introduced only at the expense of much laborious arithmetic, or the introduction of subjective factors. The method might perhaps be adapted as part of a test of the adequacy of rain-gauge networks by the comparison, over a series of occasions, of the arithmetic means and the Thiessen polygon estimates.

Spreen developed an objective method based on a sound statistical technique for an area in western Colorado[10]. This was a multiple regression analysis, carried out graphically, relating the winter precipitation of 32 stations to altitude, slope, degree of exposure, and aspect. He obtained a multiple correlation coefficient of 0·94, "indicating that about 88 per cent of the original variance was attributable to the four topographic parameters". On such a basis it would be possible to draw a very detailed isohyetal map and make a completely objective estimate of areal rainfall with a known standard error. Mr. Grindley had attempted to adapt this method for British conditions, using areas in Cornwall and south Wales, but the results were not so satisfactory.

Radar has also been used for the determination of precipitation pattern and areal amount. Intensive studies have been made by the State Water Survey Division of Illinois, some of the earlier reports being very optimistic, and later conclusions rather more cautious[11, 12]. Difficulties include: the uncertainty of the relationship between radar echo intensity (proportional to the sum of the sixth powers of the rain-drop diameters) and rainfall intensity (proportional to the sum of the cubes); and a possible change of the rainfall pattern as observed by radar, perhaps a few thousand feet above the ground, before the rain reaches the surface. Radar, as we know it at present, cannot replace rain-gauge networks entirely, but can give additional information about rainfall distribution which is the more valuable the sparser the network of conventional gauges. If the expense and labour are considered to be justified, radar methods would be useful in areas where networks are necessarily sparse, and also in special investigations. Marshall, Hitschfield and Gunn reach a similar conclusion in a recent evaluation of the technique[13].

As the assessment of areal rainfall is of fundamental importance in hydrology, there is a need for the development of rigorous statistical tests to be applied to areal estimates, so that any such estimate can be associated with an accurately determined standard error, a task which probably requires the collaboration of first-class statisticians.

Measurement at a point.—Consideration of the errors which may arise in point measurements must also be incorporated in the statistical evaluation of areal estimates, and these in themselves pose formidable problems. A useful guide to the literature on rainfall measurement is given by Kurtyka, with over 1,000 references, mostly annotated, up to year of publication 1952[14].

Exposure and shielding of rain-gauges.—The standard exposure of rain-gauges in Britain represents a compromise to avoid the worst effects of excessive catch through in-splashing, and loss of catch due to wind eddies caused by the gauge. The wind effect, discussed as early as 1811 by Luke Howard[15], is known to be serious in exposed situations. In some other countries, where the standard height of the rim of the gauge above the ground is greater than in Britain, the problem is aggravated, so that more attention has been given to the design of rain-gauge shields (see references in Kurtyka indexed under "shields" and "exposure").

As a result of experiments in 1926–32[16], the standard shield in Britain became the turf wall (photograph between p. 208 and 209), though other devices have been used experimentally. Dutch experiments in 1935–45 were based on a pit gauge as the standard of comparison[17]. The rim of the gauge was surrounded by a brush with vertical 2 in. bristles on a wooden base, the brush being surrounded over a wider area by a grid, with the rain-gauge rim, brush and grid all flush with the ground. (The brush device was suggested in 1842 by Thomas Stevenson who introduced the standard thermometer screen[18].) In these experiments the British turf wall proved almost as good as the pit and brush standard, and gauges with Nipher-type shields (see Kurtyka) were intermediate between the turf-wall gauges and those with the standard British exposure without protection. Experiments now in progress at Stocks Reservoir (photographs between pp. 208 and 209) near Slaidburn, Yorkshire, under Mr. Law, Engineer of the Fylde Water Board, appear to be confirming the Dutch results (but using grid gauges without the brush).

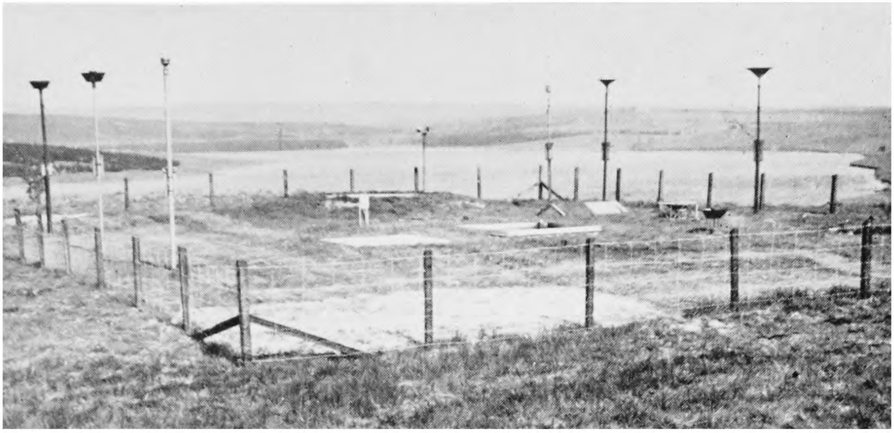
There have been doubts about whether the brush and grid gauges, designed to avoid errors from either in-splashing or wind eddies, are in fact free from in-splashing. This could be tested by having a closely-packed group of nine square gauges surrounded by brush and grid. On occasions of negligible wind the separate catches of the nine gauges should show a symmetrical pattern with amounts a in the centre, $(a + b)$ in each side gauge (in-splashing possible along one side), and $(a + 2b - c)$ in each corner gauge (in-splashing possible along two sides, with perhaps a small reduction, c, arising from a corner effect). If the amount for in-splashing, b, is not completely negligible, the installation could be used to test improved devices of the brush and grid type.

Experience has shown that it is necessary and quite practicable to improve the performance of exposed gauges by some form of shield. This increases the expense and trouble of recording rainfall, and in particular the correct maintenance of a turf wall on rough moorland is not easy. There is a need for increased interest in the exposure and shielding of rain-gauges, and meanwhile an adequate programme of inspections is important, so that at least the existing defects may be known, even if they cannot be fully corrected.

Rainfall sampling in rugged terrain.—Apart from problems of loss of catch in exposed situations, there is the hydrological problem of the distribution of rainfall on the ground in hilly country, which is distinct from the purely meteorological problem requiring the correct measurement of rainfall by means of gauges with horizontal rims. A windward slope intercepts more rainfall per unit projected area, and a leeward slope less, than a horizontal surface. The problem has been neglected in Britain, the neglect having been encouraged by insistence that, wherever possible, the gauges must be set up on level sites. Whilst there is much to be said for the rule for the majority of rainfall observers, it definitely introduces a bias in the sampling of rainfall in hilly country. An approach which has been investigated in several countries in Europe[19, 20, 21, 22, 23] and in the United States of America[21] makes use of gauges with the rims parallel to the slope of the ground on which they stand. Two versions have been employed: the "tailored" or "stereo"-gauge, with the upper part of the funnel formed from a vertical cylinder, cut off obliquely to match the slope at the chosen site; and the ordinary gauge set normal to the slope, instead of vertically (photographs between pp. 208 and 209), which provides readings requiring a correction factor $1/\cos\alpha$ (where α is the angle of the slope) before being plotted on the rainfall map. The ideal would probably be a stereo-gauge flush with the slope, surrounded by a brush and grid which had previously been tested for the prevention of in-splashing. Hamilton has indicated a simpler solution in his conclusion that the shielding of sloping gauges is unnecessary, even with the rim as much as 40 in. from the ground[21], but this is a conclusion which may legitimately arouse slight suspicion about an otherwise excellent report.

An adequate network of sloping rain-gauges would need to be much denser than a conventional network of standard gauges, possibly by a factor of two or three, to provide sufficient sample data for the great variety of slopes in a catchment area. A practicable compromise might be to supplement a conventional network with a small number of paired gauges, sloping and standard, to obtain some information about correction factors for various slopes in different conditions. The actual distribution of rainfall on the ground in hilly country is a problem beyond the scope of the radar technique.

[*To face p.* 208



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EXPERIMENTAL RAIN-GAUGE INSTALLATION AT STOCKS RESERVOIR

(see p. 208)

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EVAPORATION PAN AT STOCKS RESERVOIR

United States Weather Bureau class A type.

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INSTALLATION AT STOCKS RESERVOIR

Grid rain-gauge appears in left foreground.
(see p. 208)

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TURF WALL AT STOCKS RESERVOIR

(see p. 208)

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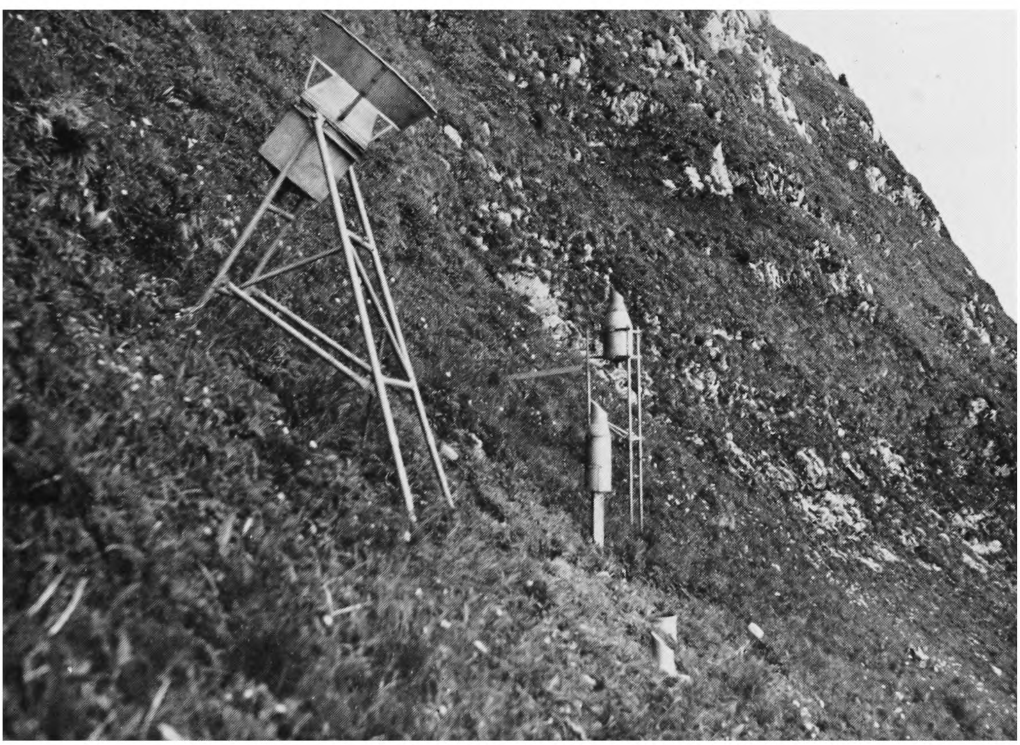

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TAILORED AND SLOPING RAIN-GAUGES ON A MOUNTAIN SLOPE IN SWITZERLAND

(see p. 208 and overleaf)

To face p. 209]

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TAILORED AND SLOPING RAIN-GAUGES ON A MOUNTAIN SLOPE IN SWITZERLAND
(continued)

Snow.—The ordinary rain-gauge is a very poor snow-gauge and supplementary observations of snowfall are necessary, either from samples cut from representative snow cover, or from special instruments. The well organized snow surveys of Canada, the United States[25, 26], and some European countries cannot be emulated in Britain because of the very irregular nature of the snowfall experienced, and we have so far relied largely on the initiative of individual observers. Quantitative data on snowfall could be obtained by methods which are basically quite simple, and it would probably be useful to imitate the organized snow survey methods at least to the extent of carrying out a pilot trial, perhaps on the gathering grounds of a water supply undertaking, or at Eskdalemuir, to obtain information about the required effort and to try out simple items of equipment.

Most snow-gauges (see references in Kurtyka) are modifications of the rain-gauge, a main part of the modification usually being some form of shield, since the errors due to wind effects are much more serious with snow than with rain. In the United States wind-tunnel work using sawdust for snow has led to a development of the type of shield originated by Alter, with improved catches both in the tunnel and in the field[27]. In Britain, two experimental snow-gauges have been produced and set up at Eskdalemuir, but there has been little snowfall since they were installed. Snow-gauges developed as modifications of the rain-gauge should, generally, measure rainfall as well as snowfall, but there is a gauge of a quite different type which measures the water equivalent of snow lying. This is the radio-active snow-gauge[28, 29] based on the principle that radiation from a slug of cobalt-60 (suggested as one of the most suitable radio-isotopes), buried in the ground, is reduced in intensity on passing through a layer of snow. The instrument is said to be accurate within 2 or 3 per cent and to have successfully measured up to 55 in. water equivalent. It is hardly likely that the device will be adopted to measure the very uncertain snowfall of Britain, but if it is there are some difficulties, and possibly dangers, to be considered.

Dew.—With a conventional rain-gauge there are some readings of "trace", and even of measurable small amounts, which result from dew. But it cannot be supposed that the rain-gauge collects a representative sample. Various attempts have been made to devise reliable dew-gauges, and the indications are usually that in Britain the total amount may be of the order of 1·0 to 1·5 in. a year. Work carried out in the United States during the 1940's gave a much higher value for "condensation-absorption", namely about 9 in., or 19 per cent of the total water supply available to plants and soil at the site of the investigation[30]. This rather startling result appears to have been accepted in a semi-popular account of the role of dew in the 1955 Yearbook of Agriculture of the United States Department of Agriculture[31], and to have been used as part of the basis of a paper by Buettner, of which only an abstract is at present available in Britain[32]. The paper includes "a brief survey of the laws on heat, mass and momentum transfer involved", and should be of outstanding interest to hydrologists, agricultural meteorologists and others, if it sufficiently supports the claim that the additional contribution of dew (and absorption from mist) "may result in a water supply usable to plants much in excess of precipitation measured with standard techniques". Meanwhile it seems permissible to be sceptical. If the energy released during the condensation of such substantial amounts of water does not become available to promote compensating processes of evaporation and transpiration, it is necessary to inquire how and when it is (in this context, harmlessly) dispersed. A possible explanation might be that some plants, because of structure or other individual properties, are able to capture this additional supply of water, but ultimately at the expense of others.

Fog precipitation.—Nagel has recently drawn attention to the possible deposition of substantial amounts of water from fog when the ordinary rain-gauge catches little or nothing[33]. He refers to similar work on Table Mountain going back to 1904, but his interest appears to be mainly meteorological. Other workers (Grunow[34, 35], Hori[36]) have attempted to relate the amount of precipitation caught by a fog-catcher to the amount caught by vegetation, particularly trees. Grunow concluded that fog-drip "is important for hydrological calculations in mountain forests and coastal mist belts".

The problem is a part of the more general problem of the effect of vegetation on the water balance of drainage areas, a subject about which little is known in an accurate quantitative sense. Results of investigations in different parts of the world are not altogether consistent. Mr. Law's experiments at Stocks Reservoir include some relevant work with respect to trees, and he has concluded that there is a water loss from afforested gathering grounds which is very serious for the water-supply engineer[37]. Mr. Bleasdale said that he had already expressed opinions contrary to Mr. Law's conclusions, based on arguments that the additional loss from trees would be compensated in various ways, part of the compensation coming from fog-drip[38]. This was not an appropriate time to pursue the substance of the argument, but to note that such disagreements exist, and to consider how to improve quantitative knowledge of the hydrological balance of vegetated areas, in order that the problems could eventually be solved. At this point too, it was suggested, the discussion of precipitation leads, through the introduction of the topic of fog-drip, to consideration of the whole field of hydrology, since this phenomenon above all others which had been mentioned, could not be adequately investigated in isolation.

Conclusion.—Mr. Bleasdale concluded with the suggestion that insufficient attention has so far been given to the determination of the limits of uncertainty associated with all types of hydrological measurements, and that this would be a profitable line of study, both to assess the value of attempted water balance investigations, and to stimulate efforts to improve methods of measurement.

Discussion in London

Mr. Veryard referred to the session of the Commission for Climatology of the World Meteorological Organization from which he had recently returned. It was evident that increased interest in water resources was world-wide, and was not confined to the special problem of the arid zones, but was closely linked with industrial development in moister regions. In this country there had been serious attention to the matter in the press, and the re-constitution of the Central Advisory Water Committee, with its Sub-Committee on Information on Water Resources, demonstrated official recognition of the problem. He re-emphasized the difficulties associated with the measurement of snowfall and of rainfall in rugged terrain, as discussed by the opener, and also referred to problems of evaporation measurement—the need to standardize instruments, partially recognized by the recommendation to install American type evaporation pans for the International Geophysical Year; and the need to build on the work of Penman and Ferguson to obtain estimates of evaporation for hydrological use. He compared the combined hydro-meteorological services of such countries as Sweden and the U.S.S.R. with the different situation in Britain, which called for the collaboration of several different organizations and depended on the maintenance of the good liaison which at present exists. He also drew attention to the need for developing the most useful forms of presentation of data, asking for guidance from users, and finally paid tribute to the thousands of voluntary observers on which the rainfall and hydrological work in this country depends so much.

Mr. Wolf spoke of the post-graduate course in hydrology at the Imperial College of Science and Technology, and of his special interests in the assessment of hydro-electric resources and in the investigation of floods. The amount and quality of data available for such work illustrated the problems of hydrological measurement, and of the patient effort required over periods of years to produce satisfactory results. For the assessment of areal precipitation he preferred to use both the Thiessen polygon method and the isohyetal method. He thought that there was a great need for further investigation in hilly country, and that the benefit to the national economy would amply repay the effort and expenditure. Owing to cautious underestimates of precipitation in some areas, hydro-electric projects had not always been developed to the fullest possible extent. He referred to the possibilities of using radar to forecast river floods, and concluded with the suggestion that there was a field for collaboration in hydrological research between the Meteorological Office and the universities.

Mr. Green discussed work he was doing in the Nature Conservancy with a network of percolation gauges, to obtain standardized measurements of potential evaporation. Estimates obtained by Penman's method appeared to be in closest agreement with observed values for the more maritime situations, whilst Thornthwaite's method appeared better where "continental" tendencies were more pronounced. There were sometimes very large negative values for observed potential evaporation in winter, and this might be an indication of the role of dew and hoar-frost, or might be connected with as yet unknown changes in soil structure at certain times of the year. Among other interesting items mentioned was that the large loss, much greater than potential evaporation, of an experimental drainage area in Upper Teesdale covered with undisturbed bog, gave a good measure of the contribution to ground water by percolation through the Carboniferous Limestone.

Mr. Law stated that there were a number of matters which he considered needed attention by the Meteorological Office. The first of these was the design of a rain-gauge which would give a correct answer wherever it was placed—whether on a moorland slope facing the prevailing wind, near ground level, or at the top of a forest canopy. He instanced transpiration gauges 33 inches in diameter with surfaces sloping at 1 in 5·5 into the prevailing wind, which in eleven weeks had caught 10 per cent more than had been caught on similar transpiration gauges with flat surfaces—yet similarly sloping rain-gauges had not caught anywhere near the 10 per cent extra. For measuring rainfall above a forest canopy he was experimenting with gauges with Nipher shields set up on 10-ft. poles, alongside other experimental rain-gauges. On level or gently sloping ground turf-wall gauges seemed approximately correct and should be used more often. (Photographs betwen pp. 208 and 209).

He thought the second item should be the investigation of the variation of the rainfall over an area. The recommended number of gauges for a water catchment area of 10,000 acres was 15, but he suggested one might as well try to draw a contour map with 15 spot levels as try to draw an isohyetal map based on that number of gauges. He suggested the Meteorological Office should arrange for 100 gauges to be spread over an exposed hilly area so that the variability from place to place could be assessed. He instanced Saddle Hill on his own catchment near Slaidburn in Yorkshire, where the annual rainfall varied between 70 inches and 80 inches or more over a distance of only 250 yards.

Regarding evaporation he thought it was a pity that evaporation tanks had gone out of favour during recent years and that this was partly due to the present inability to estimate with sufficient accuracy the rain falling into the tank. He hoped that in the near future the Meteorological Office would install evaporation tanks at stations with extremes of climate, and, by means of climatological observations, would reconcile the differences between measurements so obtained.

There seemed to be a general opinion that evaporation was fairly constant over an area such as a reservoir catchment, but he thought this was totally wrong, and that there could be as much relative variation in the evaporation as there was in the rainfall.

He said he would also like to see experiments carried out into the changes which could be made in evaporation and transpiration from catchment areas by the draining of bogs by moorland gripping. He was investigating the effects of planting conifers on water supply catchments but did not consider that the meeting was the proper place to discuss the detailed results.

Dr. Penman first discussed the difficulties of hydrological work on the extensive scale, dealing with areas of about the size of the Thames Valley. It was not yet possible to say whether land drainage operations seriously affected the flow of rivers, despite careful consideration of the problem by a committee of experts; their report was inconclusive. There was a need for intensive investigation on selected small catchments, and he thought that such research should be done by the Meteorological Office as it could not be successfully "farmed out". There were papers in the press reporting work done at Rothamsted on dew, showing that it amounted to about 1 inch a year. In opposition to a suggestion from Mr. Green he thought that to proceed from measurements of evaporation to estimates of rainfall was not possible; the degree of accuracy obtainable was not good enough. Neutron-scattering equipment was being obtained at Rothamsted for the measurement of soil moisture, and it could also be made available for experiments to determine the water equivalent of a layer of snow.

Mr. Reynolds illustrated by slides his investigations of the exposure of the rain-gauge at Bidston Observatory. The site was known to be poor, and comparisons with a nearby gauge, set up for a year on a better site, clearly showed the effects of some obstructions when the results were analyzed according to wind direction. There remained, however, a random variation of the relative catches on the two sites, and it was not possible to make completely satisfactory corrections to the data from a poor site.

Mr. Watkins introduced a new topic by referring to the purely man-made problem of storm-water drainage in built-up areas. This was under investigation by the Department of Scientific and Industrial Research Road Research Laboratory with the collaboration of the Meteorological Office on the rainfall side. There was a possibility of savings on expenditures of the order of £1,000,000 for the initial work in a new town, or over £600,000 a year in the London County Council area, by providing a sounder basis for the design of storm-water sewers. If such savings were only of the order of 3 to 5 per cent, as in one instance quoted, the amounts were still very considerable. He referred to arrangements now in hand for the collection of data on intense falls of rain in short periods, with the collaboration of engineers serving local authorities using open-scale rain recorders; and also to the intensive investigation of areal rainfall, using a close network of open-scale rain recorders, which is being carried out by the Meteorological Office at Cardington. These were of fundamental importance in the research with which he was concerned.

Dr. Leyton spoke of the interest of foresters in hydrology. There were some indications, from work in various parts of the world, that forests derived a substantial part of their moisture requirement from fog-drip and even by direct absorption from the air. On the other hand, Mr. Law's experiments on the water-losses caused by trees had come as a sharp stimulus to foresters in this country. They were considering how to start investigations to solve the problems, and resolve the inconsistent results reported by different workers, in a field in which foresters and water-supply engineers might find themselves in conflict.

Prof. Manley instanced work in Norway on the assessment of snowfall, in which maps of winter precipitation had been based on the data obtained from stream-gauging during the spring run-off. He thought that similar work could be carried out experimentally for a selected drainage area in Scotland.

Mr. Smith demonstrated, with approximate values of rainfall, run-off and evaporation appropriate to south-east England, that the useful assessment of the water balance of an area was more critical for the hydrologist than for the agricultural meteorologist. There was a reserve of about 3 inches of water which could be held by the soil, to become available to plants, which was of outstanding importance during the three-month summer period of high transpiration rates. This provided a "cushion" which enabled the calculated irrigation need to be successfully applied, without requiring a very high standard of accuracy. In the past the water-supply problem had also not required a very high standard, but in the future, even in the near future, the increasing demand for water would impose a greater need for accuracy of observation and for hydrological research. It was necessary to keep in mind three different levels in work of this kind, none of which we could afford to neglect. These were fundamental research, field experiments aiming directly at the general application of results, and the supply of information and advice. For this last, there was a constant and sometimes insistent demand which took no account of whether there were adequate basic data available. At all levels the urgency of work must be related to the certainty of a general water shortage in this country within the next two decades.

Mr. Gold was suspicious of the underlying idea, which is a tacit assumption in many rain-gauge investigations, that the gauge which catches the most rainfall is necessarily the best. He wondered whether the brush gauge which had been referred to was really free from in-splashing. The measurement of rainfall was not equivalent to a laboratory experiment with controls. He thought that it was unnecessary to attempt a high order of accuracy, which he considered to be unattainable because of time variations and space variations which could not be adequately sampled.

Discussion in Edinburgh

At this smaller meeting the discussion was more informal. The report is abbreviated with regard to some of the direct questions, with immediate replies, and to fuller information given about some of the references quoted by the opener.

In reply to *Mr. Gloyne* it was suggested that the standard errors mentioned for areal estimates of precipitation should be regarded in the usual way as positive or negative, though the additional sampling errors for individual gauges were likely to be more frequently negative than positive. In-splashing and some types of leak could cause positive errors. The standard errors suggested for areal estimates did not take full account of the special problems of rainfall measurement in rugged country.

Mr. Hamilton introduced discussion of the standard instrument and site to be adopted for experiments with rain-gauges, with *Mr. Cranna* pointing out that the Dutch brush and grid gauge was intended to serve this purpose by reducing both in-splashing and the effects of wind eddies.

Mr. Anderson pointed out that if the recommendations for rain-gauge densities for areas of a few square miles were extrapolated to a few hundred square miles a very large number of rain-gauges would be required. *Mr. Bleasdale* replied that for a large area, regarded as a single unit, a lower density of rain-gauges would be adequate, but, using the recommendations as a general guide, he would prefer to examine each area individually with the aid of a good contour map, rather than apply any rigid rule.

Mr. Cooper spoke of the difficulties of getting observers in remote areas of Scotland and thought that recording rain-gauges might provide a solution. He thought that the Meteorological Office did not favour the use of recording rain-gauges for this purpose. *Mr. Bleasdale* replied that the Meteorological Office was fully aware of the problem, but the unfortunate fact was that no recording rain-gauge had yet been devised which could be left unattended for long periods and give reliable results. The faults which could develop meant that in general a recording rain-gauge was more troublesome than an ordinary gauge, and should be visited at least once a day.

Mr. Cuthbertson thought that the future increase in the demand for water would be more on the industrial side than the domestic. Some industrial enterprises had not exercised sufficient control over water use when it was a small item in their economy, but it had been shown in the recent drought that much could be done to save water without limiting production. Moreover, there were still large areas undeveloped in Scotland. For the areal assessment of rainfall many water engineers developed their own systems of weighting the readings of individual gauges, on the basis of local knowledge of the catchment areas. The speaker emphasized the difficulties of maintaining turf walls on rough moorland, where they soon become overgrown, and drew attention to the great variety of protective fences in use, which surely called for some standardization. He regretted that there was not yet in existence for Scotland an organization completely equivalent to the River Boards system covering England and Wales, and thought that the time had come, under such a system, to pay more attention to the collection of run-off records. The excellent work of the British Rainfall Organization in the past had led many engineers to rely almost entirely on rainfall records, but he favoured a two-fold development from this position: first that there should be a drive towards more river-gauging, under a central authority, with particular attention to the undeveloped areas; and secondly that the Meteorological Office itself should give more attention to the undeveloped areas, and to features of the hydrological cycle other than rainfall, in particular to run-off measurements.

Mr. Colville thought that Mr. Cuthbertson, in his remarks on River Boards, had not done full justice to the River Purification Boards in Scotland, a number of which were already actively engaged in stream-flow measurement.

Mr. Wilson was impressed by Mr. Law's work on the effects of afforestation on water losses and discussed the serious implications by quoting in some detail from the paper which had been referred to. *Mr. Bleasdale* in his reply emphasized that whilst he did not entirely agree with Mr. Law's conclusions, he considered that experimental work of this kind was very valuable. There were practical limits to the extension of the work of the Meteorological Office, which other speakers had called for, and it was desirable that more engineers should take part in investigations of evaporation, and hydrological problems generally.

Mr. Dewar pursued the subject of evaporation measurement. So far as he knew there were only two evaporation tanks in Scotland, and much more information was required for moorland areas. He spoke of a hydro-electric scheme with which he was concerned, pointing out that a power output 10 to 15 per cent in excess of estimates had been obtained. This might be due to cautious underestimation of rainfall, over-estimation of evaporation, or neglect of a possible contribution from cloud and dew, which might stabilize the flow in a dry period. It was obvious that further research was required and he thought that the Meteorological Office should take a leading part in the work.

Mr. Aitken paid tribute to the Meteorological Office for the help given to the Hydro-Electric Board in planning their schemes, and for the interest shown on tours of inspection. The rainfall estimates supplied had been of paramount importance, though he confirmed that in general they had turned out to be about 10 per cent on the low side. He drew attention to the work of Mr. Green of the Nature Conservancy on potential evaporation, stating that the implications of some of the measurements in 1955 were rather disturbing. The need for more measurements of evaporation was again emphasized.

Mr. Cooper asked whether the Meteorological Office reviewed or revised their estimates of rainfall in the light of new data, and *Mr. Bleasdale* in reply explained that although maps and books of averages were published at relatively infrequent intervals, estimates were invariably reviewed for all areas of current interest and importance. The most up-to-date information could always be obtained by correspondence. He also mentioned present work on the new period for averages, 1916–50, for which information would be published in the near future, and referred briefly to some of the problems involved. Whilst it was true that there was an apparent trend towards increased rainfall (compared with the old standard period 1881–1915) in nearly all parts of the country, it was not possible to say whether this trend would be continued or reversed in future decades. A part of the apparent increase might also be due to additional information or to improved standards.

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LETTER TO THE EDITOR

Forecasting weather in the Mediterranean

For readers of the article on *Jet streams over north Africa and the central Mediterranean in January and February* 1954[1] who have a wider concern with the problems of forecasting weather in the Mediterranean the following additional notes contain some important points of common application.

Small waves and retarded cold fronts.—The cold fronts C_A and C_B (Fig. 2[1]) were retarded in the central Mediterranean and there was an improvement of weather ahead of them, contrary to forecast.

The cold front C_A passed Malta about 2100 G.M.T. on January 4 with thunder and considerable rainfall. C_B was expected to pass Malta about twelve hours later giving similar weather; nor was any great improvement expected between the two fronts. These expectations turned out to be false. Cold front C_B was retarded before reaching Malta and C_A was retarded between Malta and Benina. Waves or smaller ripples formed. C_B resumed its south-eastward march on the 7th.

The weather in Malta was surprisingly fine on January 5 and 6. Similar improvements of weather ahead of cold fronts which become retarded after reaching Tunisia and Sicily are common.

From 1500 G.M.T. on the 3rd to 1500 G.M.T. on the 4th considerable cooling took place over south-east France. The upper trough intensified and sharpened towards the south-west, backing the upper winds even over the western Sahara (e.g. Aoulef) until the 5th.

The sequence of high-level charts (illustrated by Fig. 3a–b[1]) shows this troughing of the flow over the western Sahara as a complementary development to the ridging and northward advance of J_S, the subtropical jet stream, over Libya and the central Mediterranean.

The first European cold front C_A had so far outrun (ahead of) the upper-level cold trough as to progress to a position south-east of Malta before being held up. The movement of the second cold front C_B was affected at an earlier point and a surface pressure trough developed westwards along the coast of French North Africa.

The backing of the main upper-wind stream had the further effect of bringing drier air from the African desert over Malta and the central Mediterranean with consequent clearing skies.

C_B resumed its progress eastwards when the upper cold trough over the western Mediterranean began to move—this in its turn being associated with the breakdown and replacement of the blocking anticyclones over the Atlantic, which allowed a fresh deep north-westerly air stream into the Mediterranean.

On the 6th there was an outbreak of medium-level thunderstorms over the desert at 28°N. south of Tripoli.

Several old cold fronts had earlier moved south of the Atlas mountains from the temperate zone and become hard to find over the central desert, where only occasional variations of the amounts of cirrus cloud could be traced in the scattered observing stations' reports. How far frontolysis had progressed over the Saharan sand is unknown. It is thought, however, that some cyclonic development took place on these old fronts in the region near 25°N., 0°–5°E., where several favourable factors may have been at work at the same time. Soon this general frontal system came clearly into the picture moving north in one section as the warm front (shown as "W" on Fig. 2b–c[1]) of a small frontal wave. There is some possibility of its having been associated with the jet stream J_S.

The region was south-east of a major cold trough and at the right-hand side of the (confluence) entrance to the most intense part of the jet J_S. Both these aspects betoken a cyclogenetic region in the sense used by Sutcliffe and other writers. Moreover, the release of thunderstorms would be helped (and probably ten is helped) by the mountains in this part of the desert, the Tuareg highlands (also known as Ahaggar), which have an extensive massif above 2,000 metres and one peak of 3,003 metres near Tamanrasset.

The sequence of surface charts (Figs. 2b–c[1]) shows how the small bulge on the front moved east-north-east with the main upper-wind stream and was carried into the eastern Mediterranean ahead of the various fresh cold fronts C_A, C_B etc. from the north. Similar thundery sequences are believed to pass fairly commonly across southern Tripolitania and over parts of Cyrenaica into the eastern Mediterranean in winter.

Thunderstorms and sferic associated with frontal waves and ripples over the Mediterranean and north Africa.—The main concentration of thunderstorms associated with cold fronts in and around the Mediterranean are commonly clustered in the neighbourhood of the tips of small waves and ripples on the front. This enables the passage of such ripples along the front to be followed with the aid of a network of sferic reports if and when these are available. It also explains the location of intense activity on fronts which are often quite inactive at other points along their length.

It frequently happens that a cold front gives thunder in the Sicilian–Tunisian Narrows and later passes over Malta giving no precipitation and innocuous cloud, yet later again aircraft reports indicate activity east of Malta. The alternative case also arises when intense thunderstorms affect Malta in association with a front which passed almost unnoticed through the Narrows and again faded out farther east. Such cases baffled the forecaster's efforts to handle them until it was realized that these patches of activity moved along the fronts in association with waves which are liable to deepen as they move north-east, especially when the airmass contrast or the thermal instability is great.

Origins and associations of the Mediterranean jet stream examined in January 1954.—The jet stream in the Mediterranean sector seems to have been continuous over Cyprus and Asia Minor with the winter jet stream across Asia. Data were insufficient to determine whether there was also a continuous wind maximum farther west over the Atlantic in latitudes probably about 25°N. There was nothing conclusive about this, but some of the following relationships may be found useful in other cases.

Before the development of the sequence of early January 1954, the mainstream of the upper westerlies in the higher latitudes split over the western North Atlantic, initiating a blocking pattern. This development seems to have been associated with an outstandingly intense phase of the cold pole over Hudson Bay and south-west of Baffin Land from December 25, 1953 onwards. The main branch of the flow could be traced north around over Iceland and turned south again (more and more sharply as time went on) over the British Isles as a north-westerly and later north-easterly air stream, having no doubt the usual structure of a middle latitudes jet stream. On either side of this main branch the upper flow split into several strands, none of which appeared to be of any great breadth or strength save, perhaps, a northward branch over west Greenland and the Davis Strait.

There were signs of another maximum in the high-level winds near the Atlantic coast of north Africa in 25°N. on December 29 and 30, which may have continued from farther west or may have only marked the intensification of the upper westerlies south of the sharpening cold trough east of the north Atlantic blocking anticyclone.

The following observations from Fort Trinquet (25°14′N., 11°35′W.) considerably exceeded the contemporary wind speeds in the Wheelus Field–Benina sector:

		300 *mb.*		200 *mb.*	
Dec. 29, 1953	0300 G.M.T.	260°	75kt.	260°	105kt.
Dec. 30, 1953	0300 G.M.T.	280°	97kt.	270°	158kt.

The wind velocities measured at Fort Trinquet through the 1953–54 winter showed no consistent relationship with periods of peak velocity farther east. This may indicate that maxima near the north-west coast of Africa are associated rather with a subtropical jet stream in the Atlantic sector. There were seven main maxima at Fort Trinquet between October and April; only two of these, on December 30 (the case studied) and March 4, appeared related to and preceded maxima farther east.

In general the maxima in longitudes 0°–15°W. during the 1953–54 winter appeared to be farther south (mean latitude 26°N.) than in longitudes 15°–30°E. (mean latitude 32°N.).

By contrast the maxima at Aoulef (27°04′N., 1°08′E.) were in most cases related to those farther east and occurred either on the same day or one day earlier or later than in 15°–20°E.

Maxima in 30°E. were related to maxima noted at the central Mediterranean and Libyan stations in four cases out of six, and came 0 to 4 days later in 30°E.

During the period January 1–10, 1954 the western Saharan upper-wind stations Fort Trinquet, Colomb Béchar (31°51′N., 2°13′W.) and Aoulef indicated a continual confluence in the flow at levels above 500 mb. over that area.

H. H. LAMB
J. ROBINSON

Harrow, January 7, 1957.

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METEOROLOGICAL OFFICE NEWS

R.A.F.V.R. (Meteorological Section).—*Awards.*—It was announced in Air Ministry Orders dated May 1, 1957, that the undermentioned officers in the Meteorological Section of the Royal Air Force Volunteer Reserve had been granted the Air Efficiency Award. We offer them our congratulations.

Flight Lieutenant H. T. Carter.
Flying Officer K. H. Humphreys.

NOTES AND NEWS

Science Museum

International Geophysical Year Exhibition

The Science Museum, South Kensington, London, S.W.7, announces that an exhibition to illustrate the scope and aims of the International Geophysical Year will be on view at the Museum from May 10 to October 31.

The exhibition includes a representative collection of scientific instruments of the types to be used during the Year. The exhibits will cover earth satellites, high altitude rockets, meteorology, terrestrial magnetism, aurorae, solar flares, cosmic rays, glaciology and oceanography.

An illustrated handbook is being published in conjunction with the exhibition, presenting a general account of the phenomena to be studied and the observations to be made during the Year.

The Museum is open, free of charge, from 10 a.m. to 6 p.m. on weekdays and 2.30 to 6 p.m. on Sundays.

A lamp protector for a tilting-siphon recorder and a grass-minimum thermometer support

We are indebted to Mr. G. M. Puckle, Observer at the Bodiam, Sussex, climatological station for information on two appliances which he has devised and found useful.

"A lamp protector is illustrated in Fig. 1. When no electric supply is available, a small paraffin lamp of the nursery night light type can be placed inside a tilting-siphon rain recorder to prevent freezing. A difficulty experienced when

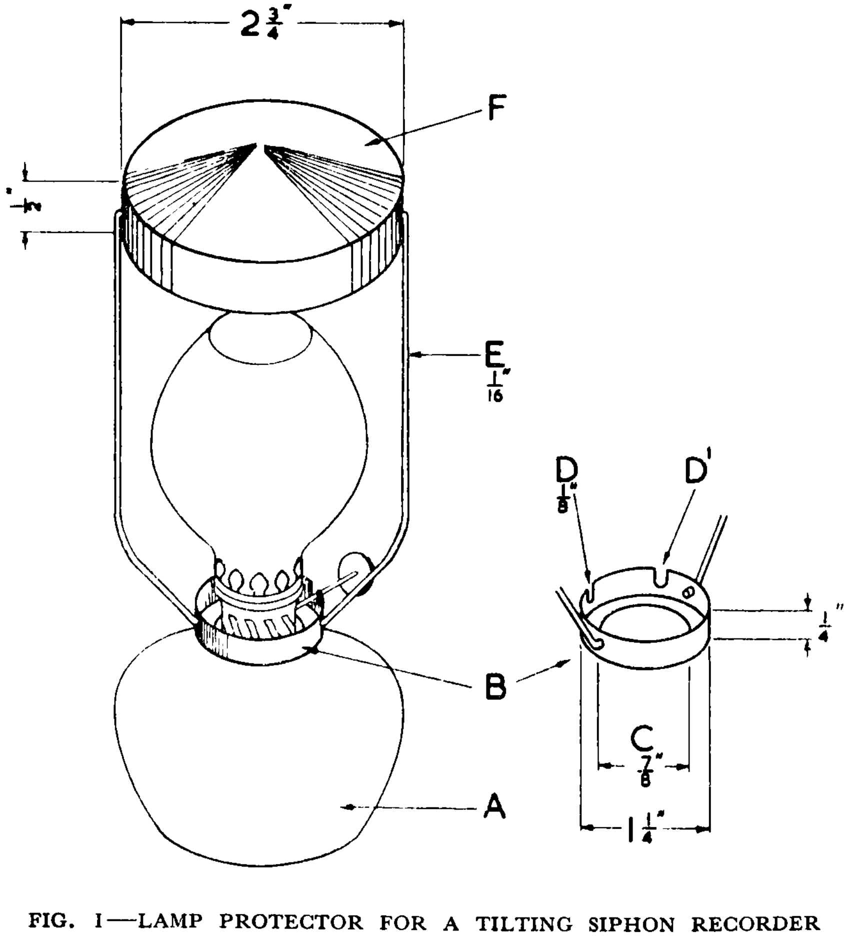

FIG. 1—LAMP PROTECTOR FOR A TILTING SIPHON RECORDER

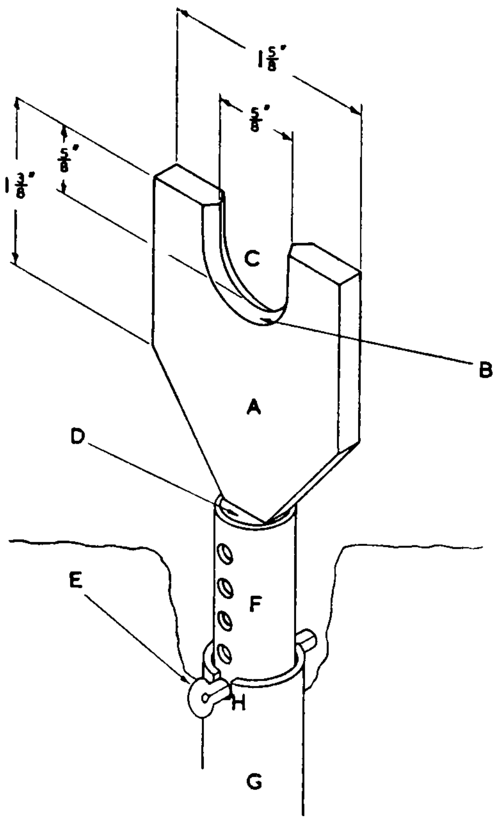

FIG. 2—GRASS MINIMUM THERMOMETER SUPPORT

such a lamp is used is dripping, on the wick, of water condensed on the cold collector of the recorder from the water vapour produced by combustion. To prevent this dripping from extinguishing the lamp the fitting of a roof to the lamp in the shape of a flat round tin lid, F, of about 2¾-in. diameter has been found effective. The lid is beaten out until dome-shaped. It is then supported by two wires, E, fitted into it and which are fixed in turn to a collar, B, round the lamp-glass holder, made by making a hole in a smaller lid and filing a notch, D and D_1, for the shaft of the wick winder.

The grass-minimum thermometer support illustrated in Fig. 2 is intended to permit of easy removal for grass cutting. The supports are fitted to two vertical tubes which slide down into slightly wider tubes fixed in the ground. The details are as follows:—

A is made of $\frac{3}{16}$-in. three-ply wood and painted white.

At C, the wood is shaved off to a knife-edge around the U cut out, B, to receive the thermometer. The stalk of this, D, is fixed inside a brass ½-in. tube, F, then holes, ⅛-in. between them, are drilled in, F, to allow a split-pin, E, to pass through. This pin rests in grooves, H, cut in the top of the outer tube, G, and allows the thermometer to be levelled.

The outer tube, G, is driven into the ground to about 1 in. below the surface. These supports are easily removed for weeding or cutting grass to the correct height, and save a lot of time".

REVIEWS

Report of Director of Meteorological Services, Federation of Rhodesia and Nyasaland, 1954–55

This is the first annual report on the Federal Department of Meteorological Services formed on July 1, 1954 by fusion of the three separate services of Northern and Southern Rhodesia and Nyasaland. The early part, as might be expected in a report addressed to a newly constituted Federal Assembly, is mainly explanatory of the functions of a meteorological service in general and the organization of the Rhodesia-Nyasaland service in particular together with an account of the changes at Federation.

The services provided are mainly for Civil Aviation and Agriculture; forecasts are also provided for the general public. As in many other developing countries, communications difficulties are a great handicap to synoptic meteorology and it is interesting to see how these are met without a specialized telecommunications system. There are 1,460 rainfall stations irregularly distributed over 476,000 square miles; it is estimated that the number of stations will have to be doubled in order to provide data for an accurate rainfall map.

On the research side, in a region where temperate-latitude forecasting techniques are not of much help, it is not surprising to find that a good deal of attention is given to radar storm-detection. Two well equipped meteorological observatories are maintained and in 1954–55 plans were well advanced for the establishment of a third observatory for the special purpose of studying the weather of the area of Lake Nyasa.

A. G. FORSDYKE

Les anomalies du réseau aérologique européen. J. Lugeon and P. Ackermann. 11 in. × 8½ in., pp. 31, *Illus.*, Station centrale suisse de Météorologie, Zurich, 1956.

Resolution 7 of the first session of CAe-I[1] asked for an investigation to be made for a trial period of one year of the homogeneity of the upper air network over Europe. *W.M.O. Technical Note* No. 14[2] presents the bare statistics of the resulting investigation which was carried out under the supervision of the Director of the Swiss Meteorological Service, the various European meteorological services contributing the basic data. The paper under review also gives the results of the investigation together with a useful and interesting discussion.

The results are presented in two sets of charts. The first shows the mean thickness of the layers 850 to 500 mb. and 500 to 300 mb. over Europe for the two periods October 1953 to March 1954 and April to September 1954 and for each of the hours of observation 0300 and 1500 G.M.T. (8 charts). The second shows the 12- and 24-hr. variances of the thickness of the same layers for the same periods (16 charts). The anomalies shown up by these charts are striking, especially on the first set, and should be studied by everyone who has occasion to draw upper air charts. The effects of lag and of direct radiation on the instrument are the two main sources of systematic error in radio-sonde observations. Anomalies caused by lag errors are clearly shown by the charts of mean thickness for 0300 G.M.T. Unfortunately it is not possible to deduce corrections from these charts though for some instruments they must be of the order of 1°C. in the troposphere. Mean radiation errors in the troposphere are deduced for seven different types of radio-sonde for the two periods and these values will be useful to the synoptic meteorologist as a rough guide. It was hoped that the charts of 12- and 24-hr. variances would show up those radio-sondes most liable to random day-to-day errors. Observations from French- and American-type instruments show most variation but the variance charts are difficult to interpret because of real geographical differences.

Since early 1956 radio-sonde observations made by the Meteorological Office have been corrected for errors of lag and radiation[3]; some other European observations are also corrected. Eventually it is hoped all radio-sonde observations will be so corrected but until this is done anomalies such as are demonstrated in this paper will remain.

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1. Geneva, World Meteorological Organization. Commission for Aerology. Abridged final report of the First Session. Toronto, 1953.
2. LUGEON, J. and ACKERMANN, P.; Homogeneity of the radio-sonde network in Europe. *W.M.O. Tech. Note, Geneva,* No. 14, 1955.
3. HAWSON, C. L.; Meteorological Office practice for the application of radiation and lag corrections to temperatures measured by radio-sonde Mk. IIB. *Met. Mag., London,* **85,** 1956, p. 75.

J. K. BANNON

LATE RAINFALL REPORTS 1957
Great Britain and Northern Ireland
JANUARY

County	Station	In.	Per cent. of Av.
Cornwall	Scilly, Tresco Abbey ...	2·35	75
Aberd.	Dyce, Craibstone ...	2·45	104

MARCH

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
Suffolk	Felixstowe	1·19	79	*Argyll*	Poltalloch	6·20	161
Devon	Ilfracombe	4·21	146	„	Inveraray Castle ...	9·01	142
Notts.	Mansfield, Carr Bank ...	1·91	91	*Fife*	Leuchars Airfield ...	1·52	78
Ches.	Manchester, Ringway ...	2·79	128	*Perth*	Loch Dhu	9·21	140
Lancs.	Squires Gate	1·85	82	*Inverness*	Loch Ness, Garthbeg ...	3·87	116
Yorks.	Hull, Pearson Park ...	1·51	83	*R. & C.*	Inverbroom, Glackour	5·41	109
Cumb.	Geltsdale	2·72	97	„	Achnashellach	7·54	111
Mon.	A'gavenny, Plâs Derwen	3·68	110	*Caith.*	Wick Airfield	3·48	153
Glam.	Cardiff, Penylan ...	5·10	162	*Shetland*	Lerwick Observatory ...	4·37	138
Carn.	Llandudno	1·85	91	*Antrim*	Aldergrove Airfield ...	2·28	91
Midl'n.	Edinburgh, Blackf'd. H.	1·52	77	*L'derry*	Garvagh, Moneydig ...	2·75	88
Bute	Rothesay, Ardencraig ...	5·78	161				

OFFICIAL PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 17—*Temperature-compensated equivalent headwinds for jet aircraft.* By A. F. Crossley, M.A.

The effect of an increase of air temperature on the performance of certain types of jet aircraft is expressed in terms of that headwind which, if the temperature were standard, would have the same effect on the range in still air as is produced by the actual temperature. This headwind is then combined with the ordinary headwind to give the temperature-compensated equivalent headwind. The fundamental formula and expression are derived in §2 for the mean and standard deviation of the compensated equivalent headwind over a period for any one point of the track on the assumptions of normal frequency distribution of wind and temperature. Next, similar statistics are developed for the whole cruising stage of a route supposed flown at constant-pressure level. Finally in §3 the formulae are adapted for a flight in which a gradual increase of pressure altitude takes place as fuel is consumed. The application of the theory to air-route operation is described in §4, with a worked example for the route London to New York in both directions in July at a height in the neighbourhood of 40,000 ft. This report does not apply to recent types of jet aircraft such as the Comet IV which have sufficient power in reserve to make their performance practically independent of the temperature effect.

WEATHER OF MAY 1957

Lowest pressure on the North Atlantic was in the usual position for May, near 57°N. 45°W., the value (1006 mb.) being a little low but probably within the range of commonest values: an unusual feature was that lowest pressure had been concentrated in the same position already on the April mean map. May 1957 was a month without impressive anomalies anywhere in the region between Europe and the eastern Pacific, except perhaps over southern Mexico and over the central Mediterranean where pressures were 3 mb. below normal in regions of normally small variability. The high pressure system over the Polar Basin was rather more intense than usual and extended farther south in ridges of high pressure towards Hudson's Bay and Scotland. The Azores anticyclone also extended well to the north-east.

Average temperatures for the month were 3 to 4°C. above normal at 50°N. across the Canadian Prairies and 3 to 4°C. below normal over central Europe, where there was an unusual prevalence of winds from a northerly point. Elsewhere temperatures seem to have been mostly near normal.

Rainfall exceeded twice the normal over Lapland and was above normal from northern Scandinavia and Jan Mayen all down the North Sea to the middle German Highlands. There were rainfall excesses of a similar order in many parts of the Mediterranean. There was rather less than the normal rain, owing to lee effects, in a strip across central Europe and over most of the Baltic, also in parts of western Europe affected by the Atlantic anticyclones.

In the British Isles weather during the first six days of the month was dominated by a large anticyclone which remained almost stationary to the west of Ireland. In England and Wales it was generally dry with north-easterly winds, cloudy and rather cold in eastern districts but milder and sunnier in the west and north. In Scotland wind was generally north-westerly and weather cloudy with occasional rain. Arctic air reached Scotland on the 3rd but in the south it was sunny and warm with temperatures rising well into the sixties, except near the east coast, and reaching 70°F. at Poole, while Plymouth reported 13·5 hours of sunshine. With the spread of the arctic air southwards, the following day was about 10°F. colder, and on the 5th light sleet and snow showers reached as far south as East Anglia. Nearly the whole of the month's rain fell during a two-weeks period of rather thundery, cyclonic weather which commenced on the 7th. Winds backed to the south and there was widespread rain on the 7th and 8th, as pressure fell generally and fronts from the Atlantic moved into the western part of the country, and on the 9th rain was heavy and prolonged locally, some places recording nearly an inch during 24 hours. Extensive early morning fog persisted in many parts of central and southern England until midday on the 10th, but on the 11th one centre of a complex depression in the eastern Atlantic entered our south-west approaches, afterwards swinging north-east over the country, giving widespread thunderstorms, particularly on the 12th. The complex depression remained to the west of Ireland during the next three days and there were further outbreaks of thundery rain and scattered thunderstorms in many places, and on the 16th a small secondary moved north-eastwards from the Irish Sea to the northern North Sea accompanied by strong winds, heavy showers and local thunderstorms. A depression formed off south-west England on a trailing cold front on the 17th and continued to deepen as it moved over the Irish Sea and thence to north-east Scotland; rainfall was widespread and heavy in places near the centre of the depression, more than one inch being recorded at both Valley and Ronaldsway in 24 hours. The following day was fine and sunny as pressure rose generally over the British Isles, and after the passage of a further rain belt on the 20th, high pressure became established over the whole country. For most of the remainder of the month pressure was highest to the north and north-west of the country, with easterly winds in the south, which were strong at times in the English Channel. The 26th and 27th were particularly sunny days with more than 14 hours of sunshine in many places but on the 28th dull weather reached Scotland from the north-west and spread slowly south. During the last few days of the month there was a good deal of cloud in the east and Midlands but long sunny periods in the west.

The dry weather of April continued in parts of Wales and the western half of England during the first week of May. Many stations which commenced a dry period about April 20th had no measurable rain until May 6th, and on that day absolute droughts of 41 days were reported from stations in the Lower Wye Valley. Places along the east coast reported less than half their average amount of rainfall, while Anglesey had more than 150 per cent. In England and Wales the total rainfall during April and May was the lowest for these two months since 1896. The severe frosts of the 5th to 7th caused widespread but rather variable damage particularly in the Midlands, East Anglia and Kent; many growers fear that summer crops will be about 10 days late for this reason. The break in the drought was welcome but after the prolonged sunshine during the last week the land became very dry and seed germination poor.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	76	23	−1·1	83	−1	111
Scotland	74	18	−0.6	74	−2	107
Northern Ireland ...	69	27	−0·4	80	−4	108

RAINFALL OF MAY 1957
Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	1·22	69	*Glam.*	Cardiff, Penylan ...	1·73	71
Kent	Dover	1·50	90	*Pemb.*	Tenby	2·52	110
,,	Edenbridge, Falconhurst	1·65	89	*Radnor*	Tyrmynydd	3·35	98
Sussex	Compton, Compton Ho.	1·61	73	*Mont.*	Lake Vyrnwy	3·31	103
,,	Worthing, Beach Ho. Pk.	·86	52	*Mer.*	Blaenau Festiniog ...	4·54	80
Hants.	St. Catherine's L'thouse	·66	40	,,	Aberdovey	1·95	78
,,	Southampton (East Pk.)	1·57	79	*Carn.*	Llandudno	1·63	92
,,	South Farnborough ...	1·15	66	*Angl.*	Llanerchymedd ...	3·59	153
Herts.	Harpenden, Rothamsted	1·28	66	*I. Man*	Douglas, Borough Cem.	3·07	123
Bucks.	Slough, Upton	1·13	67	*Wigtown*	Newton Stewart ...	3·42	130
Oxford	Oxford, Radcliffe ...	1·66	89	*Dumf.*	Dumfries, Crichton R.I.	3·02	110
N'hants.	Wellingboro' Swanspool	1·70	88	,,	Eskdalemuir Obsy. ...	2·19	66
Essex	Southend, W. W. ...	1·19	82	*Roxb.*	Crailing...	1·40	70
Suffolk	Felixstowe	1·55	117	*Peebles*	Stobo Castle	1·90	84
,,	Lowestoft Sec. School ...	1·39	86	*Berwick*	Marchmont House ...	1·41	57
,,	Bury St. Ed., Westley H.	1·26	69	*E. Loth.*	North Berwick Gas Wks.	1·44	73
Norfolk	Sandringham Ho. Gdns.	1·45	79	*Midl'n.*	Edinburgh, Blackf'd. H.	1·55	76
Wilts.	Aldbourne	1·93	93	*Lanark*	Hamilton W. W., T'nhill	2·08	87
Dorset	Creech Grange... ...	2·01	99	*Ayr*	Prestwick	1·90	97
,,	Beaminster, East St. ...	2·40	116	,,	Glen Afton, Ayr San. ...	3·20	107
Devon	Teignmouth, Den Gdns.	1·78	97	*Renfrew*	Greenock, Prospect Hill	2·28	70
,,	Ilfracombe	1·79	87	*Bute*	Rothesay, Ardencraig ...	...	...
,,	Princetown	4·28	100	*Argyll*	Morven, Drimnin ...	1·46	45
Cornwall	Bude, School House ...	1·57	85	,,	Poltalloch	2·14	74
,,	Penzance	3·19	144	,,	Inveraray Castle ...	2·09	53
,,	St. Austell	3·28	136	,,	Islay, Eallabus	1·72	65
,,	Scilly, Tresco Abbey ...	1·28	76	,,	Tiree	2·76	110
Somerset	Taunton	1·57	92	*Kinross*	Loch Leven Sluice ...	1·91	78
Glos.	Cirencester	1·59	75	*Fife*	Leuchars Airfield ...	1·26	65
Salop	Church Stretton ...	1·77	70	*Perth*	Loch Dhu	3·98	89
,,	Shrewsbury, Monkmore	1·45	74	,,	Crieff, Strathearn Hyd.	2·69	108
Worcs.	Malvern, Free Library ...	1·82	84	,,	Pitlochry, Fincastle ...	1·92	91
Warwick	Birmingham, Edgbaston	1·26	53	*Angus*	Montrose Hospital ...	1·60	78
Leics.	Thornton Reservoir ...	1·31	65	*Aberd.*	Braemar	1·09	46
Lincs.	Boston, Skirbeck ...	1·90	108	,,	Dyce, Craibstone ...	1·52	60
,,	Skegness, Marine Gdns.	2·00	118	,,	New Deer School House	1·06	49
Notts.	Mansfield, Carr Bank ...	·84	40	*Moray*	Gordon Castle	1·35	64
Derby	Buxton, Terrace Slopes	2·49	80	*Nairn*	Nairn, Achareidh ...	·83	47
Ches.	Bidston Observatory ...	1·39	73	*Inverness*	Loch Ness, Garthbeg ...	1·31	53
,,	Manchester, Ringway...	1·45	68	,,	Loch Hourn, Kinl'hourn	3·25	61
Lancs.	Stonyhurst College ...	2·16	76	,,	Fort William, Teviot ...	2·16	55
,,	Squires Gate	3·08	148	,,	Skye, Broadford ...	...	...
Yorks.	Wakefield, Clarence Pk.	1·35	69	,,	Skye, Duntulm... ...	2·11	74
,,	Hull, Pearson Park ...	1·14	59	*R. & C.*	Tain, Mayfield... ...	1·46	71
,,	Felixkirk, Mt. St. John...	1·37	73	,,	Inverbroom, Glackour...	1·49	50
,,	York Museum	·94	47	,,	Achnashellach	2·15	51
,,	Scarborough	·93	49	*Suth.*	Lochinver, Bank Ho. ...	2·23	88
,,	Middlesbrough... ...	1·04	54	*Caith.*	Wick Airfield	1·33	64
,,	Baldersdale, Hury Res.	2·05	83	*Shetland*	Lerwick Observatory ...	2·42	116
Norl'd.	Newcastle, Leazes Pk....	1·53	77	*Ferm.*	Crom Castle	2·12	76
,,	Bellingham, High Green	1·52	63	*Armagh*	Armagh Observatory ...	2·43	102
,,	Lilburn Tower Gdns. ...	1·90	82	*Down*	Seaforde	2·89	110
Cumb.	Geltsdale	2·67	103	*Antrim*	Aldergrove Airfield ...	1·74	77
,,	Keswick, High Hill ...	2·87	90	,,	Ballymena, Harryville...	1·55	54
,,	Ravenglass, The Grove	2·90	104	*L'derry*	Garvagh, Moneydig ...	1·94	76
Mon.	A'gavenny, Plâs Derwen	2·44	82	,,	Londonderry, Creggan	1·49	57
Glam.	Ystalyfera, Wern House	3·47	99	*Tyrone*	Omagh, Edenfel ...	2·20	85

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METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 86, No. 1,022, AUGUST 1957

REORGANIZATION OF THE METEOROLOGICAL OFFICE

By the Director-General

In 1955 the Secretary of State for Air appointed a Committee under Lord Brabazon to review the organization of the Meteorological Office in relation to current and future requirements. The Committee took voluminous evidence, written and oral, from user interests, both within and outside the Government service, and also from senior members of the directorate and from the Meteorological Office Staff Side. In addition, the Committee visited a number of headquarters units and outstations of the Office. The report of the Committee, which was produced in 1956, is intended for departmental and interdepartmental use and will not be published. Its main conclusions were recently announced to the House of Commons in a written reply by the Secretary of State for Air.

It is obviously impossible here to give more than a brief summary of the salient points in the Committee's report. First, the Committee considered that the decision, taken in 1919 and re-affirmed in 1945, to entrust responsibility for the State Meteorological Service to the Air Ministry, is sound and should continue. It also came to the gratifying conclusion that the present standing of the Office as a scientific institution is high, that user interests appreciated the advances in recent years and that, all told, there is considerable confidence in the services provided. Second, in looking at probable lines of advance, the Committee singled out the development of numerical methods of forecasting as one of the more important, and it welcomed the decision to install an electronic computer in the Office. It was considered, also, that there was a possibility of achieving greater precision in local forecasting by a more detailed study of weather characteristics, coupled with the use of radar scanners. The Committee also welcomed the decision to develop a unified Headquarters at Bracknell.

Reorganization of the Directorate.—The main result of the Committee's more detailed recommendations has been that the Office is reorganized in three 'prongs', dealing with forecasting and services, research, and administration, respectively, with a regrading of the senior posts. The post of Director has been raised to that of Director-General (D.G.M.O.). The forecasting and services side of the Office is placed under the Director of Services (D.S.M.O.) and the research side under the Director of Research (D.R.M.O.), each

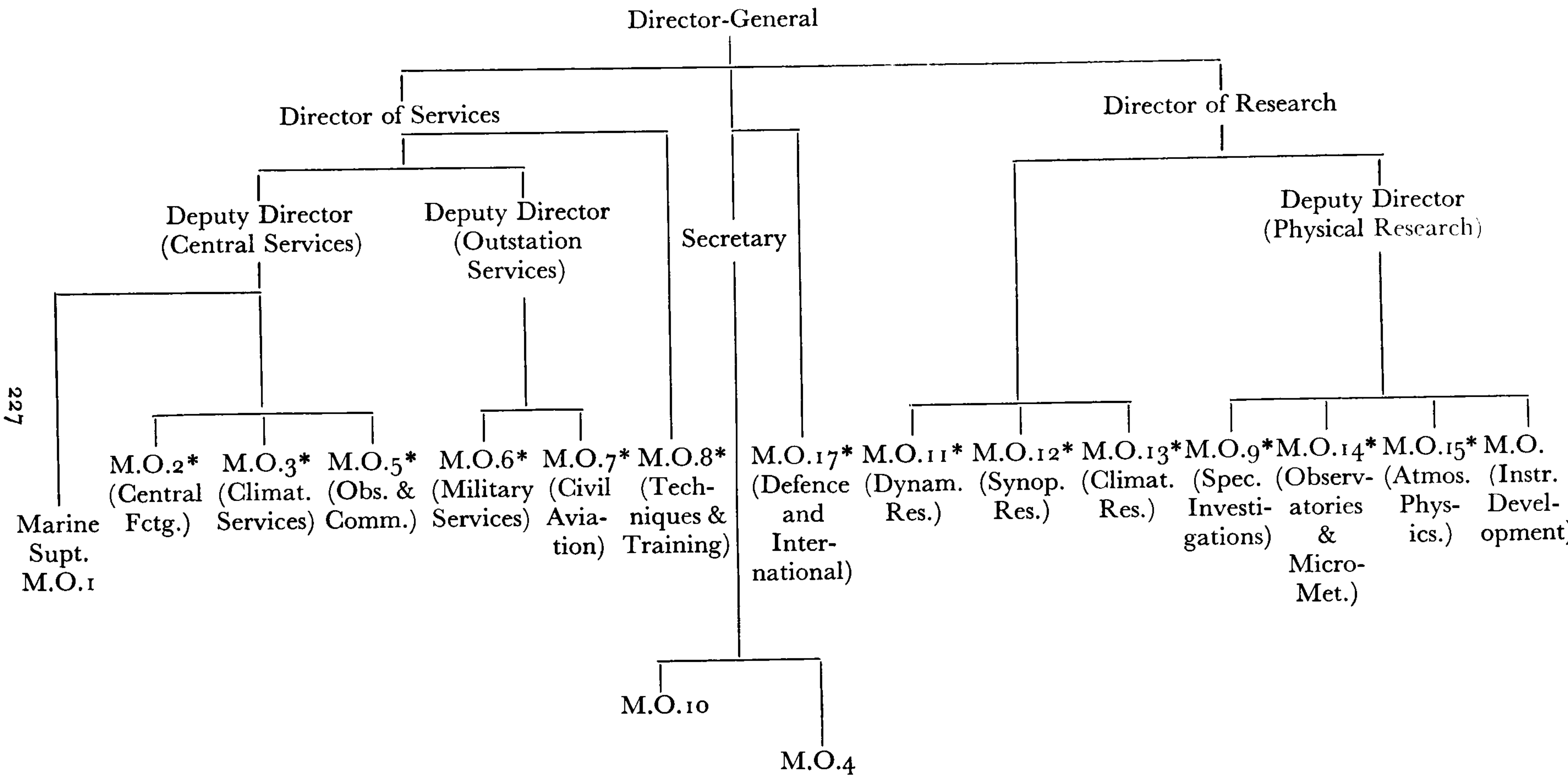
Director being in the grade of Chief Scientific Officer. The administrative prong has been placed under an Assistant Secretary with the title of 'Secretary of the Meteorological Office'. The effect of these changes is to make the Meteorological Office a much more self-contained unit than hitherto, especially on the administrative side.

In addition, new posts have been created in the grades of Deputy Chief Scientific Officer and Senior Principal Scientific Officer. The Brabazon Committee expressed concern regarding career prospects for members of the Scientific Civil Service in the Meteorological Office. The need for improvement was especially evident in the Scientific Officer class, and poor prospects may have contributed in part to the difficulty experienced in the past of keeping up the rate of entry of men and women of high ability into meteorology as a career. The precise weight of this factor in slowing down recruitment probably can never be decided with certainty, for the Meteorological Office has had to compete with other branches of the Scientific Civil Service in attracting recruits at a time when the country's output of scientists and technologists has been insufficient to meet the demands of industry, the universities and the technical colleges, but it is certain that improvements in career prospects must have a beneficial effect.

The new headquarters organization is shown in detail in the diagram on p. 227. All told, the total number of posts above Principal Scientific Officer has been increased to 23 (20 at headquarters and 3 at outstations). Concurrently, it is proposed, by stages, to reduce the overall establishment in the Scientific Officer class by a relatively small amount, again with the primary object of improving the chances of all entrants to this class of reaching the higher levels. At the same time it is proposed to increase the number of senior appointments in the Experimental Officer class, so that the net result will be an overall improvement in the careers available to entrants in all classes.

Services.—Some of the new posts are novel in scope. It will be seen that an Assistant Director is to be appointed with the title of 'Techniques and Training'. This post is designed to meet a need which has been felt in the Office for some time, a need which was emphasized in the evidence submitted by the Staff Side to the Brabazon Committee. Meteorology is rapidly becoming a more exact science, with a considerable volume of research effort now available, in this country and abroad. There is a real need for operational forecasters, especially those in the more remote outstations, to be brought into closer contact with the results of research. Equally, it is of prime importance that research should not lose contact with operations. In the past the Meteorological Office has attempted to meet this need by the institution of what have come to be known as the 'Monday Evening Discussions' and by the circulation of specially prepared abstracts of selected papers, but today this is not enough. The prime duty of the occupant of this new post will be to ensure that the flow of information from the research side to the operational side, and the equally valuable return flow of operational experience to the research side, is maintained at a high level. In addition, this post carries with it the cognate responsibilities of directing the training of new entrants and of providing refresher courses at the Training School, as well as the supervision of the preparation of manuals and handbooks intended for use by professional meteorologists in the field.

HEADQUARTERS ORGANIZATION 1957



*Assistant Directorates

Another new Assistant Director post, reporting directly to the Director-General, carries responsibility for certain defence and international aspects of meteorology. The volume of work connected with the World Meteorological Organization, its Technical Commissions, Regional Associations and Working Groups, has grown enormously in recent years, and may be expected to increase still further. Until now, the coordination of this work has been carried out by the Director and his personal staff, but the need has now been recognised for a senior officer to coordinate the very large efforts made by the Meteorological Office, in common with the other meteorological services of the world, to maintain this highly important international work.

The post of Assistant Director (Public Services) no longer exists. This in no way indicates any decrease of interest in the non-aviation aspects of the work of the State Meteorological Service. On the contrary, the Brabazon Committee emphasized the necessity of expanding this side of the work of the Office, particularly by means of the automatic telephone weather service and other aids. The abolition of this particular post reflects the intention to integrate the public services work with existing services much more closely than in the past. The groundwork of such integration has been well laid, as is evidenced by the growing popularity of the sound and visual broadcasts, and the country-wide extension of WEA. The Brabazon Committee were of the opinion that a requirement undoubtedly exists for local forecasting units for non-aviation users, particularly in agricultural districts, but it was recognized that man-power considerations and other factors must be taken into account, and it will be much easier to estimate the value of such schemes when more experience has been gained with the present improved systems of dissemination.

Research.—It is, perhaps, in the improved facilities for research that the reorganization is most striking. For the first time in its history the Office may now say truly that it has a fully developed research side. In its review of the purely scientific activities of the Office the Brabazon Committee paid tribute to the work of the Meteorological Research Committee, and they saw no reason to suggest any changes in its constitution or terms of reference. The M.R.C., which was formed in 1942, has been an outstanding success and the Office has every reason to be grateful to the many outside scientists who have devoted so much of their time to its activities. In one important matter, however, the Committee felt that a change was needed. For some years now the Gassiot Committee of the Royal Society has received from the Air Ministry a separate grant for fundamental research. The present grant, which is for £7,000 a year, lasts until 1961. The Committee, while recognizing the value of the work done by the Gassiot Committee since the end of the war, felt that in future grants for meteorological research emanating from the Air Ministry should normally be channelled through the Meteorological Research Committee. This recommendation is now being discussed with the Royal Society.

Some new subdivisions of research have been recognized. The Director of Research will have under him a Deputy Director whose interests will be specifically in physical meteorology. All the existing Assistant Directorates in research are retained, and two new headquarters posts have been added. These are: an Assistant Director to coordinate and supervise research in micro-meteorology (which at the present time is going on chiefly at Kew, Cambridge and Porton), with special responsibilities also for the Observatories; and an

Assistant Director for research in dynamical meteorology, who will be primarily responsible for the development of numerical methods in the synoptic field. The Assistant Director (Synoptic Research) will be mainly concerned with long-range forecasting and general synoptic problems, and the existing Assistant Directorates of Special Investigations, Climatological Research and Physical Research (renamed Atmospheric Physics) will cover much the same fields as at present. Instrument Development becomes purely investigational, with the provisioning and accounting side transferred to the Secretary. The post of Head of the Meteorological Research Flight, which has now attained world-wide recognition as one of the primary units of upper-air research, has been raised to Senior Principal Scientific Officer.

Finally, the reorganization has allowed certain anomalies in the historic system of numbering divisions of work to be rectified, and in future the letters 'M.O.' followed by a number will be used as a short title for an Assistant Directorate. The only exceptions to this rule are M.O.1, which remains under the Marine Superintendent and the personnel administration and provisioning branches, M.O.10 and M.O.4, which come under the Secretary.

The Meteorological Committee.—The system of general supervision of the work of the Office by the Meteorological Committee has been overhauled. Hitherto the Meteorological Committee has included representatives of the various Government Departments which have a user interest in meteorology, the universities, the Royal Society and the Royal Society of Edinburgh. Such a body is unavoidably large and, in the view of the Brabazon Committee, its structure was such that it had ceased to perform any very useful function. Instead, the Brabazon Committee suggested that it should be replaced by an advisory committee of not more than five members, all from outside the government service, and this advice has been accepted by the Secretary of State. The new Committee is not a 'representative' committee in the usual sense of the word. It consists of an independent chairman and four members, two of whom will be scientists and two normally laymen. One of the scientists will be the chairman of the Meteorological Research Committee and the other scientist member will be appointed after consultation with the President of the Royal Society. The Meteorological Office may count itself exceptionally fortunate in that Lord Hurcomb has accepted the invitation of the Secretary of State to become the first Chairman of the reconstituted committee.

The Committee will be required to keep under review the progress and efficiency of the Meteorological Office and the broad lines of its current and future policy, as well as the general scale of effort and expenditure devoted to the Meteorological Office, and also to study contact between the Office and the users. The Meteorological Office Advisory Committee for Scotland remains in its present form.

It would be unwise to attempt to forecast here the ultimate result of these changes on the Meteorological Office and on meteorology in the United Kingdom generally. The full benefit of the reorganization will not be felt until the headquarters units have settled into the new buildings at Bracknell, for which design work is now well advanced. The recognition of the Meteorological Office as a major national scientific institution with two functions of equal importance, of providing a public service and of leading research in meteorology in this country, cannot but help to promote the growth and well-being, not only of the Office itself, but also of the science to which it is dedicated, and we are grateful to Lord Brabazon and his colleagues for their help in bringing about these changes. At the opening of its second century, the Meteorological Office may look forward to an even brighter future.

METEOROLOGICAL OFFICE DISCUSSION

Stratocumulus Clouds

The Meteorological Office Discussion held at the Royal Society of Arts on Monday, March 18, 1957 was opened by Dr. D. G. James. His statement dealt with the behaviour of a sheet of stratocumulus cloud situated under a dry type inversion, and the physical processes leading up to the dissipation of the cloud.

Forecasting experience shows that winter anticyclones near the British Isles frequently produce extensive areas of stratocumulus cloud over the country. Radio-sonde soundings through such a sheet of stratocumulus invariably show a well-marked temperature inversion accompanied by a steep hydrolapse in the layer directly above cloud top. It is generally agreed that some degree of subsidence is necessary to give the very low dew-points above cloud top, but various authors have shown that subsidence is rarely responsible for the full magnitude of the temperature inversion. In 1933 Mal, Basu and Desai carried out investigations by aircraft of several of these dry-type inversions when no cloud was present[1]. They concluded that the temperature inversions were intensified by radiative cooling from the tops of the haze layers always found in association with these conditions. They noted that the haze layers were composed largely of hygroscopic nuclei which, though not forming cloud, were sufficiently moist to produce a large increase of long-wave radiative cooling over that expected from dry air.

The formation of the cloud has been described by Douglas[2] and Wood[3] who deduce that turbulent convection is mainly responsible. Douglas, in an analysis of air which had arrived in this country after crossing the North Sea, showed that a considerable amount of water was evaporated at the sea surface, and that on average, the flux of water vapour upwards by turbulent diffusion was sufficient to increase the humidity mixing ratio of the first 3,000 ft. of an air mass by about 1 gm./Kg. This is frequently sufficient to cause a layer of stratocumulus to be formed by the time the air mass reaches the land. The rate at which this water vapour is carried upwards is determined by the lapse rate of temperature upwards from the surface and also by the wind shear. Wind shear is also important in determining the pattern which the cloud will take when it begins to break up. Wind tunnel experiments carried out by Phillips and Walker in 1932 showed that, in the absence of any vertical shear across a stratified cloud sheet, the breaking up of the cloud caused polygonal patterns to be formed. For large values of shear alternate vortices were produced with axes parallel to the shear, whilst for small shear rectangular patterns were formed. Although for the clouds which will be considered later the wind shear was thought to be negligible—the clouds were very thin—clearly accurate surface observations of the cellular pattern of the cloud can give a good indication of the wind shear, and hence of the degree of turbulence to be expected at cloud level.

Recent work in the Forecast Research Division at Dunstable has been concerned with the dissipation of a sheet of stratocumulus under a dry-type inversion. The work falls naturally into two classes: firstly a statistical analysis of radio-sonde soundings and surface observations on occasions of extensive stratocumulus sheets, and secondly an analysis of observations made near stratocumulus clouds from an aircraft. The first part of this work has been published in the *Meteorological Magazine* as "Nocturnal dissipation of stratocumulus cloud", and it is proposed merely to review some of the conclusions of that paper[4].

Hourly charts for the four years 1944 to 1947 were examined for occasions of extensive stratocumulus sheets present at midday, it being the intention to consider only the clouds which were present during a given day and which persisted through or dissipated during the night. The appropriate radio-sonde soundings were examined to ensure that the clouds were bounded at their tops by dry-type inversions. The first significant fact which emerged from this selection was that of the 53 occasions considered suitable, 52 occurred in the winter months.

The occasions were divided into two groups according to whether the cloud sheet had or had not dissipated within 12 hours of the afternoon radio-sonde soundings. In fact, of the 53 cloud sheets selected, 26 dissipated within the stipulated time. For the purposes of the investigation, the cloud was considered to have dissipated if the surface observations reported that the sheet had reduced to 2 oktas or less for at least two consecutive hours. This is not to say that the cloud only partially disperses: on the contrary, synoptic experience shows that if a stratocumulus sheet does dissipate then it goes quickly and it goes completely.

Examination of the appropriate radio-sonde soundings showed that, for the two groups considered—namely cloud sheets which do or do not dissipate within 12 hours—the means of several synoptic variables were significantly different at about the 10 per cent. level.

Although the means of these variables are statistically significant, individually they are of little use for forecasting purposes. However, using a linear combination of the variables it is possible by maximizing "Student's" t value[5] to obtain an expression which may be of some assistance in forecasting the future behaviour of the cloud sheet up to 12 hours from the time of the afternoon radio-sonde sounding. Using such a linear combination we can obtain a parameter defined as:—

$$\xi = x - 9 \cdot 15y - 0 \cdot 77z$$

where x is the maximum depression in °F. of dew-point below temperature at any level up to 50 mb. above cloud top, y is the average hydrolapse in 10^{-2} gm./Kg./mb. over 50 mb. below cloud base and z is the cloud thickness in mb. The difference in the means of the ξ's for the two groups of dissipating and persisting clouds is now statistically significant at the 0·2 per cent. level, which suggests that this variable may well be of some use to the forecaster. The errors which arise, however, are large and can be directly attributed to inaccurate assessment of the three variables x, y and z. The lags of the radio-sonde elements are too great to reproduce faithfully the steepness of the temperature inversion and hydrolapse directly above cloud top. Furthermore, surface observations from neighbouring stations of the base of the stratocumulus sheet were not mutually consistent, and on occasions could not be fitted to the temperature and dew-point profiles as indicated by the radio-sonde soundings. Consequently, considerable errors sometimes arose in estimates of the cloud thickness. It was thought therefore that a better appreciation of the problem could be obtained only by accurate measurement of all the synoptic variables by an aircraft flying through and in the neighbourhood of a stratocumulus cloud sheet.

The second part of the work was therefore concerned with flights carried out by an aircraft of the Meteorological Research Flight during the latter half of November 1955. The pre-arranged flight plan was such that following an ascent to about 10,000 ft. the aircraft performed level runs of 3 to 5 minutes at 250-ft. intervals from 1,000 ft. below cloud base to cloud top, then at 100-ft. intervals up to 500 ft. above cloud top. Finally two level runs of 8 minutes duration were carried out at 200 ft. above cloud top and 200 ft. below cloud base. Height, airspeed, temperature and frost-point were observed every 250 ft. on the ascent to 10,000 ft., and every 30 secs. on the level runs, along which an accelerometer was used to record the bumpiness experienced by the aircraft. In cloud an attempt was made to measure the liquid water content.

The second half of November 1955 was particularly favourable for the formation of extensive sheets of stratocumulus cloud over the southern half of the British Isles. An anticyclone centred over Scotland during the early part of the month moved slowly westwards, later returning and moving gradually south-east into the continent. Generally, during this period, south-east England was in an anticyclonic weak north-easterly flow which was shown by radio-sonde soundings to exhibit a well marked dry-type inversion. Strato-cumulus frequently formed under this inversion and sometimes it dissipated during the night.

Eight flights were carried out in the period November 14–28, 1955, but on only four of these were full sets of data obtained.

The temperature measurements were made by a standard Meteorological Office flat plate thermometer the lag of which is about 8 sec. A level run of 3 to 5 minutes thus allows ample time for the thermometer to settle down, but the standard deviations of any fluctuations of temperature recorded will be reduced. Furthermore, on a level run the height of the aircraft was noted to the nearest 10 ft. and varied as much as ± 50 ft. so that, particularly in the inversion layer the temperature fluctuations which are observed will be considerably greater than those which actually occur at any particular level. Even so the recorded standard deviations have been used to provide a linear increase of temperature with height in the profile which we must assume later.

The temperature profiles near the cloud sheets as shown by the aircraft observations indicate that

(i) below cloud base the lapse rate is dry adiabatic almost down to ground level,

(ii) the cloud top is bounded by a sharp temperature inversion which is considerably steeper than that shown by the corresponding radio-sonde sounding in the same place and at the same time,

(iii) the slope of the inversion is about 2 to 3 °C. per 100ft., the whole of the inversion occuring within the first 500 ft. of cloud top.

The frost-points were measured by a Dobson-Brewer manual hygrometer. In the range in which observations of frost- and dew-points were taken, i.e. -20°C. to $+10$°C. this instrument is accurate to about 0·5°C. As the hygrometer is manually operated, the frost-points obtained are not, in general, synchronous with the temperature observations. In the inversion layer where the hydrolapse is very great, small variations in aircraft height can lead to large variations of frost-point, so that the standard deviations of the measurements are unreally large and cannot be used as an estimate of turbulent mixing at any particular level. However, as will be seen later, the standard deviation as well as the means of the frost-points on level runs are used to obtain a linear variation of dew-point with height above cloud top. The hydrolapse in the inversion layer is of the order of 1 to 2 gm./Kg./100 ft., the "fall of humidity" taking place entirely within the first 500 ft. or so above cloud top. This is again considerably greater than the hydrolapse indicated by the appropriate radio-sonde sounding.

Dr. James then showed accelerometer records obtained by a Hastings aircraft of the Meteorological Research Flight in and near a stratocumulus sheet on November 14, 1955. The considerable turbulence recorded in and below the cloud decreased sharply above cloud top until at some 500 ft. above cloud the turbulence was negligible. Evaluation of the turbulence index confirms this impression, the index having maximum values in the cloud and at cloud top. This suggests that the turbulence is instigated near cloud top and is effective below cloud base and also, to a lesser extent, above cloud top.

Accurate assessment of vertical velocities from the accelerometer traces, as was made by Jones using traces obtained in CuNb clouds[6], proved impossible since a recording altimeter was not used, and therefore the zero errors could not be applied to the integrated traces.

A slide presenting the assumed temperature and humidity profiles near a stratocumulus cloud sheet was then shown. The temperature measurements indicated a dry adiabatic layer extending for some considerable depth below cloud base, and it was assumed that this lapse rate is effective down to ground. In the cloud, although no accurate observations are available, the lapse rate is probably wet adiabatic up to the cloud top with an apparent discontinuity at the base of the inversion layer in which the temperature increase has been assumed linear with height.

Complete saturation was not indicated by the hygrometer on any flight, but the observations below cloud suggest that the humidity mixing ratio is constant from cloud base to near the ground, and this constant value has been obtained by assuming saturation at cloud base. This assumption is supported by the accelerometer records, the turbulence shown in and below cloud probably being sufficient to distribute evenly the available water vapour below cloud top. In the inversion layer the decrease in dew-point has been assumed to be linear with increasing height.

All flights support the existence of such profiles and furthermore show that there is little variation in the magnitudes of the temperature inversions and hydrolapses from flight to flight. On all occasions the clouds had been in existence for some 10 hours prior to the times of the flights and had persisted for several hours afterwards. Also, no systematic change was noted in the heights of the base or top of a given cloud sheet during a flight. It is unlikely therefore, that at the times of observation the temperature and humidity profiles were changing rapidly. The second assumption made is that during the day the *status quo* of the cloud and inversion layer is preserved.

However, the accelerometer records show considerable turbulence immediately above cloud top. This turbulence will transfer heat downwards into the cloud and water vapour upwards from the cloud top. The indicated turbulence decreases with height through the inversion layer and is negligible some 500 ft. above cloud top, so it seems that the heat added to and water vapour taken from the cloud at cloud top are respectively taken from and added to the inversion layer. The turbulence would thus quickly change the magnitude of the temperature inversion and hydrolapse directly above cloud, and the cloud would build upwards into the inversion layer. However, no such tendency was observed on any flight—though the flights were necessarily of limited duration. It is therefore concluded that the air immediately above the cloud top is continually being replaced by subsidence which operates against the turbulence to give an approximately steady state at and immediately above the cloud top.

Before evaluating the rate of subsidence it was first necessary to consider the heat and water vapour budgets of the cloud and air below, so that an estimate could be made of K, the coefficient of eddy diffusion appropriate to the inversion layer. An initial guess of 3×10^3cm.^{2}/sec. was made for K in respect of the diffusion of both heat and water vapour. This is the value given by Taylor for stable conditions at lower levels over the sea.

The heat budget of the cloud and air below was then considered. Radiation measurements made from aircraft above sheets of stratocumulus indicate that the albedos of the clouds vary considerably with cloud thickness. Values between 0·3 and 0·8 have been obtained for clouds whose thicknesses range from "very thin" to 4,500 ft. For the cloud investigated by Meteorological Research Flight aircraft on November 14, 1955 which was about 300 ft. thick an albedo of about 0·5 is probably close enough for our calculations.

Measurements at Kew show that on a clear day in November, about 180 cal./cm.^{2} are available at the surface from solar radiation, or an average of about 20 cal./cm.^{2}/hr. between sunrise and sunset. This figure is supported by data given by Charney and also Houghton for solar radiation received at the surface at latitude 50°N. during November[7, 8]. It will therefore be assumed that about 25 cal./cm.^{2}/hr. were available at cloud top i.e. 5,000 ft., on November 14, 1955 from solar radiation. An albedo of 0·5 allows some 13 cal./cm.^{2}/hr. to pass into cloud top.

The loss of heat at cloud top by long wave radiation may be obtained by use of the Elsasser radiation chart, and was about 10 cal./cm.^{2}/hr. for the case considered. Measurements at Kew show that, during November, about 1 cal./cm.^{2}/hr. is conducted into the earth during the day, the heat being restored by the earth at the same rate during the night.

Some heat is used in the evaporation of water at the earth's surface. On the dates of the flights the evaporation from tanks of water at Kew was about 7×10^{-2} gm./cm.^{2}/24 hours. It is known that the average rate of evaporation during the day is some 3 or 4 times that at night, so that the average rates of evaporation during the day and night on the dates of the flights were $6 \cdot 0 \times 10^{-3}$ and $1 \cdot 5 \times 10^{-3}$ gm./cm.^{2}/hr. respectively. The heat required for these rates of evaporation is about 4 and 1 cal./cm.^{2}/hr.

The flux of heat downwards into cloud top by turbulence is given by

$$F_H = \rho c_p K_H \frac{T}{\theta} \frac{\partial \theta}{\partial z},$$

where ρ is the air density at the heights considered,
c_p is the specific heat at constant pressure of the air,
K_H is the appropriate coefficient of eddy turbulence,
T is the absolute temperature,
θ is the potential temperature
and z is the height.

For November 14, 1955, assuming a linear variation of temperature with pressure from cloud top at 851 mb. to the top of the inversion layer at 838 mb., then $\frac{\Delta\theta}{\Delta p}$ through this layer is $0 \cdot 44$°C./mb. Assuming $K = 3 \times 10^3$cm.^{2}/sec. the flux of heat into cloud top by turbulence is about 1 cal./cm.^{2}/hr.

A further slide showed a summary of the figures presented for the heat balance of the cloud and air below. These suggest that during the day the cloud and air below lose about 1 cal./cm.^{2}/hr., which causes a cooling of about $0 \cdot 2$°C. during the daylight hours. (It was pointed out that to facilitate simple analysis a day in mid-November was considered to consist of 8 hours of daylight and 16 hours of darkness.)

At night there is a net loss of about 9 cal./cm.^{2}/hr. which gives a cooling of the cloud and air below of about $3 \cdot 3$°C. during the night. This is about twice as great as is actually observed from radio-sonde soundings at 12-hour intervals through the same air mass, and must therefore be considered further.

The main factor responsible for this excessive rate of cooling is the long wave radiation loss from cloud top computed from the Elsasser radiation chart. However, measurements from aircraft of the flux of long-wave radiation near stratocumulus cloud by Houghton and Brewer in 1955 confirm the Elsasser value to within ± 1 cal./cm.^{2}/hr.[9]. To obtain a rate of cooling comparable with that observed the cloud and air below should lose heat at about 5 cal./cm.^{2}/hr. instead of the 9 calculated above. This could be obtained by increasing the value of K in the inversion layer to 10^4/cm.^{2}/sec. or perhaps a little more. This value of K would, through more rapid transport of heat downwards into cloud top, 4 cal./cm.^{2}/hr., restrict the cooling of the cloud and air below to about $2 \cdot 2$°C. during the night, which is much closer to the actual cooling observed. There is thus some indication that we need to consider values of K considerably greater than 3×10^3 and possibly greater than 10^4 cm.^{2}/sec. For a value of K equal to 10^4 the cloud and air below warms by $0 \cdot 4$°C. during the day and cools by $2 \cdot 2$°C. at night.

The water vapour budget of the cloud and air below were next considered. The water vapour available by evaporation at the surface is about 6·0 and $1 \cdot 5 \times 10^{-3}$ gm./cm.^{2}/hr. by day and night respectively. Since all flights indicate a constant humidity mixing ratio from cloud base to ground it is likely that the turbulence below cloud as shown by the accelerometer records is sufficient to distribute the evaporated water evenly through the cloud and air below.

The cloud loses water vapour by turbulent diffusion upwards in the cloud top. The measurements of liquid water content in the cloud are not reliable, but it is reasonable to assume that the humidity mixing ratio in the cloud (including liquid water) is determined by the dry adiabatic immediately below cloud and the observed level of the cloud base. Thus for the data of November 14, 1955 the average hydrolapse $\frac{\Delta x}{\Delta p}$ through the inversion layer immediately above cloud top is $0 \cdot 20 \times 10^{-3}$ gm./gm./mb. The flux of water vapour upwards from cloud top is given by

$$F_w = \rho K_w \frac{\partial x}{\partial z},$$

where ρ is the air density at the heights considered,
K_w is the appropriate coefficient of eddy turbulence,
x is the humidity mixing ratio
and z is the height,

which for K 10^3 cm.^{2}/sec. gives the flux as $2 \cdot 2 \times 10^{-3}$ gm./cm.^{2}/hr.

Thus for K 10^3 cm.^{2}/sec., there is a net gain of water vapour of $3 \cdot 8 \times 10^{-3}$ gm./cm.^{2}/hr. by day and a net loss of $0 \cdot 7 \times 10^{-3}$ gm./cm.^{2}/hr. by night. The changes in humidity mixing ratio would thus be about 0·2 gm./Kg. during the day and −0·07 gm./Kg. during the night. For K 10^4 cm.^{2}/sec. the changes would be −0·06 and −0·5 gm./Kg. by day and night respectively.

We now consider the effect of various values of K on the balance of the inversion layer. The accelerometer records show considerable turbulence in and below the layer from cloud top up to some 10 mb. above cloud top, but none whatsoever in the dry air above this level. It must therefore be assumed that the heat gained by the cloud and air below by turbulent diffusion is taken entirely from this layer: also this water vapour lost by the cloud is accumulated in this layer. Now for K 3×10^3 cm.^{2}/sec., the heat gained and water vapour lost by the cloud is about 1 cal./cm.^{2}/hr. and $2 \cdot 2 \times 10^{-3}$ gm./cm.^{2}/hr. respectively, so that the inversion layer would cool at about 0·6°C./hr. and its humidity mixing ratio would increase by 0·22 gm./Kg./hr. Furthermore, these changes would be immediately effective just above cloud top where the turbulence is at a maximum, and the cloud would grow upwards into the inversion. For K 10^4cm.^{2}/sec., these changes would be 1·3°C./hr. and 0·73 gm./Kg./hr. respectively. However, no systematic variation in the height of cloud top was observed on any flight—albeit of limited duration—and so the upward growth of the cloud must be prevented by subsidence, by which the air in the inversion layer is continually being replaced by warm dry air from above.

If air is subsiding through a given layer, then the heat added to that layer is proportional to the rate of subsidence and to the difference between the potential temperatures at the limits of the layer. For the data of November 14, 1955 the change in potential temperature through the inversion layer was 6°C., so that for K 10^3/cm.^{2}/sec., a subsidence rate of rather less than 1 mb./hr. is sufficient to counteract the cooling produced by turbulence.

Similarly, if the transport of water vapour downwards by subsidence is equal to that upwards by turbulence in the inversion layer then a subsidence rate of rather less than 1 mb./hr. will maintain the hydrolapse above cloud top. Thus for K 3×10^3 cm.^{2}/sec., a subsidence rate of 1 mb./hr. is sufficient to counteract the turbulent mixing at cloud top and to maintain the cloud top at the same level. For K 10^4 cm.^{2}/sec., a subsidence rate of about 3 mb./hr. is required.

The next slide showed a table presenting the corresponding data and deductions for the four flights on which full sets of measurements were obtained. Changes of temperature and humidity mixing ratio of the cloud and air below were given for the 8 hours of daylight and 16 hours of darkness for values of K of 3×10^3 and 10^4 cm.^{2}/sec. The final columns of the table presented the calculated and actual behaviour of the cloud sheet. It was seen that for K 3×10^3 cm.^{2}/sec. and a subsidence rate of 1 mb./hr. the cloud would thicken by day and by night, predominently during the latter. Conversely for K 10^4 cm.^{2}/sec. and a subsidence rate of 3 mb./hr. the cloud would thin by day and by night but rather more by day.

Before considering the dissipation of the cloud Dr. James reconstructed the argument up to that point. In the absence of any turbulent mixing at cloud top, the cloud and air below would at all times be cooling and moistening, with an excess of cooling during the night and an excess of moistening by day. The cloud would thus be always thickening by downward growth from cloud base.

Now we know from successive radio-sonde soundings that the cloud and air below warm slightly during the day and cool some 1·5°C. to 2°C. by night. Furthermore the turbulence above cloud as shown by the accelerometer records causes warmer, drier, air to mix with the cloud partly offsetting the tendency to cool by day and night, and also removing water vapour from the cloud. The cloud now grows downwards less quickly, but extends upwards from its top into the inversion layer. This upward growth is not observed by day and so subsidence must be introduced to maintain the level of cloud top, the rate of subsidence varying directly with the rate of mixing of the cloudy air with the warmer drier air above. A value of K of 10^4 cm.^{2}/sec. with a subsidence rate of about 3 mb./hr. is sufficient to cause the cloud to thin and perhaps dissipate at day and at night, the cloud warming by day and drying out by night.

However, for the first two flights considered, the cloud sheet persisted through the day and dissipated during the night which means that either the rate of subsidence increased from about 1 mb./hr. during the day to 3 mb./hr. at night, or the value of K at cloud top increased rapidly with the setting of the sun from about 3×10^3 to greater than 10^4 cm.^{2}/sec.

The first alternative may occur on a few occasions, but there is no direct evidence which supports a regular threefold increase in subsidence at night in winter anticyclones.

The second alternative is not altogether unreasonable. It is known that the cooling caused by long-wave radiation from cloud is immediately effective in the uppermost 50 ft. or so of the cloud. In the absence of solar radiation, the absorption of which by the cloud would partly affect this loss, the top of the cloud cools very rapidly and produces vigorous convective turbulence inside the cloud. The presence of a dry adiabatic lapse rate below cloud base ensures that this turbulence is effective down to near ground level, but at cloud top the rate of cooling is so great that the convection inside the cloud may well cause overshooting of the cloudy air into the drier air above, thereby increasing the rate of mixing and the value of K. This larger K partly affects the excessive cooling of the cloud and air below, and also increases the upward flux of water vapour. With a value of K 3×10^3 cm.^{2}/sec. by day, a rate of subsidence of about 1 mb./hr. is necessary to maintain the level of cloud top. With the increase in K at night this rate of subsidence cannot counteract the upward growing tendency of the cloud, and the cloud top rises causing an increase in height of the inversion base.

This variation during the night has been noticed by Neiburger during an investigation of the formation and dissipation of stratus cloud on the west coast of the United States. On several occasions when stratus cloud was present radio-sonde soundings were made every 3 hours over a period of 48 hours or more. One of the conclusions reached was that the height of the inversion base showed a marked diurnal variation, being a maximum at early morning and a minimum in the evening.

This agrees well with the above assumptions, for if the subsidence rate during the day and night is rather more than 1 mb./hr. then clearly the base of the inversion will lower during the day without necessarily causing the cloud to dissipate. At night the base of the inversion will rise by the upward growth of the cloud, until, at sunrise the longwave cooling begins to be offset by solar radiation.

As the cloud grows upwards the slope of the humidity mixing ratio above the cloud top decreases causing a lessening in the upward flux of water vapour from the cloud. But the slope of the inversion increases so that more heat enters the cloud top from the air above.

For the two cases when the cloud dissipated before dawn it is possible to calculate a value of K which will cause the cloud to thin sufficiently during the night. For values of K less than 3×10^3 cm.^{2}/sec. and a subsidence rate of about 1 mb./hr. both cloud base and top lower, the former at a greater rate than the latter so that the cloud thickness increases downwards. For values of K rather greater than 3×10^3 cm.^{2}/sec. and the same rate of subsidence, the cloud top rises into the inversion and the cloud base lowers so that the cloud thickness increases upwards and downwards. For K rather greater than 10^4 cm.^{2}/sec. and again a subsidence rate of 1 mb./hr., cloud base and cloud top rise, but the former more rapidly than the latter, causing a thinning of the cloud. A value of K of $2{\cdot}0 \times 10^4$ cm.^{2}/sec. is sufficient in both cases to cause the clouds to dissipate before dawn.

However such a large value of K is not required, for if the sheet becomes thinner than 50 ft. or so then its radiative properties change very rapidly and the cloud can no longer be regarded as a black body for calculations of long-wave radiative losses. In fact the outward flux falls from 10 to less than 1 cal./cm.^{2}/hr. The value of K also falls from 2×10^4 cm.^{2}/sec. but is probably still sufficient to cause a net warming of the cloud sheet. In its final stages, therefore, the cloud dissipates by warming produced by turbulent mixing with the air above, the increase in stability at cloud level preventing a rapid downward transfer of heat to the air below. This warming is clearly shown by radiosonde soundings made soon after the cloud has dissipated. The simple temperature profile of dry adiabatic–steep inversion found when cloud is present is completely modified by several more stable layers found below the inversion top.

Dr. James concluded with a few hints to forecasters, though he admitted that the problem was perhaps only formally solved.

(i) The cloud thins initially by drying caused by mixing with the drier air above, and finally dissipates by warming. Thus the hydrolapse and the steepness of the inversion directly above cloud top are important. Also, since in the early stages the drying is all important, thin cold clouds are more likely to dissipate than thin warm clouds.

(ii) The mixing at cloud top which causes the thinning of the cloud is intensified by the long-wave radiation loss from cloud top. The presence of an upper cloud sheet could thus restrict the cooling at cloud top, preventing the increase in K necessary to produce the required mixing. Also, since the cloud thins gradually then the longer the night the more likely the cloud is to dissipate, i.e. stratocumulus clouds formed in late December stand a better chance of dissipating than those formed in October or March.

(iii) Finally, the amount of subsidence is critical in determining the behaviour of the cloud. With too little subsidence the cloud builds upwards by day and night and will always persist. With too much subsidence the cloud top will lower during the day and possibly at night also and the cloud will always dissipate.

Dr. James hoped that with the arrival of the electronic computer some assistance would be given to the forecaster in estimations and forecasts of vertical motion.

The Chairman, *Dr. Sutcliffe*, opened the subsequent discussion by recalling some of his forecasting experiences on occasions of anticyclonic stratocumulus clouds. He hoped that outstation forecasters present at the meeting would participate in the discussion, in particular stating what method they employed for forecasting the dissipation or persistence of stratocumulus cloud.

Dr. Pasquill presented records made by a wind vane attached to the cable of a captive balloon. The instrument was sensitive only to vertical gusts and had a lag of about 0·1 sec. The records obtained near stratocumulus clouds resembled closely the accelerometer records shown earlier, the vertical motion being a maximum near cloud. Above cloud the records were quite smooth showing little vertical motion, whilst below cloud the traces indicated convective type turbulence.

Mr. Oddie suggested that cloud physicists did not devote sufficient attention to studies of layer clouds, being concerned mainly with the physical properties of cumulus. He wondered whether the argument was correct in assuming that the upper part of the hydrolapse in the inversion layer remained unchanged. He suggested that the effect of turbulence would be to round off the corner in the dew-point profile at this level. Dr. James agreed that this should be so, but pointed out that although the clouds had been in existence for 10 hours or more the sharp corner in the hydrolapse was still present. Also, the turbulence as indicated by the accelerometer records was a minimum at this height.

Dr. Robinson wondered whether the Kew radiation measurements were sufficiently accurate for such an analysis. He pointed out that a small change in K and in the radiation values can cause great changes in the budgets of the cloud.

Mr. Murgatroyd said that there were hopes of improved accuracy of measurements from aircraft with the new albedometer and Houghton's infra-red radiometer. He asked whether a shallow stable layer had been found below cloud base which corresponded with that present during the formation of cumulus cloud. Dr. James agreed that there might be such a layer during the day when the cloud was warming slightly, but it was necessary to assume a dry adiabatic below cloud base to simplify the arguments.

Mr. Sawyer said that the persistence of the cloud sheets suggest that they possess some self-balancing mechanism. He suggested that the value of K might well be connected with the depth of the cloud. It seemed curious that the argument presented required slow descent of air to maintain the cloud sheet.

Dr. Sutcliffe doubted if the present physical analysis was sufficient in itself to enable rules to be provided to a forecaster concerning the subsequent behaviour of the cloud. However, more accurate observations and a further clarification of the physical processes operating could lead to helpful results. He wondered if the terrain over which stratocumulus sheets form had any bearing on the subsequent behaviour of the cloud.

Mr. Zobel and *Dr. Tucker* described a test carried out at Bomber Command on the forecasting of the dissipation of stratocumulus sheets using the formula given by Dr. James in his Meteorological Research Paper. They obtained quite satisfactory results.

Mr. Dight described a flight to Holland when, with no cloud over England, layers of stratocumulus were found over the North Sea. He wondered what effect a change of sea temperature might have on the formation of the cloud. He also pointed out that icing risks were considerable in stratocumulus cloud.

Another speaker wondered if any precipitation was noticed below cloud on any of the flights analysed by Dr. James. He doubted whether subsidence could lower cloud base when it seemed that the base was determined by surface conditions. His advice to forecasters was to assume that the cloud would persist unless there is any change in synoptic features.

Mr. Taylor said that the profiles of dew-points above stratocumulus cloud as shown by radio-sonde soundings differed from those shown by Dr. James. The soundings usually show an increase in dew-point just above cloud and then a rapid fall off. A forecasting rule used by him was that if the ground turbulence was not sufficient to reach the cloud base then the cloud dispersed.

Mr. Murgatroyd suggested that the discrepancy in dew-point profiles was due to the lag in the humidity element of the radio-sonde.

Dr. Scrase did not agree but argued that the wetting of the gold-beaters' skin combined with the rise in temperature above cloud top could account for the discrepancy.

Crown copyright

Crown copyright

CUMULONIMBUS TOPS

Left: Near Shetland Islands, January 9, 1957.

Right: West of Biscay, January 23, 1957.

(see p. 243)

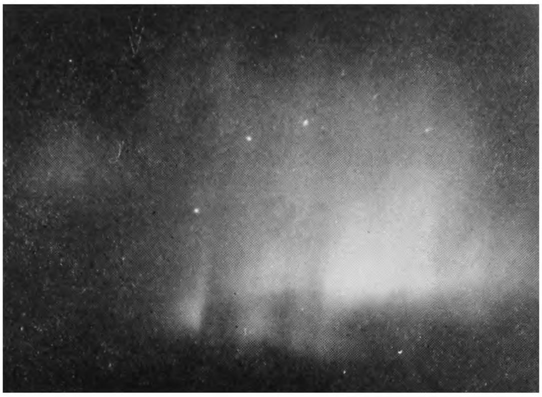
Crown Copyright

Crown Copyright

PILEUS BEFORE CUMULUS

Photographs taken at Stanmore, Middlesex, at about 0955 G.M.T. on May 27, 1957.

(see p. 245)



Photograph by J. Paton

Curtains

Photograph by J. Paton

Long rays with tops coloured a deep red

UNUSUAL DISPLAY OF AURORA, OCTOBER 26–27, 1956

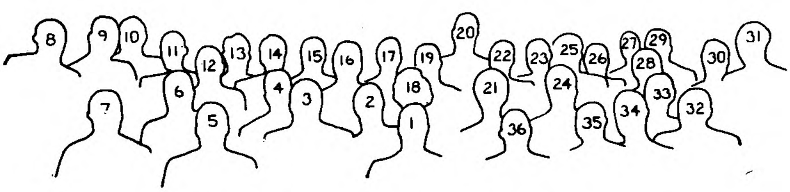
This display was characterized by very long red rays extending up to over 600 Km. The photographs were taken near the time of maximum at 2312 G.M.T. October 26. The features were quick moving so the photographs had to be somewhat underexposed. Prof. Størmer has informed Mr. Paton that he had not seen a display of this type since January 3–4, 1940.

[*To face p. 241*

Photograph by W. F. de Wildt

THE WORKING GROUP ON METEOROLOGICAL TRANSMISSIONS OF THE EUROPEAN REGIONAL ASSOCIATION OF THE WORLD METEOROLOGICAL ORGANIZATION. PHOTOGRAPH TAKEN AT UTRECHT IN APRIL 1957.

(see p. 241)



1.	Ockenden	(United Kingdom) *Chairman*
2.	Crone-Levin	(Denmark)
3.	Postma	(Netherlands)
4.	Mastrangeli	(Italy)
5.	Sundaram	(World Meteorological Organization)
6.	Popov	(U.S.S.R.)
7.	Cudny	(Poland)
8.	Ortmeyer	(Germany)
9.	Weber	(Switzerland)
10.	Venho	(Finland)
11.	Piper	(Germany)
12.	Saltin	(Finland)
13.	Rohan	(Ireland)
14.	Novotn´	(Czechoslovakia)
15.	Drevikovsky	(Czechoslovakia)
16.	Dési	(Hungary)
17.	Rafalowsky	(Poland)
18.	Denisova	(U.S.S.R.)
19.	Dené	(Netherlands)
20.	Bleeker	(Netherlands)
21.	Spanjer	*Interpreter*
22.	Methorst	*Interpreter*
23.	Magnusson	(Sweden)
24.	Dufour	(Belgium)
25.	Grandy	(United Kingdom)
26.	Van Der Ham	*Administrative Officer*
27.	Fokkens	(Netherlands)
28.	Silva de Sousa	(Portugal)
29.	Duner	(Sweden)
30.	Ribault	(France)
31.	Jakobsen	(Denmark)
32.	Lytskjold	(Norway)
33.	Leclercq	(France)
34.	Schutte	(Netherlands)
35.	Wusthoff	(Germany)
36.	Bell	(United Kingdom)

Dr. Robinson wondered if much importance could be attached to the term concerned with conditions below cloud in the statistical forecasting parameter. The absorption of solar radiation by the cloud is spread through a considerable depth below cloud, but the long-wave radiation from cloud top tends to cool only a shallow layer near the top. Dr. James agreed that perhaps this term was not very important, but pointed out that the net increase in the cooling at cloud top at night was the agency by which the mixing with the inversion layer was intensified. This could lead to the dissipation of the cloud.

Mr. Gold asked if any measurements of drop sizes had been made in cloud, particularly near cloud top. He also suggested that condensation high up in the troposphere could affect the radiation falling on the cloud top. Dr. James agreed that the presence of a high saturated layer and particularly an upper cloud sheet could modify the heat budget of the stratocumulus sheet, but on the occasions described no upper cloud was present.

Mr. Illsley wondered why a term involving the surface wind did not appear in the statistical forecasting parameter, since ground turbulence was largely dependent on the wind. The dry adiabatic lapse rate and constant humidity mixing ratio below cloud have indicated that turbulence was effective at least as far up as cloud base.

Mr. Sawyer pointed out that the origin of the turbulence was in the cloud and not at the ground, the mixing spreading downwards from the cloud to near the earth's surface.

Dr. Sutcliffe summed up and thanked Dr. James for opening the discussion.

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WORLD METEOROLOGICAL ORGANIZATION

Third Session of the European Working Group on Meteorological Transmissions

The Working Group on Meteorological Transmissions of the European Regional Association of the World Meteorological Organization met, under the Chairmanship of Mr. C. V. Ockenden (United Kingdom), in Utrecht from April 12 to 18, 1957. Some 30 representatives and advisers attended the meetings and 18 European countries were represented. In opening the Session, Dr. Warners, the Director-in-Chief of the Netherlands Meteorological Institute, recalled that it was also at Utrecht exactly ten years previously that the idea had been conceived of an international meteorological teleprinter network for Western Europe. He was glad to observe that several of those present were included in the list of representatives who attended the earlier meeting in 1947.

A very full agenda had been prepared for the session and to expedite the work, two main committees were formed under the Chairmanship respectively of Dr. Postma (Netherlands) and Mr. Bell (United Kingdom). The most important items discussed concerned the method of connecting the Western European Meteorological Teleprinter Network and a similar network in eastern and central Europe, and the possibilities for reorganizing the overall methods of exchange of basic data by land-line, radio, radio-teleprinter and facsimile within the European Region. These problems formed the subject of Resolutions at the last Regional conference, an account of which appeared in the *Meteorological Magazine* for June 1956. Regarding the first item, statistics relating to the quantity of information of various categories had to be examined to determine how the material could best be disseminated to schedules which involved the minimum of delay. It was finally agreed that, pending the implementation of any major reorganizations in communications which might arise as a result of a joint World Meteorological and International Civil Aviation Organizations meeting to be held next year, the East and West exchange should be carried out over duplex circuits between Frankfurt on Main and Prague and Frankfurt on Main and Potsdam. Lists were produced of the selected stations to be included for various countries both for surface and upper air observations for different synoptic hours for guidance.

Regarding the possibilities of reorganising the general framework for the exchange of basic data, some far-reaching proposals for an extensive use of radio-facsimile broadcasts were put forward by the representative of Western Germany but otherwise there were no firm proposals for a radical change in the system of Continental, sub-Continental and Territorial radio broadcasts or in the existing trunk circuits used in the teleprinter network. It was, however, recommended that countries concerned should forward to the World Meteorological Organization Secretariat by August 1, details of the extent to which they could implement proposals for facsimile and radio-teleprinter broadcasts. Several representatives were of the opinion that more data were circulating between the three main centres Dunstable, Paris and Frankfurt, than were actually required or used by countries connected to the network. It was considered therefore, that before a realistic approach could be made to the general problem of routine and scheduling, a first step should be to circulate a questionnaire to all countries in the Region asking for precise details of their minimum requirements. Replies to the questionnaire will be consolidated by the chairman and the comments of members obtained by correspondence so that further consideration can be given to modifying schedules and circuits and, if necessary, "areas of responsibility" of various centres, by a small *ad hoc* group to be convened at an appropriate time well before the joint World Meteorological and International Civil Aviation Organizations meeting.

A large number of other outstanding matters were discussed and recommendations adopted. These included a technical examination of reports on the 6-month trial reception in Europe of the radio-teleprinter broadcasts from New York, a review of the data which are exchanged between Europe and

North America, the block-grouping on a time-sharing basis of wireless telegraphy Territorial broadcasts from Denmark, Sweden, Norway and Finland, changes in schedules resulting from the change of standard hours for upper air observations from 03, 09, 15, 2100 to 00, 06, 12, 1800, the means of notification of changes to the contents, schedules, frequencies and call signs of radio broadcasts and the results of experience gained in the operation of the plan for broadcasts by the Ocean Weather Ships. In addition, the opportunity was taken to review old resolutions and recommendations and frame amendments where necessary.

During the Session delegates were shown the work of the Royal Netherlands Meteorological Institute at De Bilt where they were also afforded the opportunity of attending a demonstration of the latest fully automatic MUFAX Weather Chart Equipment. The Director-in-Chief of the Meteorological Institute kindly invited representatives to a cocktail party towards the end of the Session. Much of the more detailed work had to be passed to *ad hoc* subcommittees and on some days it was necessary for these to carry on until well after the time that most of the residents of Utrecht had retired for the night. Sunday provided a welcome break and many delegates had an opportunity of visiting Keukenhof Park near Lisse, the showpiece of the Dutch bulb industry.

NOTES AND NEWS

Photographs of cumulonimbus tops

The photographs of cumulonimbus tops (facing p. 240) were taken from aircraft of the Royal Air Force. In each case the pilot rightly considered that the cloud structure would be of interest to meteorologists.

On January 9, 1957, Flying Officer B. W. Crocker was flying northwards over the Shetland Islands at an altitude of 40,300 ft. He had been flying over two to three oktas of cumulonimbus cloud, tops estimated at 20,000 to 25,000 ft. and four to five oktas of cumulus cloud, tops estimated at 10,000 ft. At 1200 G.M.T., just north of the islands, a line of cumulonimbus tops appeared to starboard, each top being surrounded by a ring of cloud. The aircraft carried a camera mounted horizontally, and the pilot banked his aircraft before making several exposures.

A vigorous depression was centred over north Scandinavia at 1200 G.M.T., and the associated cold front was moving south-eastwards across Denmark and south-east England. A trough in the polar air extended south-westwards off the Norwegian coast to just north of the Shetlands. There was very little wind shear in the vertical in the deepening westerly flow of polar air over the Shetlands during the morning. The surface wind at Lerwick veered between 1300 and 1400 G.M.T., and the afternoon ascent there showed that a veer to north of west had occurred at all heights up to the cold air tropopause at 22,300 ft. There is little doubt that the line of cumulonimbus clouds illustrated in the photograph occurred along and just ahead of the trough line, with cloud tops near the tropopause. The high degree of symmetry, particularly noticeable in the cumulonimbus in the foreground, was made possible by the absence of any appreciable shear in the westerly flow of deep cold air just south of the trough line.

The cumulonimbus cloud in the foreground is in an active state of growth. Vigorous convection at lower levels on the upwind side of the cloud is well illustrated. The tropopause temperature was −48°C. Despite the ice crystal nature of the cloud top, well illustrated by the predominance of fibrous structure, it will be noticed that several bubbles there have a fairly well defined outline, indicative of continued ascent. The sun is catching the sides of protruding towers on the south-west side of the cloud top, and the tendency for the tops of these towers to spread outwards and away from the centre of the convection cloud is quite well marked. The ring of cloud round the top of the cumulonimbus is the anvil cloud which is spreading outwards in all directions as the glaciated towers accumulate at the top of the convection cloud. This spreading outwards is assumed to occur just at or below the tropopause. New bubbles penetrating the top of the convection cloud are reaching a somewhat higher level than that of the surrounding anvil cloud. The large bubble near the centre is casting a well defined shadow towards the north. Shadows on the north side of the cloud obscure detail there, but there is evidence of thin cloud overlying the spreading anvil cloud, and this may be the remnants of pileus cloud.

The pilot had to bank his aircraft in order to photograph this cloud, therefore it has not been possible to calculate the dimensions of the cloud top in the usual way, which requires a series of photographs taken in straight and level flight and with a camera at fixed and known declination. However, an estimation of the dimensions of the top of the cloud in the foreground can be made by assuming that the general cloud field of convection cloud tops and associated cirrus occurs at the tropopause. From the dip below the horizontal of the horizon line of this cloud field an estimation of the declination of the camera can be made. An estimation of the dimensions of the top of the convection cloud can then be made.

The north–south diameter of the inner core of active convection probably lies between 4 and 4½ miles, whilst the complete north–south diameter including the anvil cloud is about 6 miles. The complete east–west diameter is probably of the order of 7 to 8 miles. A diameter of the inner core of active convection of the order of 4 to 4½ miles agrees well with the depth of the cloud, which must have been about 4 miles.

The cumulonimbus clouds on the horizon to the right are considerably higher than those nearer the camera. These distant clouds are probably over Norway.

The photograph of January 23, 1957 was taken by Squadron Leader D. A. Hammatt, A.F.C., D.F.M. in a flight over the Atlantic to the west of Biscay. The aircraft was flying north-north-westwards in the early afternoon at a height of 8 miles, the horizontally mounted camera was pointing west-south-westwards, and the aircraft was banked during the exposure.

The photograph shows a field of convection cloud in maritime polar air about 200 to 300 miles behind a cold occlusion. It consists largely of relatively small cumulus clouds with larger convection cloud here and there, and some extensive patches of cirrus. The photograph is dominated by the extensive top of a cumulonimbus cloud. Wind shear in the cloud-laden air is small, with the wind blowing towards the bottom left-hand corner of the photograph.

There is a good break in the clouds just downwind of the extensive cumulonimbus cloud, but details of the side of this cloud are obscured by cirrus cloud. The top of the cumulonimbus cloud is still being fed by many bubbles rising into it, and the spreading outwards from the top of the convective column of the ice-crystal anvil cloud is well illustrated. The height of the cloud top is estimated to be about 20,000 ft., and it is about 7 miles across.

J. HARDING

Pileus before Cumulus

Up to about 0930 G.M.T. on May 27, 1957, the sky was practically cloudless at Bentley Priory, Stanmore, with good visibility and a moderate north-east wind. About 0930 numerous lenticular clouds began to form quickly to the north-east, some with fantastic shapes like a Loch Ness monster, and then in five to ten minutes small cumulus began to form under each cloud so that the sky was about five oktas covered with a double layer. In places the cumulus cloud seemed to touch the pileus and both seemed to move together with the wind.

The temperature was 61°F., and the dew-point about 39°F.; thus the bases of the cumulus cloud were about 5,000 feet and the tops mostly around 6,000 feet. Judging from the Hemsby temperatures at 0001 G.M.T. on the 27th, there was an inversion of 3°F. at about 8,000 feet with a rather moist layer just below which might determine the height of the pileus clouds.

The photographs between pp. 240 and 241 were taken looking south-east within a couple of minutes of 0955 G.M.T.

R. M. POULTER

Standard deviation of the height of the 500-mb. surface over the North Atlantic

The working charts of the Central Forecasting Office of the Meteorological Office provided the basic data for this investigation. The 1500 G.M.T. charts for each day of January, April, July and October for the period 1949–53 were used; from them values of contour height were read off, correct to the nearest 100 ft., at the points of the network 35°N. 65°N., 80°W. 30°E. Values of the standard deviation, σ_{500}, were then computed for each point of the network. These values of σ_{500} were used in connexion with other work*; but since it was considered that they might be of interest in themselves they were plotted on four charts, and isopleths were drawn. They are shown in Figs. 1–4 on pages 246–9.

A. F. JENKINSON

Altocumulus in a standing wave

In a note accompanying photographs of altocumulus published in the *Meteorological Magazine* for ~~July~~ June 1957 (between pp. 176 and 177) a superscript minus sign was omitted from the dimensions of Scorer's parameter.

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* JENKINSON, A. F.; The relationship between standard deviation of contour height and standard vector deviation of wind, with practical applications. *Met. Res. Pap., London,* No. 869, 1954.

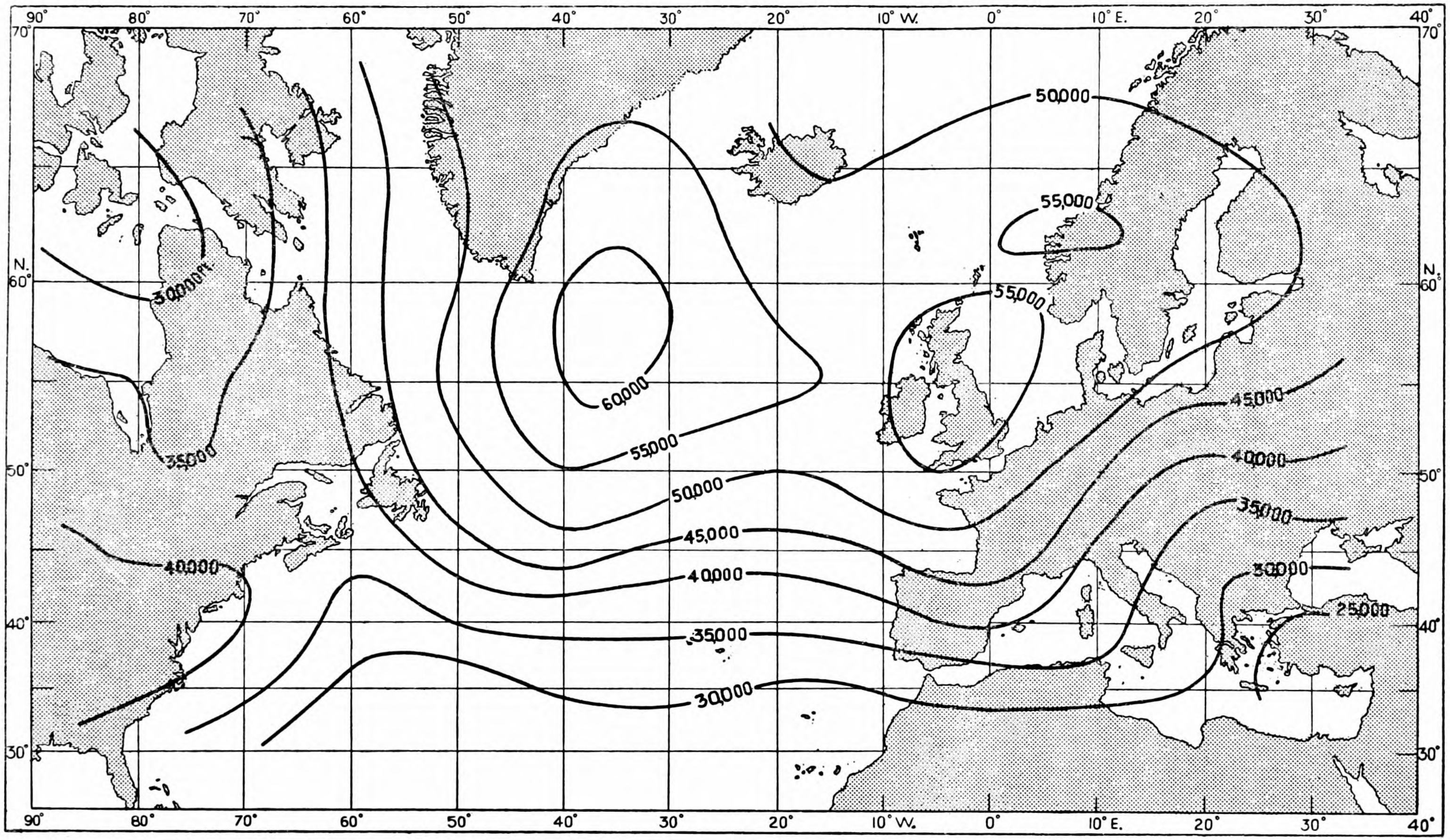

FIG. 1—STANDARD DEVIATION OF HEIGHT OF 500-MB. SURFACE, 1500 G.M.T. FOR JANUARY

(see p. 245)

N.B.—The plotted values of the isopleths must be divided by 100, thus 60,000 should be 600 ft.

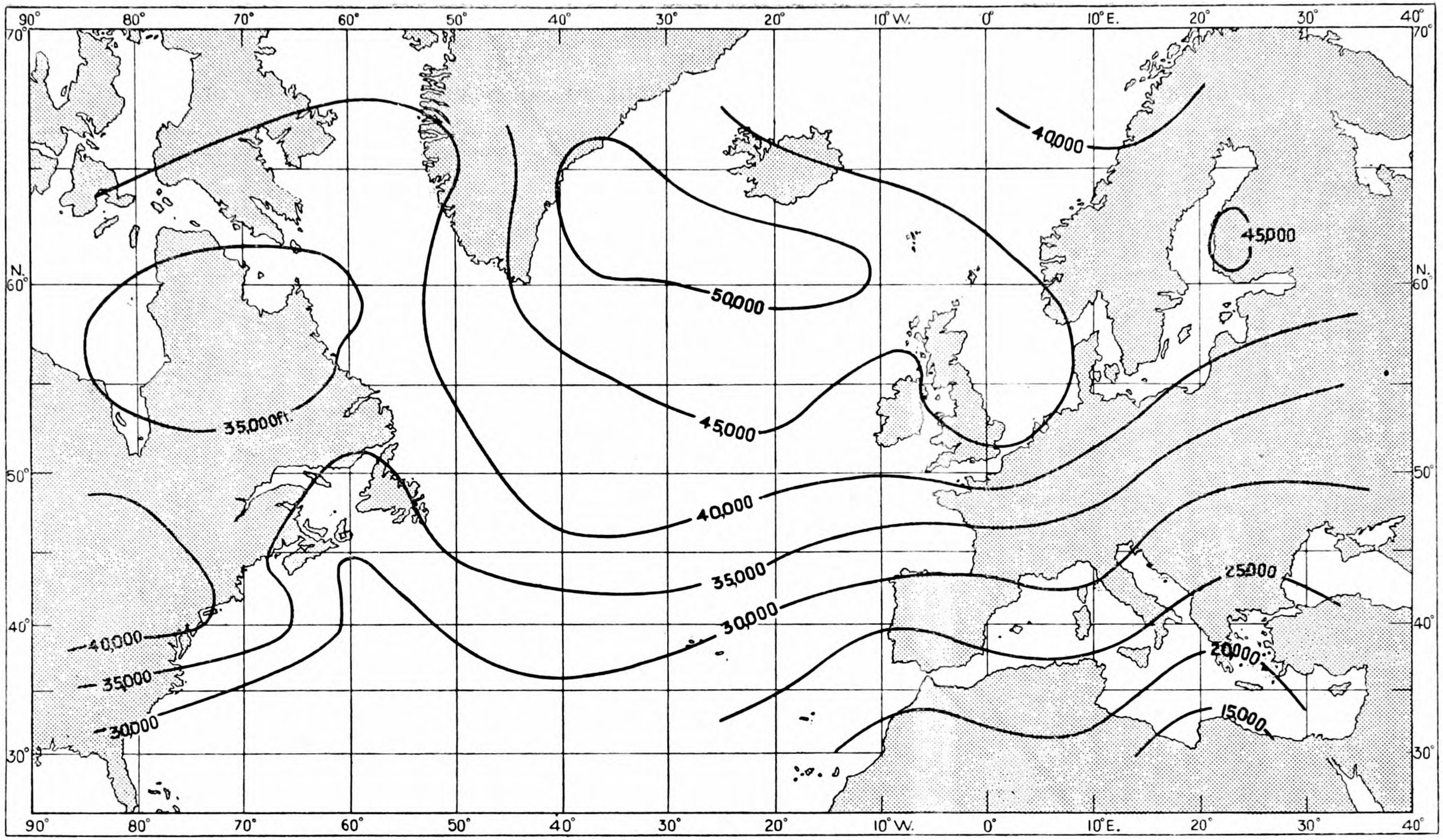

FIG. 2—STANDARD DEVIATION OF HEIGHT OF 500-MB. SURFACE, 1500 G.M.T. FOR APRIL

(see p. 245)

N.B.—The plotted values of the isopleths must be divided by 100, thus 50,000 should be 500 ft.

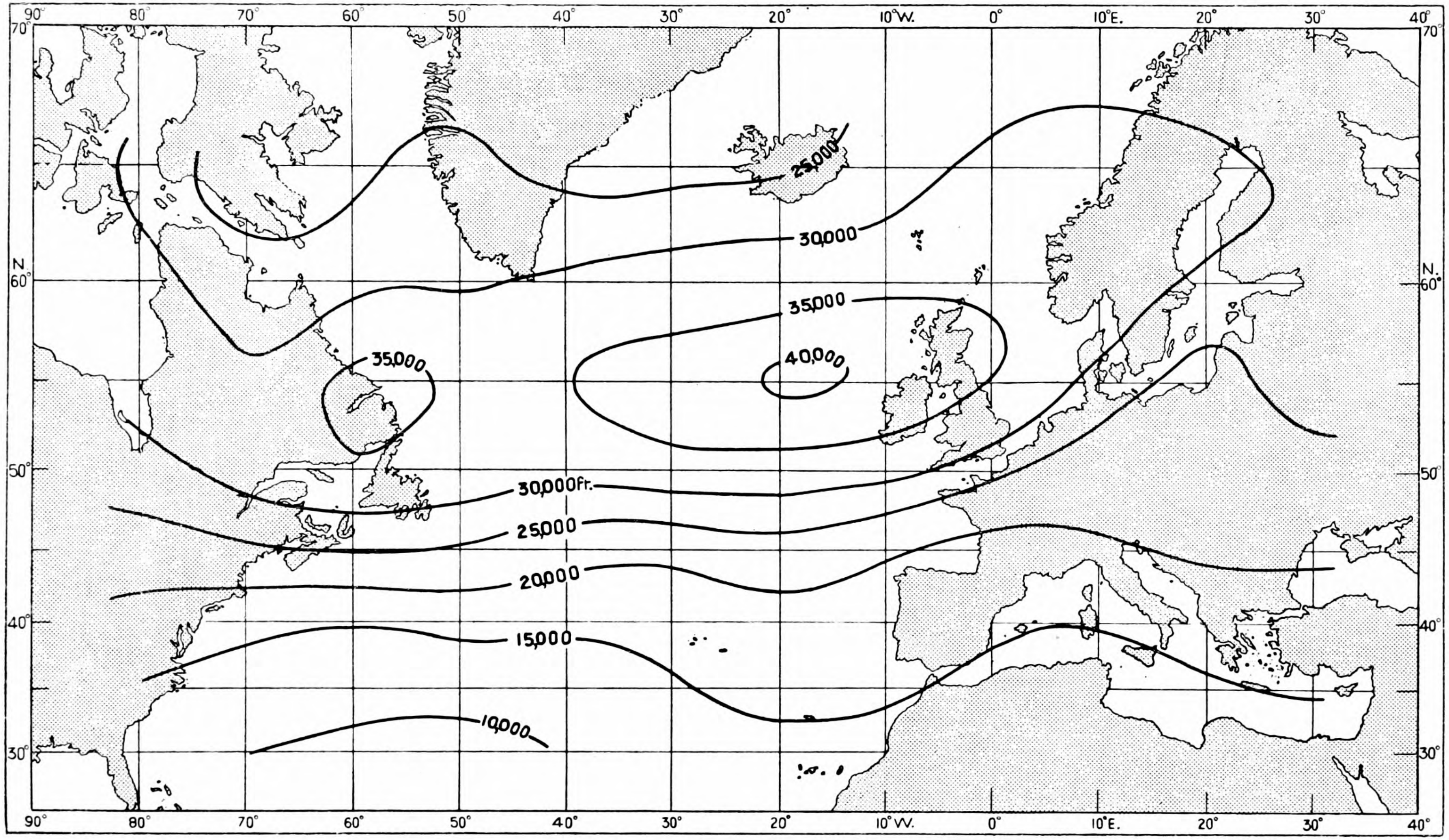

FIG. 3—STANDARD DEVIATION OF HEIGHT OF 500-MB. SURFACE, 1500 G.M.T. FOR JULY

(see p. 245)

N.B.—The plotted values of the isopleths must be divided by 100, thus 40,000 should be 400 ft.

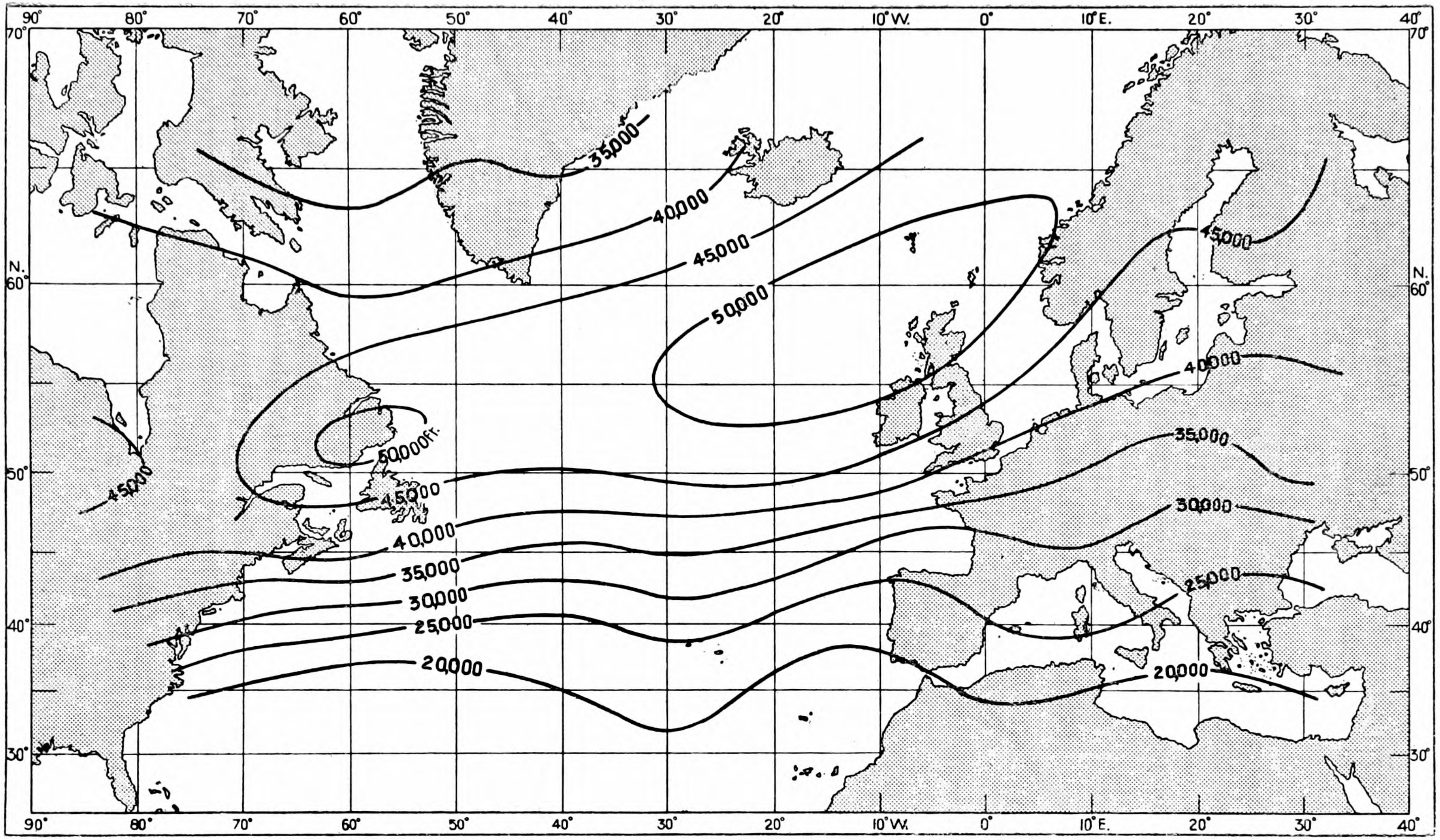

FIG. 4—STANDARD DEVIATION OF HEIGHT OF 500-MB. SURFACE, 1500 G.M.T. FOR OCTOBER

(see p. 245)

N.B.—The plotted values of the isopleths must be divided by 100, thus 50,000 should be 500 ft.

HONOURS

I.S.O.

The Birthday Honours List, June 1957, announced the appointment of Dr. J. Glasspoole, Principal Scientific Officer, Meteorological Office, to be a Companion of the Imperial Service Order.

POLAR MEDAL

In the Supplement to the *London Gazette* for June 28, 1957, it was announced that the Polar Medal has been awarded to Mr. D. W. S. Limbert for good services as a member of the Advance Party of the Royal Society Antarctic Expedition for the International Geophysical Year.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Miss E. E. Austin* relinquished her temporary appointment as Senior Scientific Officer on June 30, 1957, in which capacity she had served after her retirement on August 9, 1955. Miss Austin joined the Office in July 1918 as secretary to Sir Napier Shaw. In November 1920 she was seconded for duty with Sir Napier who was then Professor of Meteorology at the Imperial College of Science and Technology. She remained with Sir Napier until 1935 and during these years she assisted in the preparation and publication of the four volumes of Shaw's *Manual of Meteorology*. In 1935 she was posted to the Climatology Branch and became responsible for the preparation of the various handbooks on Weather over the Oceans and Coastal Regions. In 1948 she was appointed Head of the newly formed World Climatology Branch and in 1951 became Head of the new Upper Air Climatology Branch. She retired in 1955 from the latter post but continued to serve in the same Branch in a temporary capacity. Miss Austin was well known in international meteorological affairs. She accompanied Sir Napier Shaw to several International Union of Geodesy and Geophysics meetings and was later one of the British representatives on the World Meteorological Organization Commission for Aerology.

Mr. E. V. Newnham, Senior Scientific Officer, retired on June 30, 1957. He joined the Office in September 1914 as a Graduate Assistant in the Forecast Division. Apart from a period of twelve months in 1915–16 at Benson the whole of his 42 years' service has been spent at Headquarters in the Forecast, Climatological, Instruments and World Climatology Divisions. At the time of his retirement he was serving in the World Climatology Branch at Harrow.

Mr. A. W. Berry, Senior Experimental Officer, retired on June 16, 1957. He first worked at the Royal Observatory, Greenwich, and after service in the London Rifle Brigade and the Royal Air Force during the First World War he joined the Office in June 1921 as a Technical Assistant. The whole of his service in the Meteorological Office has been spent at aviation outstations. Since 1949 until his retirement he has been officer-in-charge of the Meteorological Office at Birmingham (Elmdon) Airport.

Mr. C. C. Newman, Senior Experimental Officer, retired on June 29, 1957. He joined the Office in August 1914 as a Boy Clerk in the Forecast Division. During the first World War he served in the Royal Naval Air Service from

January 1917 until October 1918 when he was gazetted a Second Lieutenant in the Royal Air Force. He returned to the Forecast Division in September 1920 and since 1923 he has been mainly concerned with forecasting for the Royal Air Force. Mr. Newman served over twenty years at various stations in the Middle East including some ten years at Aden where he was serving at the time of his retirement.

Sports activities.—Mr. J. H. Keers, London Airport, was runner-up in the Civil Service Lightweight Boxing Championship, at King Edward Buildings, London, on April 11.

The Air Ministry Annual Sports were held at the White City Stadium on June 19, and marked the end of the year for the competition for the Bishop Shield which is presented to the department gaining the highest number of points in all the Air Ministry sports competitions held during the year.

This year the Office was runner up in the competition having failed to retain the Shield they had held for eight consecutive years. Miss E. Forster won the Ladies' 100 yards Championship, Mrs. A. Brown was second in the Ladies' High Jump, Miss B. Abbott was second in the Ladies' Long Jump and Mr. D. G. Maunder was second in the 440 yards Championship. The Office was second in the Men's Inter-Divisional Relay Championship and lost the Tug-of-War by two pulls to one after a long and close struggle.

The Harrow Social and Sports Committee held its Annual Sports Meeting on the evening of Wednesday, June 26 at the Headstone Manor Ground. The events were open to all members of the Meteorological Office and there were many entries for the track events, there being 11 starters for the half-mile and 14 for the one mile. Results of the four Meteorological Office Championship events were as follows:

Men's Hundred Yards ...	Mr. P. H. Anderson (Kew)
Half Mile	Mr. G. F. Burton (Kew)
One Mile	Mr. G. F. Burton (Kew)
Ladies' Hundred Yards ...	Miss E. Forster (London Airport)

Miss M. Boucher won the Ladies' High Jump with 4 ft. 5¾ in., a new record for Harrow Sports.

The weather was excellent and many visitors, including Sir Graham and Lady Sutton, came from Victory House, Dunstable, London Airport, Kew Observatory and Stanmore. Several novelty competitions and races proved popular. Mrs. S. P. Peters presented the prizes.

REVIEW

Weather analysis and forecasting, Vol. II. By S. Petterssen. 9 in. × 6 in., pp. xii + 266, *Illus.* McGraw-Hill Publishing Co. Ltd., London, 1956. Price: 45*s.* Volume I of this publication, under the sub-title "Motion and motion systems", was published early last year, and is now followed by the second and concluding volume, on "Weather and weather systems". Broadly, the first volume was directed towards the evolution of forecast charts and the understanding of the larger-scale mechanism of the atmosphere. Volume II deals primarily with the visible elements of weather such as cloud, fog and precipitation, and with their forecasting on every scale of development.

Chapter 20, the first in the new volume, is on the production and transformation of air masses. It deals with the ways in which the atmosphere gains or loses heat and moisture by direct exchange, and then with adiabatic changes in the vertical temperature structure consequent on changes in the vorticity of the moving air stream. Temperature and humidity relationships are the subject of the next chapter, including the essential features of thermodynamic diagrams. This is followed by an elementary description of clouds and precipitation and their formation; much of the text and a number of the illustrations here are taken from the first edition.

Up to this point the material of this volume is fundamental and a necessary part of a textbook, but much of it is such as to provide little scope for attractive presentation: it includes a good deal about some of the basic tools of the meteorologist, and there are few alternative ways of describing a tool. However, the subject which follows is largely a post-war development. J. C. Thompson contributes a chapter on quantitative precipitation forecasting, a branch of research for which the meteorologist in America is perhaps the best equipped by reason of the shape and extent of his observational network. Two distinct methods are outlined. One is the wholly physical approach in which the precipitable water, with the assumptions that term involves, is estimated from the temperature structure and calculated ascent of the atmosphere. This provides a broad pattern of the expected rainfall distribution over a large area. The other method is the statistical one, described more fully in a later chapter, which is based on observed relationships between the rainfall at a place and miscellaneous parameters which are more or less independent of each other. This wholly empirical method is of course widely used in local forecasting of various elements, fog-prediction diagrams being a familiar example.

Mist, fog and stratus are the contents of the next chapter, a subject which makes interesting reading in any textbook because the main principles are clear-cut, yet in detail these are major hazards to the aviation forecaster. The author gives a certain amount of information on methods of predicting the formation of fog, but little on either the process or the forecasting of its dispersal. The term "stratus" is not used in its generic sense, for one finds that when stratocumulus and nimbostratus were defined a few pages earlier they were in fact making both their entrance and their exit. The next chapter, a long one, is shared between convective clouds and "weather", the latter covering thunderstorms, squalls, tornadoes and other violent phenomena which are so well suited to mesoanalysis, a technique to which some prominence is given in the concluding pages.

Following a discussion of some actual synoptic developments, introduced by way of recapitulation of the physical processes previously discussed, the author includes a short chapter on local forecast studies, which deals with forecasting by means of prediction diagrams and regression equations. In effect the aim is to express in usable form the kind of knowledge an experienced forecaster accumulates from familiarity with developments on synoptic charts. The method of handling the information, although quite simple, is a reminder that, although the meteorologist may be able to give a fairly adequate explanation of the mechanism of weather, when the question to be answered is "Will it happen here and, if so, when?" the problem is sometimes best put to the statistician who knows a little meteorology.

A further step towards objectivity is illustrated by the last chapter in the book, in which Dr. T. F. Malone contributes an interesting account of the application of synoptic climatology to forecasting. The problem he describes is that of using climatological data in conjunction with past and predicted charts in order to produce objective forecasts of various meteorological elements. The method applied so far has been to relate the value of an element, such as temperature, to a sequence of sea-level circulation patterns, and thus to forecast its future change as a function of the change expected in the circulation. To make the circulation pattern mathematically tractable, the isobaric surface is approximated to the sum of a number of orthogonal surfaces. Examples are given of what is in principle a wholly objective forecast of mean daily temperature at one place, but it is perhaps too early to form an opinion as to whether other elements will show an equally consistent relationship with the surface circulation patterns. Moreover, the greater promise is doubtless in medium-range forecasting, which necessarily smooths out the small-scale features.

Much of Volume I of "Weather analysis and forecasting" brings home to the reader the rapid progress of meteorology, and indeed the book can be dated by its contents. This is not true to the same degree of the second volume, which in the main deals with subjects in which advances have been made on narrower fronts. The book as a whole is an admirable and timely production. It is a common grievance of the meteorologist that he gets too little opportunity for consolidating his knowledge. He will be grateful to Dr. Petterssen for a book that is unusually concise, lucid and coherent.

C. J. BOYDEN

OFFICIAL PUBLICATION

The following publication has recently been issued:—

PROFESSIONAL NOTES

No. 121—*A statistical study of the variation of wind with height.* By C. S. Durst, B.A.

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

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

RAINFALL AT TENBY. In the Rainfall Table for April 1957 published in June the percentage of average for Tenby should read 14.

WEATHER OF JUNE 1957

The low pressure area on the western Atlantic was displaced south and east of its normal June position towards mid ocean (lowest mean pressure 1010 mb. near 52°N., 37°W.): the intensity indicated by the central pressure was about normal, but implied considerably above normal south-westerly wind between 50°N. and the Azores. The Atlantic low pressure system presented the strongest circulation in northern latitudes on the mean pressure map for the month, and must have been associated with the reported distribution of excessive amounts of ice on the north-western part of the ocean. The highest pressure in the subtropical Atlantic (1020 mb., near the Azores) was 6 mb. below normal.

The polar anticyclone was intensified and displaced towards the Atlantic sector, giving a highest mean pressure of 1020 mb. in east Greenland (the pressure anomaly was +6 mb. in this area). There was a very wide region of rather above normal pressure over Europe and the eastern Atlantic between 10 to 20°W. and 20°E. and 35 to 65°N.

Pressure was below normal over most of North America, the anomaly reaching −4 mb. over a wide area about Hudson's Bay. Pressure was below normal by a similar amount over north Russia. The lowest mean pressures in the northern hemisphere were believed to be 1008 mb. over the White Sea and 997 mb. over north-west India, the latter being a normal value for the monsoon system.

There was a marked northerly and north-westerly stream of Arctic air between the Greenland high and the White Sea depression, giving rather low mean temperatures for June in Greenland, Scandinavia and eastern Europe in spite of abnormally little ice and high water temperatures in the East Greenland Sea (a legacy of the very mild winter in this sector). Western and central Europe came more often under the influence of warm air from the south and mean temperatures were up to 3°C. high for June, with noteworthy heat waves reported in many places towards the end of the month: on the 30th temperature reached 34°C. in Paris and similar values were general over the region between Madrid, London, Hanover and Rome.

Mean temperatures for the month were 2 to 3°C. above normal on the American Atlantic seaboard near New York and Washington, also over the Rockies in California and the desert states and in Alaska; most of the rest of North America was cool, the anomaly reaching −3°C. in central Canada.

June was dry in Iceland, over much of Europe between 45 and 55°N. and in the Baltic, but rainfall excesses were reported over the greatest parts of North America, northern and southern Europe and the Mediterranean.

In the British Isles June was warm and unusually sunny; the pressure features were somewhat indefinite, but the weather was broadly, though weakly, cyclonic during the first ten days and anticyclonic during most of the remainder of the month.

Although there was some rain in Scotland, the first two days of the month in England and Wales were generally sunny and dry with afternoon temperatures reaching the seventies, but on the 3rd thunderstorms developed over a wide area in south-east England giving many places their first rain for ten days. Weather was cooler with occasional rain or showers alternating with good sunny periods during the next few days, but there were outbreaks of thundery rain and thunderstorms with unusually heavy rain in places from the 8th to the 10th as a depression moved slowly from our South-west Approaches to the North Sea. On the 8th 3·05 in. of rain fell in 2 hr. during a thunderstorm at Nantwnalle, Cardiganshire, while Camelford had the worst thunderstorm ever experienced in Cornwall; 7·06 in. of rain was recorded there in 12 hr., 5·48 in. of which fell between 13 h. and 16 h. Pressure rose rapidly in the cool northerly air stream behind the depression and by the 12th an anticyclone was situated over southern England, which later moved slowly north, giving about 10 days of brilliantly fine, warm weather. Rhayader, in Wales, reported a pressure of 1037·4 mb. on the 13th, nearly 1 mb. more than the highest June pressure previously recorded in the British Isles (in 1870). During this fine period Stonyhurst reported nine successive days, from 12th to 20th, with 15 hr. or more sunshine and Oban had four consecutive days with at least 16 hr. sun. By the 14th afternoon temperatures exceeded 80°F. at many places in southern England and at both London Airport and Hurn temperatures rose into the eighties on five successive days from that date and reached 87°F. at both places on the 17th and 18th. On the 18th thunderstorms again broke out at many places in Wales and southern England—Andover had a "noteworthy" fall of 1·68 in. of rain in 2 hr. during a storm—but although temperatures were about 10°F. lower the following day there was no general break in the fine weather until the 22nd. On that date a cool northerly air stream spread southwards over the country bringing outbreaks of thundery rain to many areas and maximum day temperatures down into the sixties generally. Fairly widespread ground frost occurred, particularly in the north; at Ross-on-Wye the grass minimum temperature was 29°F. on the 23rd, the latest date with ground frost in nearly a hundred years of records at that station, while further north screen temperature fell as low as 26°F. at Eskdalemuir. On the 26th an anticyclone over the Bay of Biscay moved north-eastwards over France and intensified, and associated with this development very warm tropical air spread over the British Isles. The last three days were the warmest of the month with temperatures reaching 90°F. in many southern and midland districts. Temperature did not fall below 70°F. on the Air Ministry roof, Kingsway, on the night of the 28th–29th—the warmest night in London since September 1949—and the following day reached 95°F. at Northolt and 96°F. at Camden Square, London, the latter being the highest temperature recorded in the British Isles during June since 1858.

It was the sunniest June on record at many stations; at Worthing since 1899 and at Stonyhurst since 1881. Rainfall over England and Wales was about 80 per cent. of the averages, the third successive month with below average fall; the total for the period April–June was the lowest for these three months since 1921. Although the weather has been almost perfect for harvesting the rather light hay crop, farmers have been severely handicapped in other directions by the very warm dry weather. Second growth grass has been negligible, milk yields have declined rapidly and great difficulty has been experienced in planting out and establishing autumn and winter vegetables.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	96	26	+1·6	79	−3	143
Scotland	87	26	+1·0	100	−2	134
Northern Ireland ...	82	32	+0·9	73	−6	155

RAINFALL OF JUNE 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	·61	30	*Glam.*	Cardiff, Penylan ...	·96	38
Kent	Dover	·21	11	*Pemb.*	Tenby	3·31	138
,,	Edenbridge, Falconhurst	1·54	70	*Radnor*	Tyrmynydd	2·60	80
Sussex	Compton, Compton Ho.	1·81	73	*Mont.*	Lake Vyrnwy	1·74	54
,,	Worthing, Beach Ho. Pk.	1·59	91	*Mer.*	Blaenau Festiniog ...	3·90	60
Hants.	St. Catherine's L'thouse	1·06	60	,,	Aberdovey	2·69	99
,,	Southampton (East Pk.)	1·69	84	*Carn.*	Llandudno	2·26	119
,,	South Farnborough ...	1·13	59	*Angl.*	Llanerchymedd ...	2·15	91
Herts.	Harpenden, Rothamsted	2·29	102	*I. Man*	Douglas, Borough Cem.	1·79	70
Bucks.	Slough, Upton	0·69	34	*Wigtown*	Newton Stewart ...	1·75	66
Oxford	Oxford, Radcliffe ...	2·19	98	*Dumf.*	Dumfries, Crichton R.I.	1·07	42
N'hants.	Wellingboro' Swanspool	2·39	114	,,	Eskdalemuir Obsy. ...	1·67	53
Essex	Southend, W. W. ...	1·11	59	*Roxb.*	Crailing...	0·80	36
Suffolk	Felixstowe	·98	57	*Peebles*	Stobo Castle	2·57	110
,,	Lowestoft Sec. School...	1·95	108	*Berwick*	Marchmont House ...	1·15	50
,,	Bury St. Ed., Westley H.	1·65	79	*E. Loth.*	North Berwick Gas Wks.	·87	53
Norfolk	Sandringham Ho. Gdns.	1·93	89	*Midl'n.*	Edinburgh, Blackf'd. H.	1·17	59
Wilts.	Aldbourne	1·56	63	*Lanark*	Hamilton W. W., T'nhill	2·01	91
Dorset	Creech Grange... ...	1·19	52	*Ayr*	Prestwick	2·13	111
,,	Beaminster, East St. ...	2·32	103	,,	Glen Afton, Ayr San. ...	1·78	59
Devon	Teignmouth, Den Gdns.	1·15	60	*Renfrew*	Greenock, Prospect Hill	2·41	77
,,	Ilfracombe	1·33	61	*Bute*	Rothesay, Ardencraig ...	...	...
,,	Princetown	2·62	65	*Argyll*	Morven, Drimnin ...	3·96	128
Cornwall	Bude, School House ...	2·72	135	,,	Poltalloch	3·79	124
,,	Penzance	1·96	88	,,	Inveraray Castle ...	4·65	117
,,	St. Austell	4·16	160	,,	Islay, Eallabus	2·52	96
,,	Scilly, Tresco Abbey ...	·75	43	,,	Tiree	2·37	93
Somerset	Taunton	3·81	216	*Kinross*	Loch Leven Sluice ...	1·56	71
Glos.	Cirencester	1·34	54	*Fife*	Leuchars Airfield ...	0·73	44
Salop	Church Stretton ...	1·75	69	*Perth*	Loch Dhu	2·71	65
,,	Shrewsbury, Monkmore	1·58	76	,,	Crieff, Strathearn Hyd.	2·06	78
Worcs.	Malvern, Free Library...	1·69	73	,,	Pitlochry, Fincastle ...	1·37	66
Warwick	Birmingham, Edgbaston	1·77	69	*Angus*	Montrose Hospital ...	1·20	72
Leics.	Thornton Reservoir ...	1·42	66	*Aberd.*	Braemar	1·60	82
Lincs.	Boston, Skirbeck ...	1·98	109	,,	Dyce, Craibstone ...	3·27	175
,,	Skegness, Marine Gdns.	1·43	79	,,	New Deer School House	2·46	124
Notts.	Mansfield, Carr Bank ...	1·44	64	*Moray*	Gordon Castle	3·04	149
Derby	Buxton, Terrace Slopes	2·12	66	*Nairn*	Nairn, Achareidh ...	1·99	112
Ches.	Bidston Observatory ...	1·11	50	*Inverness*	Loch Ness, Garthbeg ...	1·99	87
,,	Manchester, Ringway...	1·48	61	,,	Loch Hourn, Kinl'hourn	6·21	126
Lancs.	Stonyhurst College ...	1·99	65	,,	Fort William, Teviot ...	2·98	84
,,	Squires Gate	1·47	71	,,	Skye, Glenbrittle ...	4·22	99
Yorks.	Wakefield, Clarence Pk.	2·07	96	,,	Skye, Duntulm... ...	3·26	125
,,	Hull, Pearson Park ...	2·57	125	*R. & C.*	Tain, Mayfield... ...	2·44	132
,,	Felixkirk, Mt. St. John...	2·08	95	,,	Inverbroom, Glackour...	3·20	113
,,	York Museum	2·26	109	,,	Achnashellach	5·02	134
,,	Scarborough	1·29	70	*Suth.*	Lochinver, Bank Ho. ...	3·93	184
,,	Middlesbrough... ...	2·17	115	*Caith.*	Wick Airfield	3·03	168
,,	Baldersdale, Hury Res.	1·31	60	*Shetland*	Lerwick Observatory ...	2·53	141
Norl'd.	Newcastle, Leazes Pk....	2·08	99	*Ferm.*	Crom Castle	1·78	66
,,	Bellingham, High Green	1·80	78	*Armagh*	Armagh Observatory ...	1·40	56
,,	Lilburn Tower Gdns. ...	1·13	55	*Down*	Seaforde	1·16	42
Cumb.	Geltsdale	1·72	64	*Antrim*	Aldergrove Airfield ...	1·64	68
,,	Keswick, High Hill ...	1·48	51	,,	Ballymena, Harryville...	3·43	118
,,	Ravenglass, The Grove	2·55	98	*L'derry*	Garvagh, Moneydig ...	2·05	81
Mon.	A'gavenny, Plâs Derwen	·84	31	,,	Londonderry, Creggan	2·24	80
Glam.	Ystalyfera, Wern House	1·60	42	*Tyrone*	Omagh, Edenfel ...	2·08	74

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ESTIMATION OF THE FREQUENCY OF "RUNS OF DRY DAYS"

By E. N. LAWRENCE, B.Sc.

Summary.—The frequencies of runs of dry days (that is, sequences of days with nil, trace or 0·1 mm. of recorded rainfall) of different lengths are described with special reference to southern and eastern England and to the months May to September. The relation between the frequencies of different lengths, for a particular site, is examined, with special reference to persistence, and their approximation to various series is discussed. The series may be referred to as: geometric, logarithmic, "natural-persistence" or "Jenkinson-probability". Each of these types of series lends itself to one or more methods of approximation to the actual series. Each method uses one, two or three meteorological variables in a convenient form for charting. It is shown that the "natural-persistence" series with area values for the probabilities is the most convenient and accurate approximation.

Part I

Introduction.—In climatological work the rainfall chart is perhaps very familiar. With an extensive network of rainfall stations and long experience of drawing isopleths of rainfall, the charts provide a suitable basis for the estimation of monthly mean rainfall by interpolation. No doubt, this technique will in time be extended to many other macroclimatic variables. In this paper, the frequencies of runs of dry days of various lengths are examined. In order to extend the use of charts and also as a contribution to the study of weather persistence, the series of the actual frequencies of runs of different lengths was, for a number of stations, compared with or fitted to series of the geometric, logarithmic, "natural-persistence" and "Jenkinson-probability" types.

Data.—Data for some 70–80 stations in southern and eastern England (see Fig. 1) were examined for the period 1921–46, where possible, and for the months April to September. For "Jenkinson-probability" series, a special study was made of the 21 sites examined in the area of south-west England, with particular reference to August.

The daily (0900 to 0900) rainfall records were used to compute the frequencies of 1, 2, 3, etc. consecutive dry days. A dry day is defined as one on which the recorded rainfall was nil or trace, or in the case of millimetre recording, nil, trace or 0·1 mm. Days on which 0·01 in. or 0·2 mm. or more were reported are defined as rain-days.

In computing frequencies the following conventions were used:

(i) A run of dry days starting in one month and ending in another has been credited to the month with the greater portion of the spell.

(ii) If a run is equally divided between two months, each of these months has been credited with half a run of the full length.

(iii) For runs which end after September 30 or begin before April 1 (May 1 for south-west England), only those days which occur on or after April 1 (or May 1) or on or before September 30 are considered.

Ideally, runs should be proportionally divided between the months in which they occur, but this convention involves more computation and loses its advantage when long periods are used. The convention is not employed in this paper.

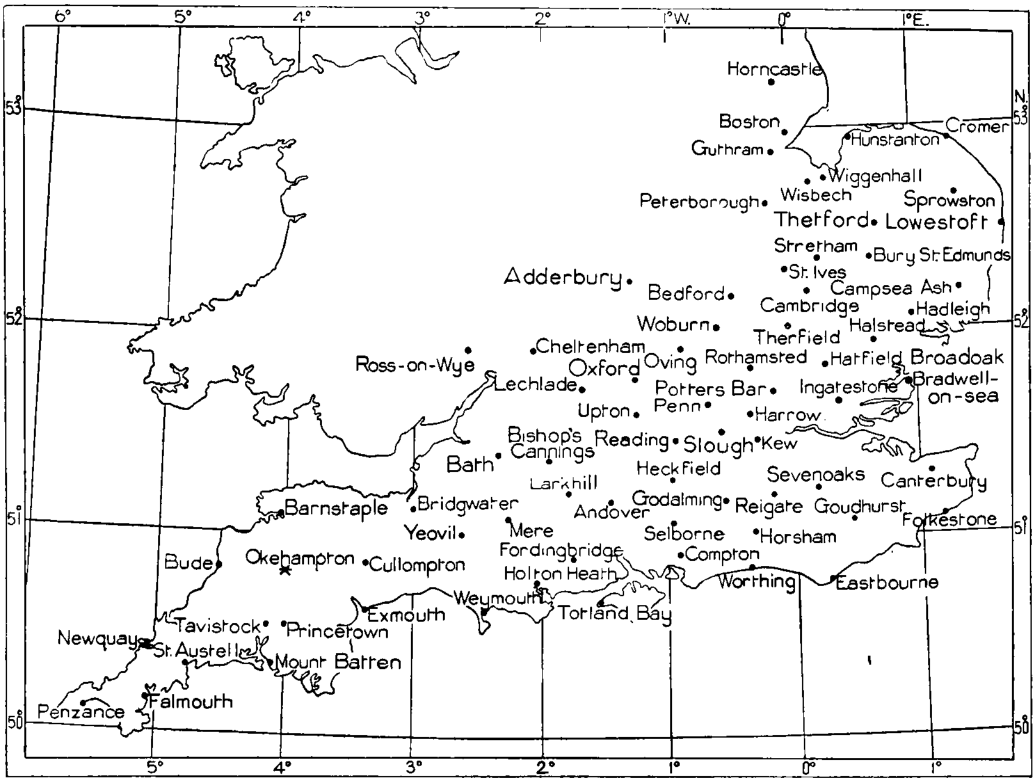

FIG. 1—STATIONS IN SOUTHERN AND EASTERN ENGLAND

Geometric series.—The representation of the frequencies of runs of different lengths by the terms of a geometric series implies that no matter how many consecutive dry days have already occurred, there is a constant probability that the next day will be dry. The validity of this approximation will be discussed later.

Given N runs of 3 or more days and P the constant probability that a run of dry days will continue for at least another day, the theoretical frequencies of runs lasting 3 or more, 4 or more, 5 or more,. . . t or more days, etc. (i.e. "cumulative frequencies") are

$$N, NP, NP^2, NP^3, \ldots\ldots NP^{t-3}, \ldots\ldots$$

If the sum of this series is S, then $S = N/(1 - P)$ and hence $P = 1 - N/S$.

For each station, P was calculated from observed values of N and S and charts of isopleths of P and N were drawn for each month. The procedure of interpolating the values of P and N from charts and calculating the frequency (NP^{t-3}) of runs lasting at least t days is illustrated in the Appendix (following Part I). The Appendix (p. 269) gives values of N and P from which charts for the summer months for southern and eastern England can be drawn.

Logarithmic series.—This series does not assume a constant value for P; it can readily be shown that it implies "positive persistence", i.e. that the longer a run lasts the more likely will it last another day. This has been discussed in an earlier paper[1].

In this representation, the number of runs in a given period lasting only 1 day, only 2 days, only 3 days . . . only t days, etc., are given by the terms

$$a, \frac{ar}{2}, \frac{ar^2}{3}, \frac{ar^3}{4}, \ldots\ldots \frac{ar^{t-1}}{t}, \ldots\ldots,$$

where a and r are constants depending on the site. If the total number of runs be T, then

$$T = a + \frac{ar}{2} + \frac{ar^2}{3} + \frac{ar^3}{4} + \frac{ar^4}{5} + \ldots\ldots$$

$$= -\frac{a}{r}\log_e(1 - r) . \qquad \ldots\ldots (1)$$

If the observed number of dry days be n, then

$$n = a + ar + ar^2 + ar^3 + ar^4 + \ldots\ldots$$

$$= a/(1 - r) . \qquad \ldots\ldots (2)$$

Therefore $r = (n - a)/n$. $\qquad \ldots\ldots$ (3)

Substituting for r in equation (1)

$$T = \frac{an}{a - n}\log_e\frac{a}{n} . \qquad \ldots\ldots (4)$$

Using the observed values of n and T, the values of a and r were calculated for each site from equations (3) and (4). A graphical method of solution described by Williams[2] was employed, using the graph of

$$\frac{n}{T} = \frac{r}{(r - 1)\log_e(1 - r)}$$

for different values of n/T and r, and substituting the graphically obtained value for r in $a = n(1 - r)$ to obtain a.

For each station, the values of a and r were plotted and charts of the isopleths of a and r were drawn for each month. The procedure of interpolating the values of a and r from the charts and calculating the frequency F_t of runs lasting t or more days, as given by

$$F_t = -\frac{a}{r}\log_e(1 - r) - \left(a + \frac{ar}{2} + \frac{ar^2}{3} + \frac{ar^3}{4} + \ldots + \frac{ar^{t-2}}{t-1}\right),$$

is illustrated in the Appendix (p. 269) where values of a and r for the summer months in southern and eastern England are also given.

Charts of T, based on equation (1), may facilitate the calculation when t is not very large, but when t is greater than about 10, the use of T charts is inaccurate.

"Natural-persistence" series.—If N is the number of runs lasting at least 3 days, the series of terms giving the frequency of runs lasting at least 3, 4, 5 . . . . t days is

$$N, NP_4, NP_4P_5, NP_4P_5P_6, \ldots\ldots NP_4P_5 \ldots\ldots P_t,$$

where P_t is the probability that, following $(t-1)$ dry days, the next day will be dry. For each of the 21 stations in the south-west of England for August, the values of P_4 to P_{15} were plotted. A specimen chart (P_4) is shown in Fig. 2. The interpolation of values of P_4 to P_{15} and N to obtain the frequency of runs lasting at least t days ($NP_4P_5 \ldots\ldots P_t$) is illustrated in the Appendix.

P_1 is defined as the ratio of the number of dry days n to the total number of days. For convenience, n was approximated by using the frequencies of runs lasting 1, 2, 3, ... days, after employing the conventions mentioned in the section on data. The values of the probabilities $P_1\, P_2\, P_3 \ldots\ldots P_{15}$ (see Table I) were plotted for each station in south-west England and the results are as shown in Fig. 3. It will be seen that a certain pattern emerges. There appears to be a tendency for graphs to run roughly parallel. Thus it would seem that an approximation to the P's for a station could be based on the mean values of P_D ($D = 4, 5, \ldots\ldots 15$) for the area and the local value of P_1. The corresponding series would be

$$N, N(\bar{P}_4 + x), N(\bar{P}_4 + x)(\bar{P}_5 + x), N(\bar{P}_4 + x)(\bar{P}_5 + x)(\bar{P}_6 + x), \ldots\ldots$$

where $x = P_1 - \bar{P}_1$ ignoring values of P_1 outside the range $\bar{P}_1 \pm 0{\cdot}05$.

This series involves two station constants: N and x. Series were also computed, using only one "station" constant, N with the mean (area) probability values $\bar{P}_4, \ldots\ldots \bar{P}_{15}$, and also using $\bar{N}$ with x the appropriate adjustment to the $\bar{P}$'s. An example of each of these series and of the previous series with both N and x station values is given in the Appendix.

"Jenkinson-probability" series.—For each year, the maximum length of run during August was extracted from observed data. If the longest run partly extended into July or September it was accepted or thrown out according as the greater or lesser part of it occurred during August. If the longest run was exactly shared between two months, then it was assumed that for one year it did occur within August, and that for a second year it did not occur, the maximum spell then being obtained from the remaining runs; all other years, in which the equally divided run did not arise, were then considered as having occurred twice. In this way the values of D_m (the average maximum length of run in days), σ_1 (standard deviation of the length of maximum run) and σ_1/σ_2 (where σ_2 is the value of the standard deviation for two-year maxima, not necessarily for two consecutive years) were computed. The details of the calculations are given in an earlier paper[3]. The computed values of D_m, σ_1 and σ_1/σ_2 are given in Table II. Specimen charts for south-west England in August are shown in Figs. 4–6. Table II shows that for June, which has a greater number of dry days than the remaining summer months, there is also a higher mean maximum length of dry run, a higher standard deviation of maximum length of dry run and a slightly lower value of σ_1/σ_2, the latter corresponding to a slightly higher degree of "mean persistence".

TABLE I—VALUES OF THE ADDITIONAL VARIABLES USED IN "NATURAL-PERSISTENCE" METHOD. AUGUST

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}
Ross-on-Wye	0·52	0·51	0·70	0·81	0·84	0·69	0·77	0·82	0·86	0·83	0·60	0·50	1·00	1·00	1·00
Cheltenham	0·57	0·64	0·65	0·73	0·69	0·82	0·78	0·89	0·81	0·92	0·83	0·80	0·75	0·83	0·60
Bishop's Cannings	0·54	0·56	0·68	0·73	0·67	0·83	0·85	0·76	1·00	0·84	0·95	0·70	1·00	0·71	0·80
Larkhill	0·55	0·56	0·66	0·75	0·82	0·68	0·81	0·89	0·81	0·76	0·89	0·88	0·60	0·78	0·14
Bath	0·56	0·51	0·69	0·78	0·73	0·72	0·95	0·79	0·74	0·91	1·00	0·62	0·77	0·60	0·67
Bridgwater	0·59	0·60	0·67	0·71	0·79	0·81	0·84	0·90	0·63	1·00	1·00	0·75	0·67	0·50	1·00
Yeovil	0·51	0·55	0·70	0·72	0·81	0·72	0·81	0·82	0·57	0·87	0·71	0·80 ,	1·00	0·75	0·67
Holton Heath...	0·61	0·63	0·68	0·72	0·70	0·84	0·71	0·83	0·87	0·69	0·89	0·75	0·83	0·80	0·75
Weymouth	0·61	0·60	0·72	0·74	0·63	0·79	0·71	0·94	0·77	0·83	0·84	0·87	0·86	1·00	0·50
Barnstaple	0·44	0·45	0·61	0·61	0·80	0·80	0·67	0·64	0·86	0·50	1·00	0·67	1·00	...	...
Collompton	0·50	0·47	0·73	0·69	0·76	0·84	0·71	0·93	0·79	0·82	0·78	0·86	0·67	0·75	0·33
Exmouth	0·58	0·58	0·72	0·73	0·76	0·71	0·77	0·88	0·80	0·92	0·86	0·89	0·76	0·54	1·00
Plymouth (Mount Batten) ...	0·53	0·60	0·75	0·72	0·68	0·71	0·80	0·94	0·63	1·00	0·95	0·67	0·67	0·75	1·00
Princetown	0·44	0·52	0·70	0·68	0·76	0·75	0·67	0·87	0·86	0·83	1·00	0·80	0·50	1·00	0·50
Tavistock	0·47	0·46	0·61	0·77	0·60	0·80	0·75	0·83	0·90	0·89	0·81	1·00	0·85	0·82	0·44
Bude	0·48	0·50	0·73	0·64	0·74	0·82	0·73	0·56	1·00	0·87	0·92	0·83	0·80	0·50	1·00
Mere	0·49	0·56	0·73	0·67	0·84	0·66	0·64	0·76	0·84	0·87	0·86	0·83	1·00	0·80	0·50
Falmouth	0·50	0·54	0·68	0·67	0·71	0·67	0·75	0·83	0·90	0·89	0·87	0·86	0·83	0·60	0·67
Newquay	0·46	0·49	0·67	0·65	0·62	0·68	0·84	0·90	0·79	1·00	0·80	0·83	0·60	0·67	1·00
Penzance	0·51	0·54	0·64	0·71	0·62	0·91	0·74	0·93	0·78	0·90	0·95	0·56	0·80	0·25	1·00
St. Austell	0·44	0·51	0·62	0·68	0·69	0·74	0·86	0·92	0·82	0·78	0·86	0·83	0·60	1·00	0·67
Mean	0·52	0·54	0·68	0·71	0·73	0·76	0·77	0·84	0·81	0·85	0·87	0·78	0·79	0·70	0·68
Standard deviation	0·05	0·05	0·04	0·05	0·07	0·07	0·07	0·10	0·10	0·11	0·10	0·12	0·15	0·24	0·29

Assuming that we know the D_m, σ_1 and σ_1/σ_2 for a station, we may draw the curve of the probability function $y\{= -\log_e \log_e (1/p)$ where p is the probability$\}$ and length of spell D using the formula[4]

$$D = D_m + R\sigma_1$$

where R is given in Table III.

TABLE II—VALUES OF THE VARIABLES USED IN "JENKINSON-PROBABILITY" METHOD

	σ_1/σ_2			D_m			σ_1		
	June	July	August	June	July	August	June	July	August
Ross-on-Wye	0·92	1·01	0·92	10·63	8·46	7·73	7·58	4·41	4·61
Cheltenham	1·01	1·13	1·07	12·33	9·17	8·31	7·59	5·99	4·43
Bishop's Cannings ...	0·97	1·05	0·91	9·77	7·77	9·19	6·09	4·19	6·63
Larkhill...	0·99	0·99	1·04	10·79	7·63	7·69	6·53	4·68	4·40
Bath	1·02	1·08	0·93	11·35	8·08	8·35	6·61	3·83	5·43
Bridgwater	0·95	0·99	1·05	13·00	7·02	8·73	7·79	4·21	4·71
Yeovil	1·07	1·05	0·97	11·94	7·94	7·79	5·72	4·47	4·48
Holton Heath	0·99	1·00	0·88	12·83	8·21	8·92	7·36	4·55	5·88
Weymouth	0·98	1·01	0·90	13·11	8·87	8·69	7·90	4·86	5·69
Barnstaple	0·89	1·02	1·00	10·02	7·06	5·81	7·21	4·14	3·16
Cullompton	1·03	1·03	1·04	10·89	7·89	7·50	5·86	4·67	4·43
Exmouth	0·97	0·95	0·94	10·92	8·67	8·85	5·85	5·13	5·83
Plymouth	0·99	1·04	0·98	12·27	7·15	8·04	8·15	4·02	4·47
Princetown	0·92	1·12	0·96	7·31	5·78	6·61	4·76	3·17	3·49
Tavistock	0·90	0·97	0·96	8·85	6·83	6·96	6·36	4·72	4·57
Bude	0·91	0·95	1·01	9·33	7·11	7·25	5·63	4·89	5·32
Mere	0·98	1·02	0·96	11·92	7·52	7·52	7·32	4·45	4·42
Falmouth	0·92	1·01	0·97	10·27	7·83	7·27	6·71	4·80	4·27
Newquay	0·88	0·91	0·91	8·87	5·92	6·27	6·39	4·47	3·93
Penzance	0·91	0·94	1·00	9·77	6·40	7·42	6·49	4·91	3·93
St. Austell	0·91	0·95	0·91	9·60	6·52	6·61	6·77	4·83	4·19
Mean...	0·96	1·01	0·97	10·75	7·52	7·69	6·70	4·54	4·68

TABLE III—VALUES OF R FOR COMPUTING EXTREME VALUES OF D LIKELY TO BE REACHED ONCE IN t YEARS

σ_1/σ_2 \ t	...	...	1·58	5	10	25	50	100	250
y	−2	−1	0	1·50	2·25	3·20	3·90	4·61	5·52
0·80	−0·95	−0·72	−0·39	0·34	0·86	1·73	2·57	3·61	5·39
0·85	−1·24	−0·89	−0·44	0·48	1·05	1·95	2·76	3·72	5·22
0·90	−1·50	−1·02	−0·45	0·58	1·18	2·06	2·78	3·60	4·79
0·95	−1·76	−1·13	−0·46	0·66	1·26	2·07	2·71	3·38	4·31
1·00	−2·01	−1·23	−0·45	0·72	1·31	2·04	2·59	3·14	3·85
1·05	−2·26	−1·32	−0·44	0·75	1·34	2·00	2·47	2·91	3·45
1·10	−2·49	−1·38	−0·42	0·77	1·34	1·93	2·32	2·67	3·09
1·15	−2·73	−1·44	−0·39	0·79	1·34	1·85	2·19	2·47	2·78
1·20	−2·97	−1·50	−0·36	0·81	1·33	1·79	2·08	2·30	2·52

The mean annual frequency[4] of runs of length D or more days (F_D) is given by

$$F_D \simeq e^{-y}$$

for values of D of the order of the maximum length of run. The value of y for values of $D = 3, 4, 5, \ldots 15$ was read from the curve, and the calculated frequencies thus obtained. The interpolation of values of D_m, σ_1 and σ_1/σ_2 from charts and the calculation of the frequency series is illustrated in the Appendix.

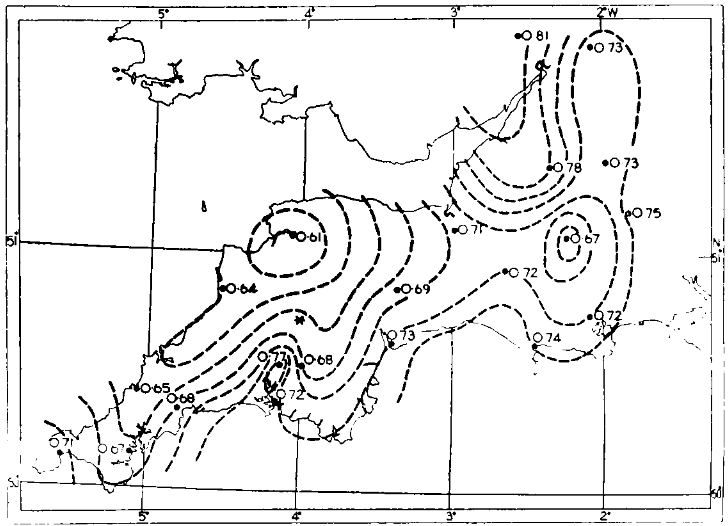

FIG. 2—VALUES OF P_4 IN AUGUST

The position of Okehampton is shown by a star.

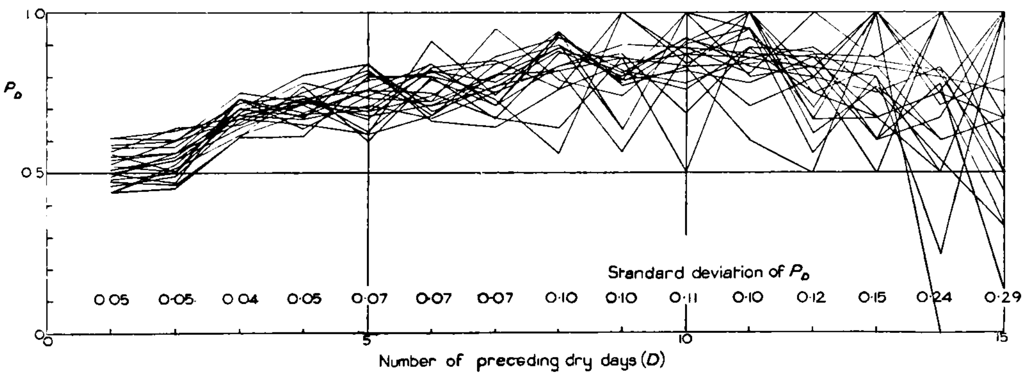

FIG. 3—VALUES OF P_D IN SOUTH-WEST ENGLAND IN AUGUST

P_1 = Proportion of dry days.

$$P_D = \frac{\text{number of spells of at least } D \text{ days}}{\text{number of spells of at least } (D-1) \text{ days.}}$$

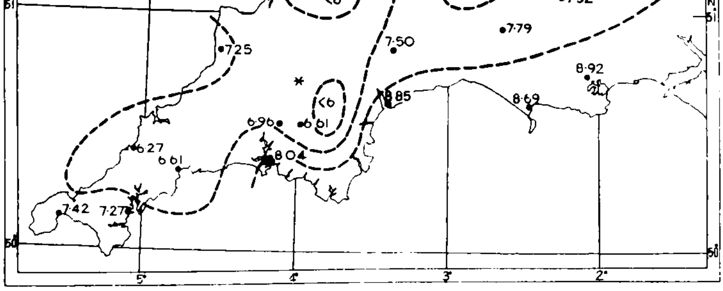

FIG. 4—MEAN LENGTH OF MAXIMUM SPELL OF DRY DAYS IN AUGUST (D_m)

The position of Okehampton is shown by a star.

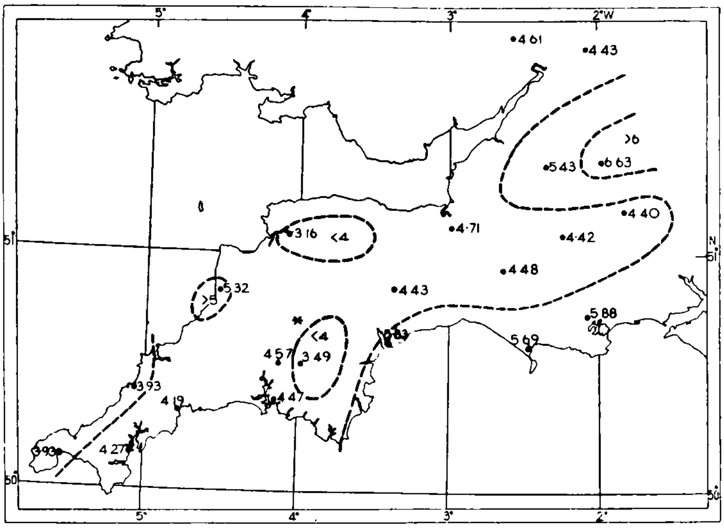

FIG. 5—STANDARD DEVIATION OF LENGTH OF MAXIMUM SPELL OF DRY DAYS IN AUGUST (σ_1)

The position of Okehampton is shown by a star.

TABLE IV—COMPARISON OF THE GEOMETRIC AND LOGARITHMIC SERIES

21 stations in south-west England, August, 1921–46

Length of run	Mean percentage error							
	Geometric series				Logarithmic series			
	N, P	$N, \bar{P}$	$\bar{N}, P$	$\bar{N}, \bar{P}$	a, r	$a, \bar{r}$	$\bar{a}, r$	$\bar{a}, \bar{r}$
days	*per cent.*				*per cent.*			
4	14	13	16	17	9	21	11	16
6	13	14	14	19	10	20	15	18
8	10	17	10	19	14	24	17	21
10	27	33	26	34	24	35	24	33

TABLE V—COMPARISON OF THE FOUR SERIES

21 stations in south-west England, August 1921–46

	Parameters		Cumulative series, mean error		
	Variable	Constant	3–10	3–15	6–15
			percentage frequency		
Geometric	N, P	...	8	11	17
Logarithmic	a, r	...	8	11	16
"Natural-persistence" ...	$N, (\bar{P}_4 + x)$ etc.	...	9	13	24
	N	$\bar{P}_D$ (D=4. . .15)	7	9	16
	$(\bar{P}_4 + x)$ etc.	$\bar{N}$	10	13	17
"Jenkinson-probability"	$\sigma_1/\sigma_2, D_m, \sigma_1$	...	17	19	20
	D_m, σ_1	$\sigma_1/\sigma_2 = 1$	19	20	22
	D_m	$\sigma_1/\sigma_2 = 1, \bar{\sigma}_1$	18	19	20
	σ_1	$\sigma_1/\sigma_2 = 1, \bar{D}_m$	28	28	25

Table IV confirms the superiority of the logarithmic series (when actual values of a and r are used) over the geometric series. Mean values for N and a

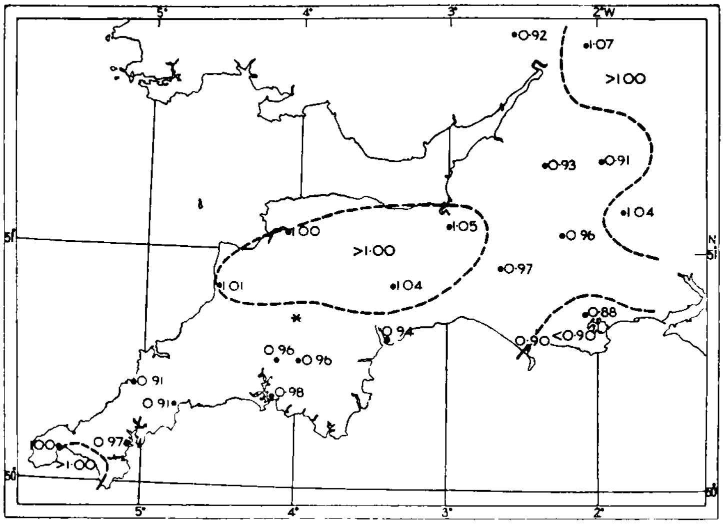

FIG. 6—RATIO OF STANDARD DEVIATIONS OF 1 YR. AND 2 YR. MAXIMUM LENGTHS OF SPELL OF DRY DAYS IN AUGUST (σ_1/σ_2)

The position of Okehampton is shown by a star.

appear to give useful approximations but, as might have been expected, mean values for P or r give errors which generally increase with length of run. However, in practice, good approximations may be obtained by reading P or r to 2 places of decimals with N or a to the nearest integer (see Appendix).

A good degree of agreement (see Table V) appears to be given by the "natural-persistence" series with area values for the probabilities, even though the latter are averaged for the whole of south-west England. When the area is more restricted an even better degree of agreement might be expected.

The approximate mean value of σ_1/σ_2 is unity, and if we assume that for a particular site $\sigma_1/\sigma_2 = 1$, we may calculate its series from the values of D_m and σ_1 (see example in Appendix, p. 269). Further approximate series may be obtained using $\sigma_1/\sigma_2 = 1$, a mean (area) value for D_m and σ_1, or alternatively using $\sigma_1/\sigma_2 = 1$, a mean (area) value $\bar{\sigma}_1$ and the local value of D_m. Examples are given in the Appendix.

It should be noted that when $\sigma_1/\sigma_2 = 1$, the y, D curve is a straight line of which the slope is $1/(0{\cdot}78\sigma_1)$, and the frequency series becomes a geometric series, i.e. there is zero persistence. The common ratio P of this series is given by

$$P = F_{D+1}/F_D = \exp(y_D)/\exp(y_{D+1})$$

$$= \frac{\exp[D/0{\cdot}78\sigma_1 + k]}{\exp[(D+1)/0{\cdot}78\sigma_1 + k]}, \text{ where } k \text{ is a station constant,}$$

$$= \exp(-1/0{\cdot}78\sigma_1)\,.$$

Comparison of the series.—The geometric and logarithmic series have been compared in an earlier paper[1]. A further comparison is given in Table IV. As a means of comparing the degree of agreement of the series with actual observations, the values of the mean percentage error,

$$\frac{\text{sum of observed minus calculated frequencies}}{\text{sum of observed cumulative frequencies}} \times 100,$$

were calculated for various stations for the ranges of lengths of run given in Table V.

TABLE VII—VALUES OF THE VARIABLES USED IN GEOMETRIC AND LOGARITHMIC METHODS

South-west England

	May				June				July				August				September			
	N	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*
Ross-on-Wye ...	53·0	0·74	22·7	0·86	54·0	0·81	16·1	0·91	49·0	0·78	22·3	0·86	47·0	0·79	22·0	0·86	45·0	0·77	21·3	0·86
Cheltenham ...	53·0	0·76	22·5	0·86	56·0	0·83	14·8	0·93	45·5	0·81	21·7	0·87	55·5	0·77	22·4	0·87	53·0	0·75	21·9	0·86
Bishop's Cannings ...	63·0	0·74	21·2	0·88	56·0	0·80	18·6	0·90	49·0	0·75	22·3	0·86	48·0	0·80	20·0	0·88	52·0	0·73	23·5	0·85
Larkhill ...	58·5	0·76	21·7	0·87	55·5	0·81	16·5	0·91	47·5	0·76	24·3	0·85	51·5	0·77	23·3	0·86	47·0	0·75	23·8	0·85
Bath ...	57·0	0·73	23·5	0·86	52·0	0·83	15·9	0·92	46·5	0·77	24·0	0·85	50·0	0·79	23·6	0·86	49·5	0·77	22·1	0·86
Bridgwater ...	57·5	0·79	18·8	0·90	48·0	0·86	15·3	0·93	49·5	0·74	24·5	0·84	55·0	0·78	21·8	0·88	49·0	0·78	21·5	0·87
Yeovil ...	53·0	0·73	20·5	0·87	50·0	0·84	14·1	0·92	43·0	0·78	20·3	0·86	50·0	0·76	22·5	0·86	44·0	0·74	22·3	0·84
Holton Heath ...	55·0	0·77	20·2	0·88	56·5	0·84	14·7	0·93	47·0	0·78	21·3	0·87	60·5	0·77	22·8	0·88	49·0	0·78	22·0	0·86
Weymouth ...	53·0	0·78	20·8	0·88	58·5	0·84	14·4	0·93	53·5	0·78	21·0	0·88	61·5	0·76	23·7	0·87	52·5	0·76	25·2	0·85
Barnstaple ...	59·0	0·71	23·0	0·86	48·5	0·83	17·6	0·90	42·0	0·74	23·3	0·83	41·5	0·70	28·8	0·79	38·0	0·75	24·4	0·82
Cullompton ...	55·5	0·75	21·4	0·87	47·5	0·85	14·9	0·92	46·0	0·77	20·2	0·86	48·0	0·76	24·9	0·84	43·0	0·76	21·9	0·85
Exmouth ...	54·5	0·78	19·7	0·89	57·5	0·82	17·2	0·91	52·5	0·77	19·3	0·88	56·0	0·78	21·6	0·88	49·5	0·78	19·9	0·88
Plymouth ...	57·5	0·78	21·1	0·89	49·0	0·83	17·4	0·91	42·0	0·80	20·8	0·86	57·0	0·75	20·0	0·87	50·5	0·73	21·8	0·85
Princetown ...	53·4	0·76	19·7	0·88	44·1	0·77	20·2	0·86	42·6	0·70	18·6	0·84	44·8	0·74	20·9	0·85	34·7	0·71	17·7	0·83
Tavistock ...	58·0	0·74	20·9	0·87	47·5	0·79	19·7	0·88	44·5	0·75	21·0	0·85	39·0	0·78	25·4	0·82	45·0	0·75	20·1	0·86
Bude ...	58·0	0·75	22·2	0·87	56·0	0·80	17·9	0·90	42·5	0·74	25·2	0·82	47·5	0·75	23·5	0·84	41·0	0·78	22·4	0·85
Mere ...	55·0	0·76	19·2	0·88	52·5	0·84	14·1	0·93	48·0	0·76	21·8	0·86	52·0	0·74	21·7	0·86	39·0	0·79	17·7	0·83
Falmouth ...	56·0	0·75	21·0	0·87	49·5	0·82	19·9	0·89	47·0	0·78	22·5	0·86	51·0	0·75	19·6	0·87	46·5	0·79	22·1	0·86
Newquay ...	52·0	0·73	23·6	0·85	51·0	0·79	19·9	0·89	35·5	0·73	26·1	0·80	46·0	0·72	25·1	0·82	39·0	0·77	22·0	0·84
Penzance ...	62·5	0·73	19·0	0·89	49·0	0·81	19·8	0·89	38·0	0·74	26·8	0·80	48·5	0·75	25·1	0·84	42·0	0·78	21·4	0·85
St. Austell ...	57·0	0·75	19·9	0·88	49·5	0·81	19·2	0·89	34·5	0·77	24·3	0·81	40·5	0·75	23·1	0·83	39·5	0·79	21·9	0·85
Mean ...	56·3	0·75	21·1	0·87	51·8	0·82	17·1	0·91	45·0	0·76	22·5	0·85	50·0	0·76	22·9	0·85	45·2	0·76	21·8	0·85

TABLE VIII—VALUES OF THE VARIABLES USED IN GEOMETRIC AND LOGARITHMIC METHODS

South-east England

	April				May				June				July				August				September			
	N	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*
Adderbury ...	47·0	0·77	22·7	0·86	56·5	0·77	18·3	0·89	54·5	0·83	14·5	0·93	50·0	0·77	21·5	0·87	53·5	0·80	20·0	0·89	56·5	0·75	22·2	0·87
Oxford ...	46·0	0·77	21·0	0·86	52·5	0·77	21·3	0·87	57·5	0·82	15·4	0·92	49·0	0·74	24·9	0·84	58·0	0·79	20·6	0·89	54·0	0·74	22·0	0·86
Lechlade ...	53·5	0·77	19·5	0·89	57·0	0·71	21·0	0·86	54·5	0·83	14·9	0·92	46·5	0·76	23·4	0·85	54·0	0·82	19·7	0·90	51·5	0·75	20·4	0·87
Oving House ...	50·5	0·78	18·1	0·89	53·0	0·77	21·0	0·87	55·5	0·82	16·9	0·91	53·0	0·74	23·1	0·86	52·0	0·80	21·2	0·88	48·0	0·77	25·0	0·25
Penn	49·0	0·80	18·8	0·89	58·0	0·80	16·6	0·91	53·0	0·84	15·3	0·92	53·5	0·77	22·8	0·87	54·5	0·77	23·1	0·87	57·0	0·74	23·3	0·86
Slough ...	55·5	0·77	18·4	0·89	56·5	0·79	16·3	0·91	52·0	0·83	16·1	0·92	55·5	0·75	21·0	0·87	59·5	0·76	20·4	0·89	45·0	0·81	20·9	0·87
Harrow ...	52·5	0·79	18·9	0·89	59·0	0·78	18·7	0·89	56·5	0·83	14·9	0·92	55·5	0·75	22·4	0·87	58·0	0·78	22·6	0·88	47·5	0·79	24·5	0 86
Potters Bar ...	55·5	0·76	18·9	0·89	60·5	0·77	19·8	0·89	53·5	0·83	16·7	0·91	52·0	0·77	21·6	0·87	53·5	0·80	20·6	0·89	50·0	0·77	23·6	0·86
Reading ...	52·5	0·77	19·9	0·88	61·5	0·76	20·0	0·89	58·0	0·81	16·2	0·92	57·5	0·74	23·8	0·86	58·5	0·79	21·1	0·89	50·0	0·77	23·3	0·86
Upton ...	45·0	0·80	19·6	0·88	55·0	0·77	20·1	0·88	59·0	0·81	15·0	0·92	54·0	0·76	22·5	0·87	44·0	0·82	21·5	0·87	57·0	0·75	22·4	0·87
Godalming ...	45·0	0·78	21·8	0·86	61·0	0·76	20·9	0·89	56·0	0·82	14·9	0·92	57·5	0·74	23·6	0·86	56·5	0·75	22·4	0·87	50·0	0·77	24·1	0·86
Kew	49·5	0·78	19·9	0·88	55·0	0·78	20·9	0·88	56·5	0·83	15·0	0·92	56·5	0·74	23·4	0·86	55·5	0·78	20·8	0·89	50·0	0·76	25·3	0·85
Reigate ...	50·0	0·78	19·9	0·88	60·0	0·78	18·7	0·90	55·5	0·83	15·6	0·92	58·5	0·77	22·4	0·87	54·0	0·78	22·4	0·87	52·0	0·77	23·9	0·86
Canterbury ...	60·0	0·76	21·1	0·88	57·5	0·79	20·1	0·89	60·5	0·80	18·8	0·91	60·0	0·78	21·8	0·89	57·5	0·79	20·5	0·89	50·5	0·78	23·4	0·86
Folkestone ...	51·0	0·77	21·9	0·87	52·5	0·81	19·3	0·89	60·5	0·80	17·4	0·91	56·5	0·75	21·4	0·87	57·5	0·79	20·8	0·89	52·0	0·76	24·1	0·86
Goudhurst ...	55·5	0·77	20·8	0·88	65·5	0·78	18·6	0·91	61·0	0·80	18·5	0·91	65·0	0·77	18·5	0·90	58·0	0·78	22·6	0·88	57·0	0·77	23·9	0·87
Sevenoaks ...	49·0	0·80	18·8	0·89	62·5	0·78	21·0	0·89	56·0	0·83	15·6	0·92	61·5	0·76	20·3	0·89	55·5	0·77	24·0	0·87	51·5	0·77	26·4	0·85
Andover ...	59·0	0·78	18·9	0·89	61·0	0·78	20·3	0·89	50·0	0·86	14·1	0·93	59·5	0·73	23·2	0·86	55·5	0·79	21·3	0·89	52·0	0·78	21·9	0·87
Fordingbridge	49·0	0·79	21·0	0·87	56·5	0·78	18·3	0·89	52·5	0·84	15·1	0·92	42·5	0·81	21·8	0·87	54·0	0·79	22·6	0·87	41·5	0·79	24·1	0·85
Heckfield ...	52·0	0·79	18·7	0·89	56·5	0·78	17·2	0·90	64·0	0·79	15·1	0·92	54·0	0·78	19·9	0·89	56·5	0·80	20·4	0·89	48·0	0·78	19·3	0·88
Selborne ...	46·0	0·78	19·5	0·87	53·0	0·80	19·3	0·89	56·0	0·81	15·1	0·92	50·5	0·73	24·5	0·84	56·5	0·75	21·8	0·87	50·0	0·76	21·0	0·87
Totland Bay ...	55·0	0·78	21·4	0·88	54·5	0·79	18·9	0·89	55·5	0·85	15·8	0·93	60·0	0·75	22·6	0·87	65·0	0·76	23·5	0·88	51·0	0·78	22·2	0·87
Compton ...	51·5	0·78	20·9	0·87	61·0	0·76	19·5	0·89	56·5	0·84	14·0	0·93	57·0	0·75	22·8	0·87	53·0	0·78	22·0	0·87	53·0	0·77	21·5	0·87
Eastbourne ...	48·0	0·77	24·6	0·85	59·0	0·76	20·2	0·89	61·0	0·79	18·3	0·91	48·5	0·79	23·7	0·86	56·0	0·72	25·4	0·85	46·5	0·77	24·6	0·85
Horsham ...	48·0	0·79	19·8	0·88	58·5	0·76	19·9	0·89	59·5	0·83	15·6	0·92	53·5	0·76	19·4	0·88	54·5	0·79	19·9	0·89	48·0	0·78	23·6	0·86
Worthing ...	57·0	0·78	20·6	0·89	61·0	0·80	18·5	0·91	63·0	0·82	16·1	0·92	58·0	0·78	21·1	0·89	57·0	0·80	21·6	0·89	52·0	0·79	22·1	0·87
Mean	51·3	0·78	20·2	0·88	57·9	0·78	19·4	0·89	56·8	0·82	15·8	0·92	54·8	0·76	22·2	0·87	55·7	0·78	21·6	0·88	50·8	0·77	23·0	0·86

TABLE IX—VALUES OF THE VARIABLES USED IN GEOMETRIC AND LOGARITHMIC METHODS

East England

	April				May				June				July				August				September			
	N	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*	*N*	*P*	*a*	*r*
Guthram ...	53·0	0·78	21·5	0·87	61·0	0·77	22·5	0·88	58·5	0·80	16·5	0·91	61·5	0·79	20·6	0·89	65·0	0·71	26·3	0·86	58·0	0·73	27·7	0·85
Boston	53·0	0·76	22·8	0·86	52·0	0·81	20·5	0·89	60·0	0·79	18·0	0·90	64·0	0·77	21·1	0·89	57·0	0·79	20·1	0·89	60·0	0·72	25·0	0·86
Horncastle ...	56·5	0·69	22·6	0·85	51·0	0·78	23·9	0·86	58·5	0·79	19·3	0·89	56·5	0·75	20·4	0·88	59·5	0·71	25·3	0·85	53·0	0·73	24·6	0·85
St. Ives ...	53·0	0·77	21·5	0·87	69·5	0·75	21·4	0·89	61·5	0·78	17·9	0·90	64·0	0·75	23·7	0·87	58·0	0·78	22·6	0·88	56·0	0·76	24·5	0·86
Peterborough ...	50·5	0·77	21·5	0·87	59·0	0·77	20·9	0·89	55·0	0·80	17·3	0·91	64·0	0·75	20·9	0·89	64·5	0·69	27·5	0·84	59·0	0·74	22·7	0·87
Cambridge ...	54·0	0·76	19·4	0·89	68·5	0·76	21·2	0·89	61·5	0·80	13·5	0·93	51·5	0·79	21·1	0·88	55·0	0·79	22·5	0·88	56·5	0·77	22·5	0·87
Stretham ...	62·0	0·78	20·9	0·89	70·5	0·76	20·1	0·90	60·5	0·81	15·8	0·92	56·5	0·81	20·5	0·89	61·0	0·79	24·3	0·88	59·5	0·77	21·7	0·89
Wisbech ...	55·5	0·74	24·3	0·86	61·5	0·76	21·1	0·89	60·5	0·80	18·0	0·91	55·5	0·75	23·2	0·86	62·0	0·73	24·0	0·87	56·0	0·73	26·1	0·85
Thetford ...	47·5	0·76	23·7	0·85	58·5	0·73	20·8	0·87	57·5	0·79	16·3	0·91	56·0	0·75	23·2	0·86	53·5	0·73	24·8	0·85	44·0	0·74	26·2	0·82
Hunstanton ...	62·0	0·72	23·2	0·86	53·0	0·77	22·2	0·87	59·5	0·79	18·8	0·90	58·5	0·77	23·2	0·87	61·5	0·75	21·9	0·88	57·5	0·75	23·0	0·87
Wiggenhall ...	61·0	0·74	21·8	0·87	61·0	0·77	21·6	0·89	59·5	0·80	17·4	0·91	59·5	0·76	22·2	0·87	63·5	0·74	24·1	0·87	60·5	0·73	24·2	0·86
Sprowston ...	51·5	0·74	19·8	0·87	62·0	0·75	17·2	0·90	57·5	0·79	17·5	0·90	60·5	0·76	21·5	0·88	58·0	0·75	23·7	0·86	48·5	0·71	24·3	0·83
Cromer ...	57·5	0·69	25·6	0·84	56·5	0·73	21·8	0·87	63·0	0·77	17·1	0·91	58·0	0·72	22·6	0·86	52·0	0·72	24·8	0·84	45·0	0·73	24·4	0·83
Lowestoft ...	50·5	0·74	23·5	0·85	60·0	0·79	18·0	0·91	54·5	0·81	18·0	0·90	52·5	0·79	22·7	0·87	62·5	0·74	21·9	0·87	58·0	0·73	21·9	0·87
Bury St. Edmunds	56·5	0·75	20·7	0·87	65·0	0·76	20·4	0·89	57·5	0·80	13·8	0·92	49·5	0·80	18·8	0·89	63·0	0·76	24·3	0·87	50·5	0·75	24·5	0·85
Campsea Ash ...	63·0	0·74	23·3	0·87	57·5	0·79	18·7	0·90	61·5	0·82	16·3	0·92	54·0	0·80	21·6	0·89	66·0	0·77	22·9	0·89	57·0	0·75	24·6	0·86
Hadleigh ...	49·0	0·77	21·0	0·87	61·0	0·78	18·6	0·90	55·5	0·81	18·2	0·90	57·5	0·77	21·5	0·88	65·0	0·73	23·2	0·87	48·0	0·75	26·8	0·83
Woburn ...	42·0	0·79	21·8	0·86	59·0	0·70	22·3	0·86	54·0	0·79	17·7	0·90	52·0	0·74	23·2	0·86	49·5	0·76	21·7	0·86	50·5	0·72	26·6	0·83
Bedford ...	49·5	0·80	19·5	0·89	65·0	0·74	21·8	0·88	55·0	0·82	16·7	0·91	61·0	0·76	21·6	0·88	58·0	0·76	22·6	0·87	52·5	0·77	22·6	0·87
Rothamsted ...	47·0	0·80	20·6	0·87	54·0	0·75	22·2	0·86	55·0	0·82	16·8	0·91	47·0	0·76	25·7	0·84	56·0	0·77	23·9	0·87	43·0	0·76	27·3	0·82
Therfield ...	50·0	0·77	21·6	0·87	60·0	0·73	23·1	0·86	55·5	0·81	16·6	0·91	56·5	0·74	26·3	0·85	58·0	0·74	24·6	0·86	52·0	0·75	24·0	0·86
Bradwell-on-Sea	56·0	0·80	21·8	0·89	69·5	0·79	17·7	0·92	62·0	0·82	16·5	0·92	65·5	0·79	20·2	0·90	69·0	0·79	21·0	0·90	59·0	0·78	21·5	0·89
Ingatestone ...	48·0	0·80	18·7	0·89	57·5	0·76	22·1	0·87	60·5	0·80	18·2	0·91	61·0	0·76	21·7	0·88	62·0	0·75	25·5	0·86	54·0	0·72	27·7	0·83
Halstead ...	54·0	0·78	21·1	0·88	60·0	0·78	19·7	0·89	58·0	0·83	17·9	0·91	60·0	0·79	18·3	0·90	63·0	0·78	22·1	0·89	56·0	0·76	25·5	0·86
Hatfield Broad Oak	50·0	0·77	19·7	0·87	63·5	0·78	18·4	0·90	55·5	0·83	15·6	0·92	52·5	0·78	21·9	0·87	57·0	0·78	21·0	0·89	52·5	0·73	24·7	0·85
Mean	53·3	0·76	21·7	0·87	60·6	0·76	20·7	0·89	58·3	0·80	17·0	0·91	57·4	0·77	21·9	0·88	60·0	0·75	23·5	0·87	53·9	0·74	24·6	0·85

APPENDIX

To calculate the frequencies of runs of dry days at Okehampton in August.

Geometric-series method.—Interpolating from charts based on the actual values of N and P observed at other stations, a selection of which is given in Table VII, N is 42 and P 0·74 for Okehampton. Using these values, the cumulative frequencies are calculated from N, NP, NP^2, NP^3, ... The results are shown in Table VI.

TABLE VI—OKEHAMPTON: OBSERVED AND CALCULATED DRY-RUN FREQUENCIES

	Chart parameters	No. of runs during the period 1921–46 with lengths (in days) ≥3	≥4	≥5	≥6	≥7	≥8	≥9	≥10	≥11	≥12	≥13	≥14	≥15
Observed ...	...	41	29	21	17	11	9	7	6	6	3	2	2	1
Geometric ...	N, P	42	31·1	23·0	17·0	12·6	9·3	6·9	5·1	3·8	2·8	2·1	1·5	1·1
Logarithmic ...	a, r	42·5	28·5	19·9	14·3	10·4	7·7	5·8	4·4	3·3	2·5	1·9	1·5	1·2
"Natural persistence"	$N, P_4 \dots P_{15}$	42	28·1	20·3	16·8	11·3	8·8	8·0	6·9	6·3	5·1	4·3	3·4	1·4
"Jenkinson probability"	σ_1/σ_2, D_m, σ_1	48·3	35·8	26·3	19·3	14·1	10·4	7·6	5·6	4·1	3·0	2·2	1·7	1·2

Logarithmic-series method.—Interpolating from charts drawn from actual values at other stations (see Table VII), a is 24 and r is 0·82 for Okehampton. Using these values the non-cumulative series is calculated from $a, \frac{ar}{2}, \frac{ar^2}{3}, \frac{ar^3}{4}, \frac{ar^4}{5}$, etc., and the cumulative series is

$$\frac{a}{r}\log_e\left(\frac{1}{1-r}\right) - a, \quad \frac{a}{r}\log_e\left(\frac{1}{1-r}\right) - a - \frac{ar}{2}, \quad \frac{a}{r}\log_e\left(\frac{1}{1-r}\right) - a - \frac{ar}{2} - \frac{ar^2}{3}, \text{ etc.}$$

The results are shown in Table VI.

"Natural-persistence" method.—Interpolating as before from values in Table I N is 42 and $P_4 \dots P_{15}$ are 0·67, 0·72, 0·83, 0·67, 0·78, 0·91, 0·86, 0·92, 0·80, 0·84, 0·80, 0·40 respectively. The series is N, NP_4, NP_4P_5, $NP_4P_5P_6$, etc. The results are shown in Table VI.

"Jenkinson-probability" method.—Interpolating from stations in the region (Figs. 4–6) $\sigma_1/\sigma_2 = 0·99$, $D_m = 6·9$ and $\sigma_1 = 4·2$. Values of D are calculated from the formula

$$D = 6·9 + 4·2\,R,$$

where R is obtained from Table III (for $\sigma_1/\sigma_2 = 0·99$ and $y = -2, -1, 0, 1·50, 2·25, 3·20, 3·90$). The curve of y against D is plotted, and values of y corresponding to $D = 3, 4, 5, 6 \dots 15$ are read off from this graph. The values of e^{-y} are then obtained from standard tables and, after multiplying by 26 (the number of years in the period), are shown in Table VI.

To be concluded

A TEST OF SYNOPTIC CHARTS FOR THE SOUTHERN OCEAN

By U. RADOK, Ph.D., B.Eng.

The construction of synoptic charts for the Southern Ocean presents problems without parallel in meteorological practice. In no other region must so many conclusions be drawn from so few observations. Except for the whaling grounds in summer the analysis has to rest on single-station techniques and models for the behaviour of pressure systems established from subsequent events on similar previous occasions. Yet just as the available observations define the present state only imperfectly they often leave considerable doubt about subsequent events, and it seems clear that only a limited check on a synoptic analysis for the region is provided by the time series of the data used in its construction.

A much more stringent test can be made by means of ships' observations which were either not reported or else not available to the analyst at the time. Quite a few such sets of observations must be in existence, and their systematic examination in conjunction with Southern Ocean charts for the same period would be instructive. To exemplify this, the present note deals with a short series of observations made by the writer in the course of a summer journey on board the M.V. *Tottan* from Hobart to the Antarctic continent and back, at a time when there was no other ship anywhere in the region and the only reports received were those from Macquarie Island and Campbell Island, further east, and from Heard Island, much further west.

Two different series of Southern Ocean charts for the period of the journey were available for examination. They will be distinguished by the letters A and B in the following, and differed from one another in several respects. A small number of the ship's observations were used in analysis A, whereas analysis B was made without any knowledge of them. However, while analysis A was left in its initial form the charts of set B were re-drawn later with subsequent events as a guide. A comparison of these two analyses, with the observations at a moving point, will thus show not only whether the charts are realistic, but will also have a bearing on the relative merits of careful re-analysis as against just one more isolated station.

Method of comparison.—An exhaustive comparison of synoptic analyses represents a major task much beyond the scope of this note. Instead, the comparisons here will be exclusively in terms of surface pressures, those observed by the ship on the one hand and those given by the two chart series for the location of the ship on the other. The ship's observations were made every three hours during the day, with larger gaps at night, whereas the charts were drawn once a day, at 0600 G.M.T., only. To enlarge the comparisons, use was made of continuity. Each chart series was transformed into a diagram showing isobars for the ship's latitude in a time-longitude coordinate system. Fig. 1 shows the diagrams constructed from seven charts from series A and B covering part of the return journey. This representation gives a clear idea of the motion of pressure systems provided this is largely zonal. The ship's track has been indicated and the pressures expected from the analysis can be found by interpolating between the points of intersection of the track with the isobars. Naturally the new sets of isobars involve some additional smoothing, so that exact agreement between the observed and the chart pressures is ruled out. However the pattern of changes in the two pressure series would certainly be similar if the analysis were realistic.

Such comparisons between the observed pressures and those given by the two chart series are shown in Fig. 2 for two 7-day periods. The second of these is that illustrated in Fig. 1. The ship during the first part of this period was heading north but later was forced by the seas from a 60-kt. gale to turn west. Thus the total latitude change amounted to less than 10° during this period. On the other hand during the first 7-day period the ship travelled south through some 20° of latitude; the time-longitude isobars have not been reproduced for this period because they permit of no simple interpretation, even though they still serve for their immediate purpose here. The dots in Fig. 2 give the observed pressures. Some of these have been joined to the full curve of the series-A pressures to indicate that the observation in question was used in drawing the chart for that day at 0600 G.M.T.

Discussion.—The curves in Fig. 2 largely speak for themselves, but a few comments may be made. In the first period the agreement between the observed pressures and those given by the charts of series A is very good, even

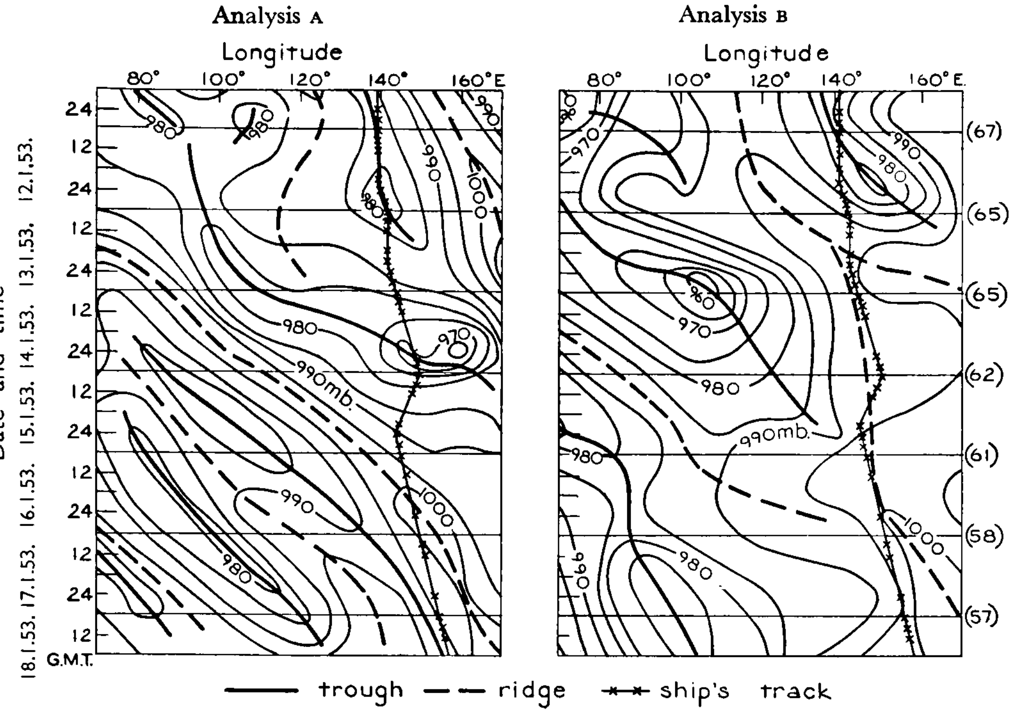

FIG. I—DIAGRAM ON A TIME-LONGITUDE-COORDINATE SYSTEM SHOWING ISOBARS FOR THE SHIP'S LATITUDE

Figures in brackets represent the ship's latitude at 0600 G.M.T. in °S.

though only every second chart included the ship's observation. The correct placing of the pressure rise on December 29 should be noted. The charts of series B show similar features but the pressures were underestimated throughout; also the Antarctic trough was placed into too low a latitude i.e. at too early a date. At the end of the period a break occurred in the weather messages while the ship was engaged in landing operations; as might be expected both chart series seem to have got out of step with events at that stage.

More striking differences between the two analyses occurred during the second period, illustrated in Fig. 1. As series A started with four successive charts including the ship's observations it was possible to appraise correctly the essential details of the intense depression which appears to have deepened right on the ship's track. Series B also showed this depression but allowed it to fill prematurely. This emerged from the individual charts; the representation in Fig. 1 permits no distinction between a filling depression and one that moves away from the ship's latitude. On the other hand the renewed pressure fall on January 17 was contained in analysis B but not in A which by then had been placed on the same footing, with the ship's radio out of action after the rough weather of the preceding two days.

The foregoing comparisons could also have been made in terms of observed and expected weather; but the pressure discussion will suffice to illustrate the enormous value of a single additional station and the magnitude of errors that can creep into the most careful analysis for the Southern Ocean in regions without at least an occasional observation. It may be hoped that the behaviour of the Southern depressions will become much better understood in

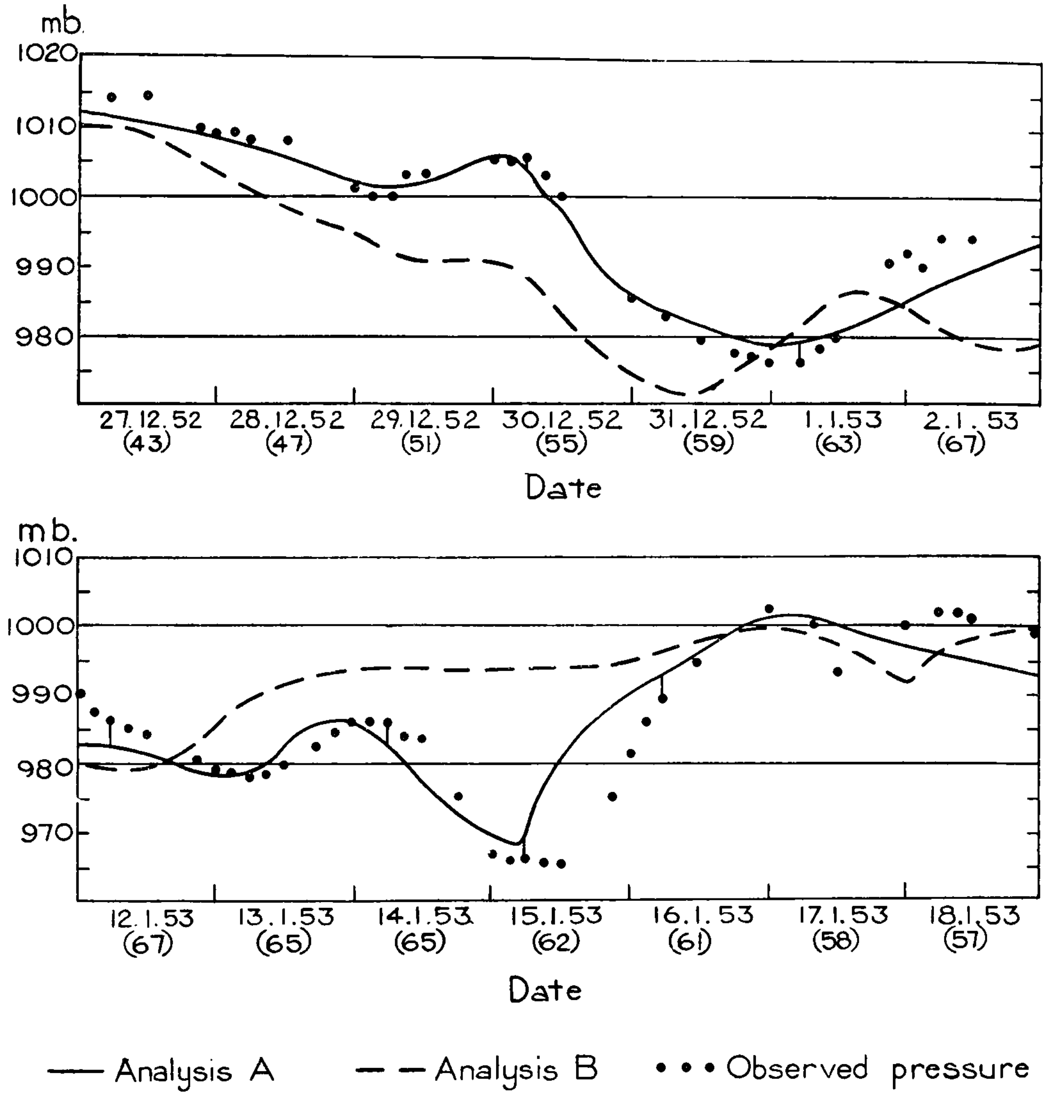

FIG. 2—OBSERVED AND CHART PRESSURES FROM ANALYSES A AND B FOR THE SHIP'S POSITION

Figures in brackets represent the ship's latitude at 0600 G.M.T. in °S.
Where the dot is joined to the full curve the chart of analysis A was drawn with knowledge of the ship's observation.

the course of the International Geophysical Year; already reports from some of the preliminary bases have given the clues to events in the Australia–New Zealand sector which would have remained puzzles with the network in existence a few months earlier. However, even greater assistance for the analysis of the Southern Ocean will result from one or other of the Antarctic stations that may be kept operating permanently after 1958.

Acknowledgement.—Thanks are due to the analysts who made available the charts used in this note.

ERRATUM

On page 196, line 16 of the *Meteorological Magazine* for July 1957 the word diameters which appears twice should be replaced by radii in both cases.

[*To face p. 272*

Photograph by D. W. S. Limbert

WATER SKY AND ICE BLINK

The phenomena of water sky and ice blink are depicted. They are the result of the reflection of the water and ice upon the lower cloud surface. To ice navigators they are of prime importance as they act as a road map to the areas of open water. At Halley Bay in summer the angular elevation of water sky boundary helped in estimating cloud height.

(see p. 285)

Photograph by D. W. S. Limbert

THE MIDNIGHT SUN—NOVEMBER 1956

At Halley Bay the sun was above the horizon continuously for approximately 100 days. To obtain complete 360° coverage of sunshine two modified temperate latitude sunshine recorders were placed facing north and south respectively (seen either side of diffuse radiation solarimeter mounting). The actual total and diffuse radiation on a horizontal surface was continuously recorded using standard Moll-Gorczinski solarimeters. All the instruments were mounted on a roof platform at ridge level.

Owing to the rate of accumulation of snow—both actual precipitation and drift—it will be necessary to build a higher platform for the summer of 1957–58.

The cloud in the picture was high altocumulus.

The longest run of continuous sunshine was from 20th to 23rd November—a total time of 79·7 hours.

(see p. 285)

Photograph by D. W. S. Limbert

THE ANEMOMETER TOWER

The anemometer tower erected in April was put to a novel use. The boat was hung upside down on davits, so that, in an emergency, a sledge could be driven underneath and the boat could be driven down to the open water about one and a half or two miles away. This was a case of learning from a previous expedition. Two men had been drowned and one spent an uncomfortable sixteen hours on a floe, after their tractor had been driven in bad visibility into the sea. The rescuers spent twelve hours digging their boat out of the snow.

At the time of the picture there was slight drift reducing visibility to about 400 yds. With overcast sky this would have meant a complete 'white out'. That is, no undulation or surface feature could be discerned, and locomotion became a form of stumbling and falling up or down drifts.

(see p. 285)

Photograph by D. W. S. Limbert

ANTARCTIC DESOLATION

The old (unmodified) and new (modified) screens are shown just after one of the worst blizzards, during which much snow accumulated, covering the optical system of the All Sky Camera (right). The storm in question lasted for five days at the beginning of September (maximum gust 74 knots) and it was necessary for the observer to follow the line of stakes to reach the screen in use (modified screen). Even a two yard separation of stakes was at times too great. It was easy to get lost ten yards away from the hut.

(see p. 285)

NOTE ON THE MEAN CHARACTERISTICS OF THE MARITIME EQUATORIAL TROPOSPHERE OVER SINGAPORE

By L. S. CLARKSON, M.Sc.

Summary.—Characteristics significant to aviation of the equatorial atmosphere over Singapore are evaluated, and some information is given on the probable errors of the mean parameters.

The Observations.—From time to time, meteorological flights have been made at approximately 0300 G.M.T. (1030 hr. local time) over Seletar (01°25′N., 103°53′E.) on Singapore Island during the period September 1949 to October 1954. These ascents are a continuation of those made from December 1946 to July 1948 which have been comprehensively analysed by John[1]. In addition to the aircraft ascents, which rarely reached levels above 250 mb., daily radio-sonde ascents to 100 mb. over Singapore at 0300 G.M.T. have been broadcast by the Malayan Meteorological Service during the period of operation of the sonde from August 1954 to October 1955.

Analysis and Discussion.—Mean monthly and annual temperatures and heights of the standard pressure surfaces and their standard deviations evaluated from the Seletar ascents are presented at Table I. The results are consistent with those set out by John[1] for the earlier series of flights, the mean annual temperatures at corresponding pressure levels differing by less than 0·5°C., except at 900 mb. and 300 mb., where the differences are 0·8°C. and 1·1°C. respectively.

The standard deviation of the temperature observations from their annual mean values varies at the different levels between 1·5°C. and 2°C. The standard random error of the observations themselves is not known, but is likely to be comparable with random errors in radio-sonde temperatures, which have been quoted[2] as 0·5–0·8°C. Thus, the real variation of temperature at 0300 G.M.T. at any given pressure level is clearly quite small, with a probable error of about 1°C. Hence it follows that there is seldom any appreciable temperature contrast between the air masses which affect Singapore, and real departures from the mean, of significance for forecasting, occur very infrequently. Consequently, it is unlikely that further regular upper air temperature observations over the Island will provide information of any considerable value for forecasting weather developments in equatorial south-east Asia.

TABLE II—MEAN ATMOSPHERE FOR 0300 G.M.T., AT SINGAPORE

I.C.A.O. Height (Sub-scale 1013·2)	Altitude	Alticor	Pressure	Virtual Temperature	Temperature	Density†
Thousands of feet		ft.	mb.	°C.	°C.	%
0·057	Zero	...	1011	31·3	+28·0	94·4
0·363	0·315	− 48	1000	28·9	+25·7	94·2
4·77	4·95	+ 180	850	19·9	+18·1	82·5
9·88	10·34	+ 460	700	10·2	+ 9·4	70·3
13·79	14·47	+ 680	600	3·0	+ 2·4	61·8
18·28	19·24	+ 960	500	...	− 5·5	53·1
23·56	24·86	+1,300	400	...	−15·6	44·2
30·05	31·78	+1,730	300	...	−30·6	35·2
38·64	40·78	+2,140	200	...	−52·9	25·8
44·63	46·67	+2,040	150	...	−67·0	20·7
53·09	54·09	+1,390	100	...	−77·9	14·6

† Relative to that of dry air at 1013·2 mb. and 15°C.

TABLE I—SUMMARY OF RESULTS OF AIRCRAFT UPPER AIR TEMPERATURE SOUNDINGS: SELETAR

Pressure		Jan. 1951–53	Feb. 1950–54	Mar. 1950–54	Apr. 1950–52, 54	May 1950–52, 54	June 1950–52, 54	July 1950–54	Aug. 1950–52, 54	Sept. 1949, 51, 53–54	Oct. 1950–54	Nov. 1950, 51, 53	Dec. 1950, 51, 53	Year
mb. 1,000	Height in ft. ...	310 (42)	309 (41)	296 (38)	267 (27)	251 (45)	255 (54)	275 (82)	284 (39)	305 (48)	306 (46)	288 (41)	315 (34)	288
	S.D.* of height ...	40	44	32	35	41	45	40	34	39	39	37	28	44
900	Temperature in °C.	20·9 (42)	19·9 (41)	20·7 (39)	21·3 (29)	21·3 (45)	21·6 (57)	21·0 (82)	21·1 (39)	21·0 (48)	21·8 (46)	21·1 (42)	21·0 (35)	21·6
	S.D. of temperature	1·9	1·4	1·3	1·0	1·1	1·1	1·1	1·3	1·2	1·7	1·7	1·6	1·5
	Height in ft. ...	3,328 (41)	3,330 (40)	3,326 (38)	3,302 (27)	3,293 (45)	3,292 (54)	3,307 (82)	3,319 (39)	3,337 (47)	3,348 (45)	3,317 (40)	3,342 (34)	3,320
	S.D. of height ...	39	53	37	42	42	46	41	43	45	42	43	27	46
850	Temperature in °C.	18·2 (42)	17·4 (41)	17·9 (39)	18·3 (29)	18·6 (45)	18·7 (58)	18·2 (81)	18·1 (39)	18·1 (49)	18·8 (46)	18·2 (41)	18·0 (34)	18·2
	S.D. of temperature	1·9	1·4	1·2	1·2	1·3	1·2	1·0	1·1	1·2	1·8	1·9	1·7	1·5
800	Temperature in °C.	15·7 (42)	14·6 (41)	15·2 (39)	15·6 (29)	15·8 (45)	15·7 (58)	15·0 (82)	15·2 (39)	15·1 (49)	15·8 (47)	15·3 (41)	15·1 (33)	15·3
	S.D. of temperature	2·1	1·4	1·1	1·3	1·5	0·9	1·0	1·3	1·4	1·8	1·6	1·5	1·5
	Height in ft. ...	6,640 (41)	6,647 (40)	6,651 (36)	6,629 (27)	6,614 (45)	6,623 (54)	6,630 (81)	6,643 (39)	6,660 (46)	6,676 (45)	6,645 (40)	6,661 (33)	6,643
	S.D. of height ...	40	64	49	53	49	46	49	46	52	56	55	35	53
700	Temperature in °C.	10·3 (42)	8·6 (41)	9·1 (39)	9·8 (29)	9·8 (44)	9·9 (58)	9·0 (82)	8·8 (39)	9·0 (49)	9·8 (46)	9·5 (40)	9·6 (32)	9·4
	S.D. of temperature	2·3	1·5	1·4	1·2	1·4	1·0	1·1	1·4	1·4	1·8	1·8	1·7	1·6
	Height in ft. ...	10,310 (41)	10,320 (40)	10,330 (35)	10,300 (27)	10,290 (42)	10,310 (54)	10,310 (82)	10,320 (39)	10,340 (47)	10,370 (46)	10,330 (39)	10,350 (32)	10,320
	S.D. of height ...	13	77	55	61	63	55	63	55	63	81	82	56	71
600	Temperature in °C.	3·4 (42)	1·3 (41)	2·4 (38)	2·4 (29)	2·4 (44)	2·0 (58)	2·1 (79)	1·7 (38)	2·0 (49)	2·8 (46)	2·6 (41)	2·4 (31)	2·3
	S.D. of temperature	2·4	1·8	1·1	1·0	1·4	1·1	1·1	1·1	1·6	2·0	1·9	1·7	1·7
	Height in ft. ...	14,450 (41)	14,460 (40)	14,500 (35)	14,470 (27)	14,450 (44)	14,570 (54)	14,450 (79)	14,460 (39)	14,490 (47)	14,530 (45)	14,490 (38)	14,510 (32)	14,490
	S.D. of height ...	27	97	102	82	90	78	75	74	91	103	120	77	93
500	Temperature in °C.	− 3·8 (42)	− 6·5 (41)	− 5·7 (37)	− 5·4 (29)	− 5·4 (44)	− 6·0 (56)	− 6·6 (78)	− 6·8 (39)	− 6·2 (49)	− 5·3 (46)	− 5·6 (40)	− 6·0 (28)	− 5·8
	S.D. of temperature	2·6	1·8	1·0	1·4	1·3	1·2	1·4	1·2	1·8	1·7	1·4	1·4	1·7
	Height in ft. ...	19,220 (41)	19,210 (40)	19,270 (35)	19,230 (27)	19,220 (44)	19,230 (52)	19,200 (79)	19,200 (39)	19,230 (47)	19,310 (46)	19,260 (37)	19,240 (28)	19,230
	S.D. of height ...	26	102	106	102	56	83	83	99	97	137	146	111	105
400	Temperature in °C.	−13·8 (40)	−17·3 (40)	−15·9 (36)	−15·6 (29)	−15·9 (43)	−16·2 (56)	−16·7 (80)	−16·9 (38)	−16·9 (48)	−16·1 (44)	−15·7 (40)	−16·5 (27)	−16·1
	S.D. of temperature	3·9	2·2	1·0	1·2	1·3	1·4	1·6	1·2	1·8	1·7	1·4	1·4	2·0
	Height in ft. ...	24,820 (39)	24,830 (39)	24,920 (33)	24,830 (26)	24,850 (43)	24,840 (51)	24,820 (78)	24,820 (39)	24,860 (47)	24,930 (43)	24,880 (37)	24,880 (27)	24,860
	S.D. of height ...	359	126	171	170	101	87	98	114	114	163	165	142	203
300	Temperature in °C.	−28·6 (39)	−32·1 (38)	−31·6 (36)	−30·4 (26)	−30·6 (42)	−31·2 (56)	−32·4 (82)	−32·4 (39)	−32·7 (46)	−32·6 (44)	−31·2 (40)	−32·2 (27)	−31·5
	S.D. of temperature	2·1	2·3	2·3	1·1	1·6	1·3	1·2	0·9	1·6	1·4	1·4	1·3	2·0
	Height in ft. ...	31,770 (39)	31,690 (38)	31,820 (33)	31,820 (25)	31,770 (42)	31,770 (52)	31,700 (78)	31,700 (38)	31,730 (45)	31,830 (44)	31,810 (36)	31,780 (27)	31,770
	S.D. of height ...	219	148	203	201	108	88	114	134	122	174	202	170	168
200	Temperature in °C.	...	...	...	...	−54·7 (9)	−54·3 (24)	−55·6 (22)	−56·0 (17)	−56·4 (19)	−56·7 (8)	...	...	−55·6 (May–Oct.)
	S.D. of temperature	...	...	...	...	2·2	1·0	2·3	1·1	1·8	1·5	...	...	1·9
	Height in ft. ...	...	...	...	...	40,780 (3)	40,760 (24)	40,570 (22)	40,570 (17)	40,550 (19)	40,500 (8)	...	...	40,620 (May–Oct.)
	S.D. of height ...	...	...	...	...	110	100	114	92	109	187	...	...	163

Heights are heights of pressure surface above mean sea level. * S.D.=Standard deviation. The number of observations is shown in brackets.

TABLE III—MEAN ATMOSPHERE FOR 0300 G.M.T. AT SINGAPORE AT 2,000-FT. INTERVALS OF I.C.A.O. HEIGHT

I.C.A.O. Height*	Altitude	Alticor	Pressures	Virtual Temperature	Temperature	Density†
Thousands of feet		ft.	mb.	°C.	°C.	%
0·057	0·00	− 57	1011·0	31·3	+28·0	94·4
2	2·05	+ 50	942·1	25·5	+23·0	89·8
4	4·15	+ 150	875·1	21·5	+20·0	84·5
6	6·25	+ 250	811·9	17·5	+16·5	79·5
8	8·35	+ 350	752·6	13·5	+13·0	74·7
10	10·45	+ 450	696·9	10·0	+ 9·5	70·0
12	12·6	+ 600	644·3	6·0	+ 5·5	65·7
14	14·7	+ 700	595·1	2·5	+ 2·0	61·4
16	16·8	+ 800	549·0	...	− 1·5	57·5
18	18·9	+ 900	505·7	...	− 5·0	53·6
20	21·1	+1,100	465·3	...	− 9·0	50·1
22	23·2	+1,200	427·8	...	−12·5	46·7
24	25·3	+1,300	392·5	...	−16·5	43·5
26	27·5	+1,500	359·6	...	−21·0	40·6
28	29·6	+1,600	329·1	...	−25·5	37·8
30	31·7	+1,700	300·8	...	−30·5	35·3
32	33·8	+1,800	274·2	...	−35·5	32·8
34	35·9	+1,900	249·8	...	−41·0	30·6
36	38·0	+2,000	227·1	...	−46·0	28·4
38	40·1	+2,100	206·3	...	−51·5	26·5
40	42·1	+2,100	187·4	...	−56·0	24·6
42	44·1	+2,100	170·2	...	−61·5	22·9
44	46·0	+2,000	154·6	...	−66·0	21·2
46	47·9	+1,900	140·4	...	−69·0	19·6
48	49·7	+1,700	127·5	...	−71·5	18·0
50	51·6	+1,600	115·9	...	−74·0	16·6
52	53·4	+1,400	105·4	...	−76·5	15·3

* Sub-scale set at 1013·2 mb.

† Relative to that of dry air at 1013·2 mb. and 15°C.

Taylor[2] has estimated the standard error of heights of the 500-mb. surface, computed from radio-sonde pressure and temperature observations, as 35 ft. The standard deviation of the computed heights over Singapore from the annual mean value of the height of the 500-mb. surface is 105 ft. (Table I). From this, it is apparent that the real variation in height of the 500-mb. surface over Singapore is small, the annual mean having a probable error of about 64 ft.

At present, no upper air temperatures are being measured over Singapore. But, because of the small scatter about the mean that has been shown by past observations, it is possible to write down the characteristics of a mean maritime equatorial atmosphere, actual departures from which should seldom be of significance for aviation. This has been done in Table II by utilizing all the aircraft upper air temperature observations, and also the Malayan Meteorological Service 0300 G.M.T. daily radio-sonde observations from August 1954 to October 1955. By graphical interpolation between the data in Table II, Table III has been derived, giving at 2,000-ft. intervals of I.C.A.O. height, the mean true altitude; altimeter correction (alticor); air pressure, temperature, virtual temperature and percentage density relative to that of dry air at 1013·2 mb. and 15°C.

It is thought that the data in Table III may prove useful in computing performance curves and characteristics of aircraft destined for Malaya more realistic than those based on the assumption of the aircraft operating in upper air temperatures and densities equivalent to those in the standard I.C.A.O. atmosphere.

Particularly in the height range 34,000–46,000 ft., the large corrections which must be added to the readings of the pressure altimeter with the sub-scale set at 1013·2 mb. to obtain true altitude over Singapore are noteworthy. Since upper air winds and temperatures are forecast at heights above mean sea level, and since there is often a marked increase of wind speed with height around 40,000 ft. over Singapore, neglect of these altimeter corrections (alticors) in flight planning is liable to lead to marked discrepancies between actual and anticipated performance of jet-engined aircraft.

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SOME EARLY OBSERVATIONS OF THE FREE ATMOSPHERE IN HIGH LATITUDES

By F. LOEWE, Ph.D.

The earliest instrumental observation in the free atmosphere of polar regions seems to have been made on January 26, 1822, when during an expedition with *Fury* and *Hecla*, W. E. Parry and G. Fisher raised a kite with a "register thermometer" attached, to a height of 400 ft. at Winter Island (66°11′N., 83°10′W.). They found that the temperature at the greatest height was almost identical with that of −24°F. at the surface[1, 2]. In other references[3, 4] the place of the ascent is erroneously given as Igloolik (69°21′N., 81°53′W.), the location of Parry's subsequent wintering. On December 12, 1836, Back, drifting icebound in the *Terror* off Southampton Island (65°12′N., 83°40′W.) sent a kite with a recording thermometer to 1,200 ft. where the temperature was found to be 8°F. lower than at the surface. These flights were repeated a few times during the same winter[5, 6, 7]. At the suggestion of Arago, two captive balloon flights to 900 and 1,400 ft. and 32 kite ascents to 200–400 ft. were made in 1838 by Bravais, Lottin and Martins during the winter at Bossekop (70°N. 23°E.) in Alta Fjord near the European North Cape[8, 9]. They found a prevalence of temperature increases with height to about 300 ft. and slow decreases above that height. The size of the temperature inversions increased with decreasing surface temperature and cloudiness. Some temperature observations were taken during Andrée's ill-fated balloon flight from Spitsbergen over the polar sea in 1897[10]. The first comprehensive studies of the free atmosphere by captive balloons and kites in a truly polar climate were made by Wegener in Danmarkshavn (76°46′N., 18°45′W.) during Mylius Erichsen's expedition[11, 12]. At the same time Hergesell had started to make sounding-balloon flights in northern waters[13, 14, 15, 16]. During these flights the stratosphere was possibly reached on July 16, 1906, off Spitsbergen (79°N., 08°E.) at a height of 25,000 ft., and definitely on August 11, 1910 (76½°N., 09°E.) at 35,000 ft. Simultaneously sounding-balloon flights had been started in Kiruna (68°N., 20°E.) in northernmost Sweden where the stratosphere had been reached in March 1907[17]. The first successful radio-sonde flights in the Arctic were probably those launched by Molchanov and Weickmann from the airship *Graf Zeppelin* during its Arctic cruise in July 1931[18, 19, 20].

In the Antarctic the first meteorological measurements in the free atmosphere to a height of 1,000 ft. were taken by the Gauss expedition in a manned balloon on March 29, 1902 from the sea ice off Kaiser Wilhelm II Land (66°S., 89½°E.)[21]. During the midday hours a weak inversion of temperature was established. No meteorological observations seem to have been made at the occasion of the slightly earlier balloon ascent of the *Discovery* expedition on February 2, 1902 on the Ross Ice Shelf (78½°S., 164°W.). The first Antarctic sounding-balloon flights were made in 1911 by G. C. Simpson in McMurdo Sound (77°S., 166°E.); the highest reached 22,000 ft.[22] Shortly afterwards, in 1912, Barkow made a great number of balloon and kite ascents during the drift of the *Deutschland* in the Weddell Sea[23, 24, 25]. After unsuccessful attempts by Holmboe at Deception Island (63°S., 60½°W.) in 1934[26], the first radio-sonde flights in the Antarctic were made by Lange and Regula during the *Schwabenland* expedition[27, 28, 29, 30]. These flights were also the first to reach the Antarctic stratosphere. It was first established by Court in *Little America III* that in high southern latitudes the stratosphere of nearly uniform temperature disappears towards the end of winter[31, 32].

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LETTERS TO THE EDITOR

Non-circular wind distributions

It is suggested that caution is needed in accepting that normal circular frequency distributions are characteristic of homogeneous upper wind observations above the friction layer in all parts of the world, including the equatorial regions.

N. Goldie[1] implies that the strongly elliptical distribution found by Scott[2] for a set of winds at 50,000 ft. over Singapore observed in September, October and November, 1953, was due to these observations not being confined to a single régime.

However, in an analysis by months of observed winds at 50,000 ft. over Singapore, Clarkson[3] has discussed the evidence for an elliptical distribution about the monthly vector means, and has shown that the chance of the observations made in the month of November, 1953 and 1954 being a sample from a normal circular distribution is negligible. Scott[4] has confirmed that 85 observations at 50,000 ft. in March, 1951–1955 are elliptically distributed.

Table I below includes statistics for all 0300 G.M.T. winds at 50,000 ft. measured by radar over Singapore up to the end of 1956. In September, and in each of the months from November to April inclusive, σ_E is at least 50 per cent greater than σ_N. It is thought that this non-circular distribution must properly be regarded as a characteristic of the high level winds over Singapore and not ascribed to the overlapping of different wind régimes in each of the seven specified months.

F.E.A.F., Changi, January 23, 1957. L. S. CLARKSON

TABLE I—STATISTICS OF MONTHLY MEAN WINDS AT 50,000 FT. OVER SINGAPORE AT 0300 G.M.T.

	No. of obs.	V_N	V_E	$\mathbf{V}_R$		σ_N	σ_E	σ
		knots		°	kt.	knots		
January	95	−8·3	38·9	102	39·8	13·0	19·7	23·5
February	102	−9·7	34·1	106	35·5	14·2	28·8	32·1
March	116	2·9	8·7	72	9·1	10·4	22·8	24·9
April	107	3·0	18·4	81	18·6	9·9	18·1	21·0
May	108	9·0	26·1	71	27·6	11·6	14·7	18·7
June	105	9·4	34·0	75	35·2	14·7	19·5	24·4
July	107	8·6	39·5	78	40·4	13·8	18·9	23·4
August	94	13·5	50·7	75	52·4	13·0	19·2	23·1
September	90	7·9	44·2	80	44·9	12·6	24·2	27·3
October	105	5·4	35·6	81	36·0	10·9	14·7	18·3
November	122	2·2	37·5	87	37·6	8·8	19·2	21·6
December	95	−3·7	31·7	97	31·9	9·2	22·5	24·4

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3. CLARKSON, L. S.; Analysis of winds at 40,000 ft. and 50,000 ft. over Singapore. *Met. Mag., London*, **85**, 1956, p. 1.
4. SCOTT, J. R.; A regression method for estimating time changes of elliptically distributed winds. *Quart. J. R. met. Soc., London*, **82**, 1956, p. 337.

Waterspout on the River Severn near Shrewsbury

A waterspout was observed on the River Severn at Montford Bridge 5 miles west-north-west of Shrewsbury by Mr. Welch of Shrewsbury and his family at 4.15 p.m. on Friday 19 April, 1957.

The waterspout appeared on the edge of the river about 50 yards from the observer, crossing to the other side, a distance of 60 to 70 yards. It was in the form of a column of water 1 to 3 feet in diameter and 1 foot tall, with spray reaching a height of 8 feet and producing a swishing sound. The phenomenon was estimated to last about 15 to 20 seconds.

The weather at the time was warm with no noticeable wind before the occurrence; afterwards the temperature dropped as a cold northerly wind blew upstream for 2 to 3 minutes producing ripples on the river surface.

At this point the river runs roughly from south to north through a valley about 200 yards from the road, with a steep partially wooded slope between.

No observation of the sky was made by Mr. Welch, but he states that the waterspout did not have any connection with cloud, the weather being quite bright at the time.

On the 1500 G.M.T. chart there was a weak ridge of high pressure over the British Isles from an anticyclone over the Continent, the gradient was very slack and a shallow heat trough had formed over the west Midlands.

This would explain the onset of the northerly wind and also the increased instability to cause a waterspout.

The Liverpool ascent for 1100 G.M.T. showed unstable air up to 6,000 to 7,000 feet. Temperature and dew-point readings at Shawbury for 1500

G.M.T. were 53° and 37°F. respectively, probably a higher temperature was experienced at Montford Bridge due to the sheltered locality.

Cloud observations at Shawbury during the afternoon were 3/8 to 4/8 fair weather cumulus base around 2,800 feet with cirrus above.

Shawbury, 29 *May*, 1957. J. J. MYATT

NOTES AND NEWS

Whirlwind at Cairngorms Nature Reserve

Mr. F. H. W. Green, The Nature Conservancy, reports that a whirlwind occurred at Invereshie Lodge, Rotheimurchus, Inverness-shire, in the Cairngorms Nature Reserve about 11 a.m. on Saturday, 2 March. A complete juniper bush, 12 to 15 ft. high was uprooted and dropped in the middle of a field with part of the root remaining and the rest of the bush broken off at ground level. The place where the bush came from has not been found. The Lodge Keeper reported that a trailer attached to a Land Rover car outside a shed in which, having heard the noise of the wind he had taken shelter, was lifted completely off the gound.

A cold front had passed south-eastwards over the area during the previous night and was stationary along the east coast of Scotland during the day. Winds were moderate south-westerly over the area.

OBITUARY

R. G. K. Lempfert, C.B.E., M.A., F.R.Met.S.

It was with great sorrow that his former colleagues learned of the death of Mr. Lempfert in the early hours of 24 June after a stroke and just over 50 hours subsequent unconsciousness. R. G. K. Lempfert was the son of Rudolf Bernard Lempfert and Olga (née von Pein) who had come independently to Manchester from Kiel and Hamburg respectively, had met at a choral society and were married in 1869. R. G. K. Lempfert was born on 7 October, 1875. It was natural, with such parents, that he should love music, find his recreation in it, and in due course (June 1916) marry a distinguished violinist, Marjorie Hayward; and that music should also be the profession of their only daughter, Marjorie.

Lempfert was tall, distinguished in appearance and courteous both in bearing and in approach: Science, Art and Courtesy found they could, indeed, live together in R. G. K. Lempfert and make, in broad truth, the perfect gentleman.

From Manchester Grammar School, famous then for the Scholars it sent to the Old Universities, Lempfert went in 1894 to Emmanuel, Cambridge, took a First Class in both parts of the Natural Science Tripos (Part I, 1896, Part II Physics, 1898) and demonstrated at the Cavendish Laboratory. In 1900 he went to Rugby School as an assistant master and thence to the Meteorological Office in 1902.

Until fifty-five years ago "one of the peculiarities of the Meteorological Office as a scientific establishment was that none of the members of the staff had had any preliminary scientific training" (Sir Napier Shaw). The appointment of Lempfert in 1902 was the first step of Sir Napier's to remedy this defect; and most abundantly has it been justified: not only by the investigations which Lempfert undertook or had a part in, but also by the influence he exerted on meteorological administration and meteorological publications throughout a quarter of a century. Among the official publications for which he was responsible were the *Observer's Handbook*, the *Codex of International Resolutions*, the *Instructions in Meteorological Telegraphy* and the English Editions of *Reports of the International Meteorological Committee.* As he was bilingual, speaking English and German with practically equal facility, he was exceptionally qualified for the task of ensuring accurate correspondence in the technical terms and in the discussions at international meetings. He was also for many years effective, though unacknowledged, editor of the *Quarterly Journal of the Royal Meteorological Society.*

Lempfert took a leading part in securing the voluntary acceptance by 'Health Resorts' of inspection (at their expense) of their meteorological stations and the transmission of their weather reports to the Press via the Office and in official code. His too was a leading part in the transfer from the Royal Meteorological Society to the Office of the oversight and publication of the monthly reports from the Society's voluntary observers. The relative homogeneity and areal completeness of our meteorological statistics are largely due to these two steps, taken over forty years ago. Lempfert's scientific investigations were made often in collaboration with others. The first was the London Fog Inquiry (with Carpenter). Then came the Life History of Surface Air Currents (with Shaw). This was the first serious scientific attempt to find out whence the wind cometh and whither it goeth, and to relate the facts to the major developments of weather. It was a monumental task to collect and co-ordinate all the observations necessary for the detailed examination of the eight selected cases of travelling and developing storms and the six cases of trajectories of air over the North Atlantic Ocean. This investigation and the two papers on Line Squalls, (Lempfert 1906, Lempfert and Corless 1910) were the natural precursors of the Norwegian introduction of the Polar Front and the consequent impetus to frontal research in the period between the two wars. The first use of the word 'front' as a technical term seems to have been made, in the 1910 paper, for the cold front of the Line Squall. Other notable papers were *British Weather Forecasts* (1913) invaluable to the meteorological historian; the *Publication of Upper Air Reports* (1928, with Sir Napier Shaw and Miss E. Austin); *Scientific Work of the Meteorological Office, Cardington* (1931) and *Presentation of Meteorological Data* (1932), with its fertile suggestions especially in respect of humidity.

His appointments in the Office were Scientific Assistant (1902), Superintendent of Instruments (1905), of Statistics (1906), of the Forecast Division (1910), Assistant Director 1919. He retired on 31 December, 1938. He was President of the Royal Meteorological Society 1930–32.

It is difficult to realize that he had been over eighteen years in retirement—half as long as the period of his active service in the Meteorological Office. He was one of the executors of Sir Napier Shaw's will and in that capacity was responsible for the establishment of the Napier Shaw Library (Meteorological) in the Cavendish Laboratory at Cambridge and for the publication of the volume of *Shaw's Selected Papers*, fortunately completed last year after many difficulties and long drawn out negotiations. When in 1915 it was decided that the needs of the Army and Royal Flying Corps in France could not be met adequately from London but required meteorologists "in the Field", Lempfert was nominated by Sir Napier Shaw to take charge of the contingent initially. After preliminary agreement the War Office changed its mind. Lempfert, loyal to the land of his birth and upbringing, had looked forward to playing a more directly active part in the war against Germany. Disappointed as he was, he went far beyond his official duty in the help and encouragement he gave to me who took his place; and never did he utter one word of bitterness at his deprivation of the opportunity which came to me instead of to him.

E. GOLD.

REVIEWS

Physical Geography and Climatology. By N. K. Horrocks. $8\frac{1}{2}$ in. $\times 5\frac{1}{2}$ in., pp. xv+368, *Illus.*, Longmans, Green and Co., London, 1956. Price: 20*s.*

This pleasantly bound book, with its many clear diagrams and excellent photographs, is intended for grammar-school use. The general tone and level of the book is quite satisfactory for its purpose and the arrangement is systematic. The book is in six parts. Only Parts III and V, Meteorology and Climatology respectively, are discussed here; the remaining parts, dealing with the structure of the earth's surface, earth sculpture, plants and soils and oceanography, do not fall within the scope of this review.

Part III, Meteorology, has many faults. The chapter on water vapour in the atmosphere gives quite a few wrong ideas to the reader. In particular, the author gets the required small difference between dry and saturated adiabatic lapse rates at low temperatures, not by a curved saturated adiabatic, but by a sharp *increase* in the saturated adiabatic lapse rate at temperatures below 32°F. (i.e. a negative latent heat of fusion).

The proof given for the geostrophic deflexion is the familiar one which only applies to meridional flow. In a book of this nature I think a statement of observed fact would be best for the school pupil, with a reference to some book where the correct proof is given for the more advanced student.

There are other criticisms of this part of the book. The cross-section diagram and the description of warm-front cloud are both misleading. It was surprising, too, to find the distinction between advection fog, warm air over cold surface, and arctic smoke, cold air over warm water, dismissed by calling the processes "much the same". Some simple statement on the behaviour of moist unsaturated air would have made for easier phraseology; by calling all unsaturated air "dry", the author is trapped into such phrases as "dry air with high relative humidity".

The chapter on Precipitation is quite satisfactory and the whole of Part V, Climatology, is well done. In particular I liked the pleasant and effective diagrams in Part V, which give a good deal of clearly expressed information.

H. D. HOYLE

Die Mondfinsternisse. By F. Link. 9 in. × 6 in., pp. viii + 127, *Illus.* Akademische Verlagsgesellschaft Geest and Portig K.-G., Leipzig, 1956. Price: 15*DM.*

There is much more opportunity of seeing lunar eclipses than solar eclipses but while most people will have seen some solar eclipses few have seen a lunar eclipse. Lunar eclipses give rise to no superstitions, no excitement, and even most astronomers take little note of them. However, much information can be gained by observing them and the information is mainly about the earth's atmosphere. Dr. Link has therefore performed a useful service by assembling all that is known in a concise and well-prepared monograph.

Although there are other important matters which have to be considered, such as the solar limb darkening and the nature of the lunar surface, the heart of the problem is to analyze the behaviour of a slightly divergent beam as it is refracted, scattered and absorbed through the earth's atmosphere. A large part of the book is taken up with this treatment, which is complex and cannot be handled analytically. The main difficulty is that the earth's atmosphere is a very complicated optical system owing to its spherical shape and the rapid change of density with distance from the earth's surface. The effect of this density variation is an advantageous one, namely that the atmosphere acts as a divergent lens and gives an enlarged view of itself projected onto the lunar surface.

Passing over this geometrical problem, the object of this kind of study is to account for the distribution of light at the edge of the shadow in terms of the properties of the atmosphere.

To account for the refraction the pressure-height relationship in the atmosphere must be assumed. It may perhaps not be important, but it is somewhat alarming to find that Dr. Link makes use of Humphreys's data up to 40 Km. and Lindemann and Dobson's data above this level.

This relationship also allows the molecular scattering to be computed which leaves to be determined the absorption by gaseous constituents and the absorption and scattering by dust. These can be distinguished by spectral characteristics. For example by observing the Chappuis band of ozone the distribution of this gas can be determined up to high levels.

As a method of ozone research this technique offers two interesting advantages. Firstly, it is possible from the same photographic plate to determine the distribution simultaneously at many latitudes. Secondly, owing to the very long path taken through the upper atmosphere very small amounts can be detected and hence the distribution can be determined up to far greater heights than balloon sondes can reach.

After all gaseous absorption and scattering has been taken into account there remains a residual effect which is attributed to dust. At this point the astronomer and the meteorologist will probably disagree. Dr. Link wants this to be meteoric dust and shows a correlation between the variable diameter of the earth shadow and meteoric showers which is not at all convincing. As he realises, this dust cannot be at high levels, for he needs an optical thickness of 0·005 to account for the observations and even at 30 Km. this would show up as bright night-luminous clouds. On the other hand, if the layer is any lower it is much more reasonable to look to the earth's surface as the source.

The question can be readily clarified by means of the search-light experiments projected by the Meteorological Office. These will show immediately the presence of dust below 50 or 60 Km. and will give quantitative data for comparison with meteor-shower frequencies.

The book contains a bibliography of 192 references which must be practically a complete bibliography of the subject. It is in German, but the style is concise and reasonably clear so that it should afford no difficulty to any interested reader. The diagrams and equations are of the high standard which is expected from a German publisher. Altogether, it is a pleasing and well constructed monograph which should appeal to a meteorologist of catholic tastes.

R. M. GOODY

BOOKS RECEIVED

Les buts scientifiques de l'expédition radiométéorologique polar suisse pendant l'anée géophysique internationale. By J. Lugeon. (Reprinted from La Suisse Horlogére No. 20, 1957). 9 in. × 11½ in., pp. 16, *illus.*

Gustave Swoboda 1893–1956. (Reprinted from Verhandlungen der Schweiz. Naturforschenden gesellschaft, Basel, 1956). 9 in. × 6 in., pp. 4, *illus.*

OFFICIAL PUBLICATION

PROFESSIONAL NOTES

No. 122—*The subtropical jet stream of the Eastern North Pacific Ocean in January and April* 1952. By H. D. Hoyle, B.Sc.

Daily maps of the main jet-stream cores in the eastern North Pacific Ocean in January and April 1952 are shown. The days are grouped into four types and average vertical cross-sections for each type are given. Two separate jet-stream cores are frequently present, one associated with the polar front and one, at a higher level, often 1,000 miles or more farther south.

Variation from day to day in the strength of the more southerly of the streams is discussed in relation to the upper air temperature field and the major surface synoptic features. The thermal-wind relation appears to hold reasonably well at these rather low latitudes and geostrophic advection of the temperature field seems to make an important contribution to these day-to-day variations in the intensity of the jet stream.

When there is only one jet-stream core, the upper air temperature field and the surface synoptic charts show interesting changes. This leads to a suggestion that the ageostrophic meridional circulation accompanying the subtropical high-pressure cell is important in establishing the upper air temperature field.

HONOURS

The Director-General, Sir Graham Sutton, C.B.E., D.Sc., F.R.S., has been elected an Honorary Fellow of the Society of Engineers.

Meteorological Office awards to airline pilots

At a pleasant ceremony at the House of the Guild of Air Pilots and Navigators, Park Lane, London on July 4, 1957, the Director-General presented the annual awards to airline pilots for long and meritorious service in the provision of weather reports. The recipients of brief-cases this year were Captain S. A. Calder of Britavia Ltd. and Captain R. H. Payne of British European Airways.

In introducing the Director-General the Master of the Guild, Mr. J. Lankester-Parker, spoke of the confidence of pilots and navigators in the Meteorological Office. The Director-General spoke of the great value of reports from aircraft in increasing knowledge of the upper air.

Books for the best series of reports are being awarded to the following Captains and Navigators:

Mr. G. F. Andrews, B.O.A.C.
Captain B. D. Barrow, B.O.A.C.
Captain A. J. Campbell, B.O.A.C.
Mr. H. L. Chandor, B.O.A.C.
Captain M. D. Deloford, B.O.A.C.
Captain R. A. J. Hanson, B.O.A.C.
Mr. P. E. Hobbs, B.O.A.C.
Mr. R. H. Hughes, B.O.A.C.
Mr. E. V. Jenkins, B.O.A.C.
Captain M. A. Kyle, B.O.A.C.
Mr. W. C. L. McKay, B.O.A.C.
Captain R. H. Rose, B.E.A.
Captain J. E. Sayce, B.O.A.C.
Mr. F. S. Tanner, B.O.A.C.
Mr. H. T. Thompson, B.O.A.C.
Captain F. A. Tricklebank, B.E.A.
Captain J. R. Turner, B.E.A.
Captain W. J. Wakelin, B.E.A.
Mr. J. B. Weston, B.O.A.C.

INTERNATIONAL GEOPHYSICAL YEAR

Royal Society Expedition to Antarctica

We are indebted to Mr. D. W. S. Limbert for the photographs and descriptions which are reproduced between pp. 272–3. Mr. Limbert was a member of the advance party which was established early in 1956 at Halley Bay.

LATE RAINFALL REPORTS 1957

Skye (Glenbrittle)*

Month ...	Jan.	Feb.	Mar.	Apl	May
In. ...	9·89	6·02	8·55	4·29	3·37
Per cent. of Av. ...	123	92	134	92	75

Rothesay (Ardencraig)

Month ...	Apl	May
In. ...	2·72	91
Per cent. of Av. ...	2·18	72

* In lieu of Skye (Broadford)

WEATHER OF JULY 1957

The month was marked by considerable mobility in the main centres of action and less firmly established circulation pattern over the northern hemisphere than characterizes July in many years. On balance, however, the average pressure field for July 1957 showed strong resemblance to that for July 1956. The Azores anticyclone was centred near 35° N. 40°W., highest monthly mean pressure 1025 mb. (about normal intensity) in both summers, though in 1957 the mid-Atlantic ridge to south Greenland was a trifle more intense than the same feature had been in 1956: this was the product of one or two spells of a few days high pressure associated with mobile anticyclones in 1957 which did not occur in the previous year; for the rest of the month the sequences over the North Atlantic were very similar in both years. Mean pressure in the Atlantic sector was lowest (about 1010 mb.) over Labrador and between central Scandinavia and north-east England. The polar anticyclone was displaced towards the Atlantic–European sector, pressure being highest (1018 mb.) in north-east Greenland and Novaya Zemlya.

As in July 1956 also, the Eurasian monsoon low gave about normal pressure values over India but below normal pressures over wide areas in extensions into eastern Europe and north-east Asia. Low pressure spread from the latter area right across the polar basin into northern Canada (the monthly mean being probably about 1005 mb. near 80°N. 180°, an apparent anomaly of −9 mb.).

The pattern described involved a great change from that of June 1957, which had produced remarkable heat waves over much of Europe culminating with reported afternoon temperatures of 35 to 40°C. as far north as central Europe about the turn of the month. The abrupt change to a cooler régime was accomplished between the 5th and 10th July as cold outbreaks swept across the continent from north Russia and the north-eastern Atlantic. About the end of the month there was a reversion to a more anticyclonic type of weather in central and northern Europe. The average temperatures for July as a whole were near normal or slightly above in Europe generally. Greatest anomalies reported in the northern hemisphere were +3°C. in Lapland and in North Dakota and −3°C. in east Greenland.

The month was decidedly wet over most of Europe, with over twice the normal rainfall in several widely separated regions. The usual dry régime was established in central and southern parts of the Mediterranean. Over North America the rainfall distribution was patchy, as also in India and South-East Asia, where the monsoon was on the whole giving less rain than normal. There were rainfall excesses over most of Japan.

In the British Isles the month began with the last of June's "heat-wave" dying away. During the first six days of July a weak low pressure area lay to the south-west of the country and weather was generally sunny though there were local outbreaks of thundery rain or thunderstorms every day. Severe thunderstorms occurred in southern England on the night of the 2nd–3rd as a shallow depression moved northward from the Bay of Biscay—2·46 in. of rain fell during one such storm at Plymouth in one hour, an amount almost equal to the average rainfall there for the whole of July. Another rare fall occurred at Hastings where more than 1½ in. of rain was collected in 15 min. Heavy thunderstorms and widespread floods were reported from many places on the 4th and again on the 6th when a depression from off the coast of Portugal moved northwards over the British Isles. Afternoon temperatures exceeded 80°F. locally during each of these first six days and 90°F. was reached at London Airport on the 6th. The nights also were very warm; by the 7th, the temperature at Kew had not fallen below 60°F. for ten days. On the 7th weather changed to a more usual westerly type, which persisted for most of the remainder of the month, with depressions from the Atlantic moving eastwards over the country. Weather was generally more cloudy than during the first week, although some places continued to enjoy almost unbroken sunshine, and there was frequent rain with temperatures generally below normal. A depression which deepened to the west of Ireland and moved eastwards on the 11th was the first of three such systems to give widespread rain, which was heavy and thundery in places over the country. This depression was slow moving and took three days to reach the North Sea, the second moved across the country on the 17th and 18th, and the third gave considerable rain in Scotland on the 20th. By the morning of the 21st 4.37 in. of rain had fallen at Aberdeen in 72 hr. On the 22nd warm air began to spread across the country from the south-west bringing light rain to many places and fog to windward coasts during the next three days. By the 25th this warm air had reached north-east Scotland and gave persistent and locally heavy rain over the mainland though Shetland, in the cooler air to the north, had 13·4 hr. of sunshine. A slow moving cold front brought a broad belt of rain from the west over the country late on the 25th and the next three days were cooler and showery with west to north-west winds. On the 29th a small anticyclone developed over the British Isles giving the first generally fine day for about four weeks.

In England and Wales this was the wettest July since 1940, with rainfall 140 per cent. of the average. Less than the average rainfall occurred locally in Cornwall, East Anglia and Cumberland, but more than twice the average fell in parts of Montgomery and Anglesey. Parts of northern Scotland had 250 per cent. of the average. Locally in south-east England temperature was as much as 10°F. above the average for the period, but during the remainder of the month temperature was generally below the average. Sunshine also was considerably below the average except during the first week when in Scotland it exceeded 150 per cent of the average for the period.

At the beginning of the month the hot dry spell was causing farmers great concern. Fruit was splitting, potatoes were very backward and the ground was very dry. Later thunderstorms with hail caused considerable damage, particularly to fruit and hops in Kent, but subsequent rain did much to alleviate the effects of the dry weather. The warm dry weather at the end of the month came at the right time, particularly for the corn harvest.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	93	38	+0·5	144	+5	78
Scotland	82	31	−0·1	152	−1	73
Northern Ireland ...	77	41	−0·3	144	+5	61

RAINFALL OF JULY 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	3·32	139	*Glam.*	Cardiff, Penylan ...	5·17	168
Kent	Dover	5·18	245	*Pemb.*	Tenby	3·66	124
,,	Edenbridge, Falconhurst	4·29	187	*Radnor*	Tyrmynydd	6·13	149
Sussex	Compton, Compton Ho.	4·45	157	*Mont.*	Lake Vyrnwy	8·00	225
,,	Worthing, Beach Ho. Pk.	3·89	191	*Mer.*	Blaenau Festiniog ...	14·53	171
Hants.	St. Catherine's L'thouse	3·89	199	,,	Aberdovey	6·51	186
,,	Southampton (East Pk.)	4·30	189	*Carn.*	Llandudno	3·23	144
,,	South Farnborough ...	3·63	178	*Angl.*	Llanerchymedd ...	5·90	206
Herts.	Harpenden, Rothamsted	2·51	109	*I. Man*	Douglas, Borough Cem.	3·01	98
Bucks.	Slough, Upton... ...	4·10	214	*Wigtown*	Newton Stewart ...	4·62	147
Oxford	Oxford, Radcliffe ...	3·35	141	*Dumf.*	Dumfries, Crichton R.I.	5·11	156
N'hants.	Wellingboro' Swanspool	2·91	127	,,	Eskdalemuir Obsy. ...	4·93	120
Essex	Southend, W. W. ...	2·24	113	*Roxb.*	Crailing...	3·15	109
Suffolk	Felixstowe	4·29	220	*Peebles*	Stobo Castle	3·91	135
,,	Lowestoft Sec. School...	2·24	99	*Berwick*	Marchmont House ...	3·79	124
,,	Bury St. Ed., Westley H.	3·27	131	*E. Loth.*	North Berwick Gas Wks.	4·35	169
Norfolk	Sandringham Ho. Gdns.	1·98	77	*Midl'n.*	Edinburgh, Blackf'd. H.	4·83	171
Wilts.	Aldbourne	3·76	149	*Lanark*	Hamilton W. W., T'nhill	3·69	129
Dorset	Creech Grange... ...	3·36	137	*Ayr*	Prestwick	3·82	156
,,	Beaminster, East St. ...	3·79	146	,,	Glen Afton, Ayr San. ...	5·28	126
Devon	Teignmouth, Den Gdns.	3·23	139	*Renfrew*	Greenock, Prospect Hill	5·97	161
,,	Ilfracombe	3·78	149	*Bute*	Rothesay, Ardencraig ...	6·56	166
,,	Princetown	7·88	147	*Argyll*	Morven, Drimnin ...	5·43	123
Cornwall	Bude	2·89	118	,,	Poltalloch	5·98	145
,,	Penzance	3·13	115	,,	Inveraray Castle ...	6·50	131
,,	St. Austell	3·09	92	,,	Islay, Eallabus... ...	5·89	173
,,	Scilly, Tresco Abbey ...	2·07	93	,,	Tiree	5·06	140
Somerset	Taunton	2·44	115	*Kinross*	Loch Leven Sluice ...	5·91	205
Glos.	Cirencester	3·53	132	*Fife*	Leuchars Airfield ...	4·97	191
Salop	Church Stretton ...	4·51	171	*Perth*	Loch Dhu	5·77	119
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ATOMIC ENERGY AND THE METEOROLOGIST

By P. J. MEADE, O.B.E., B.Sc.

The development in recent years of processes involving the large scale use of atomic energy has led to a number of problems in which meteorological advice is of the greatest importance. The meteorologist is concerned in these problems because of the fact that when quantities of matter in the form of small particles are released into the atmosphere their subsequent history is largely governed by meteorological parameters. Contamination of the atmosphere by radio-active materials inevitably follows the use of atomic energy either in a weapon or in an industrial reactor, but more especially in the former. The meteorologist is therefore consulted about the transport of these particles by the wind, their diffusion and their ultimate removal from the atmosphere by gravity or by meteorological processes of which precipitation seems to be the most important. As is well known, radio-activity is extremely harmful, combining immediate dangers to bodily health with long term hazards to mankind. It is therefore essential that everything possible should be known about the meteorological factors that play so large a part in determining the future distribution of the radio-activity which is injected into the atmosphere as a result of modern scientific inventions. Thus, on the military side, the services of the meteorologist are indispensable in such questions as the choice of a site for a weapon test and in the timing of the explosions; in peaceful applications of atomic energy, the meteorologist will help in deciding the location of a nuclear reactor and the control procedures to be imposed for its safe operation.

The employment of atomic bombs towards the end of the last war brought home to people the potentialities of nuclear energy not only for waging war but also for industrial purposes. However, continuing tests of more and more powerful weapons and a growing awareness of the resulting atmospheric contamination combined to arouse in the minds of the public considerable anxiety as to the possible effects on the human race if limits were not set to the quantity of radio-activity that could be poured into the air. Not all radio-activity in the air is artificially produced and all the time there is present a background radiation from naturally occurring sources, examples of which are the components of cosmic rays and the small quantities of uranium and thorium present in rocks and soils throughout the world. The social problem is thus the extent by which the natural level of radiation can be increased without serious risk. It is a problem which so far has revealed itself to the public mainly in terms of weapon tests but it should not be overlooked that the next few decades will witness a tremendous growth in the applications of atomic energy to the industrial field. This development, if special precautions are not taken, could lead to the existence of local areas of high radio-active contamination in the vicinity of reactor plants. From the meteorological angle this would resemble the familiar question of the air pollution caused by traditional methods of fuel consumption but, in the case of pollution by radio-activity, the most stringent safeguards would be necessary. Smoke and sulphur gas emitted during the burning of coal and oil rarely retain their characteristics for more than a day or so and to some extent their destructive properties can be removed before release to the atmosphere takes place. On the other hand radio-active isotopes may remain dangerous for periods varying, in terms of half-lives, from fractions of a second to several centuries, and it is not practicable to hasten the decay of their radio-activity.

Governments have shared the misgivings of the public about increasing the amount of radio-activity in the atmosphere and in several countries have set up committees to make a detailed appraisal of the biological effects of nuclear and allied radiations and to estimate the long term dosages liable to be incurred by human beings through a continuation of projects involving atomic energy. In the United Kingdom the Medical Research Council at the request of the Prime Minister undertook the enquiry and produced a comprehensive report, which has been made available to the public[1]. In the United States the National Academy of Sciences examined the various problems through the agency of six committees dealing separately with genetics, pathology, meteorology, oceanography and fisheries, agriculture and with the disposal of radio-active waste products. A report summarizing the findings and recommendations of these committees has also been published[2]. Both the British and American reports contain directly or by implication a great deal of meteorology. It is clear that meteorological information and advice made important contributions during the course of the enquiries; and it seems equally clear that scientists in other fields—chemists, physicists, etc.—could in their turn help the meteorologist in the use of radio-activity to attack some of the problems of the atmosphere that still await solution.

Meteorology and nuclear weapons.—When an atomic bomb is exploded at or near the surface, the release of energy produces an intensely hot fireball which draws many tons of debris from the earth into the atomic cloud. The vaporized bomb materials are able to condense on the soil particles so that the resulting radio-active dust has a wide range in size, varying in diameter from fractions of a micron (10^{-4} cm.) to several hundred microns.

The ascent of an atomic cloud has been discussed by Sutton from the point of view of the convection processes that occur[3]. Immediately following the explosion the fireball, which is at a temperature several thousand degrees higher than that of the surrounding air, expands until equality between the internal and external pressures is achieved. Then because of its density deficiency, the fireball rises very rapidly, at the same time cooling by entrainment of colder air from the environment and by adiabatic expansion, until a level is reached where the buoyancy forces have fallen to zero. The height of this level depends mainly upon the energy of the bomb itself but also to some extent upon the temperature structure of the atmosphere in the vertical. In general the radio-active debris from a bomb in the kiloton range is confined to the troposphere while a megaton weapon is so powerful that a substantial fraction of the radio-activity reaches heights far into the stratosphere.

Once the ascent of the atomic cloud has come to an end, the future course of events can be considered in two classes—close-in fall-out which returns to the earth within about 20 hours of the explosion and long range fall-out by which is meant those particles which remain airborne for days, months or even years. The essential difference between these two types of fall-out is one of terminal velocity, the particles in the close-in category being large enough to acquire falling speeds that ensure their early removal from the atmosphere. The larger particles, like all the others, are radio-active and are transported by horizontal winds during their short period of descent. The location of a weapon test and its timing must therefore be chosen so that dangerous levels of contamination do not fall upon inhabited areas. The meteorological problem is thus reasonably clear cut but, since the upper winds may occasionally vary widely both in time and in space, not necessarily easy of solution. Kellog *et al.* have discussed the main features of the problem and have described a quantitative technique for deriving from the wind structure the probable distribution of radio-active material on the ground[4]. They point out that detailed and reliable forecasts of close-in fall-out must depend upon the existence of a close upper air network providing frequent wind observations to great heights around the area likely to be affected. Such elaborate facilities can be made available in advance of test explosions and an accurate forecast of the fall-out pattern could then be expected. In an emergency situation, however, the standard upper air network would probably be inadequate and the forecaster might have to confine himself to rather broad estimates of the sectors where ground contamination is most liable to occur.

The meteorology of close-in fall-out can be assessed in fairly precise terms because gravitational settling of the particles imposes a limit, less than a day, on the time during which the winds and other processes can exert control. By contrast long range fall-out presents a baffling problem to the meteorologist because the magnitude of the time element may be anything from a day to many years and also because some of the important features, wash-out by rain and diffusion, are not fully understood. The particles comprising long range fall-out are for the most part of diameter less than about 10 microns and have virtually no falling velocities. Vertical diffusion operates very slowly and a high percentage of these particles would remain airborne almost indefinitely if scavenging by precipitation did not occur. It would appear therefore that the long range fall-out which reaches the ground within a week or so of the explosion is deposited mainly as a result of the effect of precipitation upon particles in the lower levels of the troposphere. Particles which remain in the atmosphere for extensive periods are probably carried to very great heights in the first place and eventually diffuse downwards to the earth's surface or merely to levels where deposition can be completed more quickly through the agency of precipitation. All the time the particles are airborne they are of course carried by the winds appropriate to their heights and the large scale shearing motions always present in the atmosphere ensure that the particles, which originally formed a cloud of comparatively small size, are scattered to all longitudes and over a wide range of latitude.

With so many uncertainties, not least the time factor, the life history in the atmosphere of the particles forming long range fall-out is primarily a question of measurement and can only be regarded as a forecasting problem in the most general and qualitative way. Since shortly after the war observations of the rate of deposition of radio-active dust upon the earth's surface have been made at an increasing number of places, mostly in the northern hemisphere, and in addition several countries have carried out programmes for measuring the concentration of radio-activity at various heights in the atmosphere up to about 50,000 feet. If observations of this nature were made and exchanged over a sufficiently wide area, it would become feasible to make reasonable estimates of the total amount of radio-activity in the atmosphere and of its rate of deposition upon the earth and the oceans. Such information would be of the greatest interest and value to health physicists, biologists and many others.

Since 1948 the Royal Air Force Meteorological Reconnaissance Squadron which is based at Aldergrove in Northern Ireland has sampled the air for radio-active dust while engaged on routine weather observing duties. 'Bismuth' flights, as they are called, follow a triangular course over the Atlantic, the cruising level changing from 1,500 feet to 18,000 feet or vice versa at each corner of the triangle. The aircraft carries on its wing a cylindrical filter of high collective efficiency and a representative sample of the dust content of the lower troposphere is thereby obtained. At the end of each flight the filter with its collected dust is sent for analysis to the Atomic Energy Research Establishment on whose behalf the sampling programme is carried out.

The efforts of the Bismuth squadron have been supplemented from time to time with the aid of aircraft flying at much greater altitudes over the United Kingdom. It has thus been possible to measure the concentrations of radio-activity at various levels to about 48,000 feet in the neighbourhood of the British Isles which, situated far from test sites and therefore free from local effects, form a suitable observation area for the study of contamination on a global scale. These aircraft observations must therefore rank among the most important contributions to this problem and it is noteworthy that the results obtained have been used in the American[2] as well as in the British[1] report.

Stewart, Crooks and Fisher have analysed the data accumulated from the air sampling programmes and have reached important conclusions which have a direct bearing on the meteorological factors involved[5]. Of special interest is the observed difference over a long period between the concentration of radio-activity produced by a kiloton or atomic bomb and the concentrations produced by a megaton or hydrogen bomb. The cloud resulting from the explosion of an atomic weapon at the American test site in Nevada moves in the circulation of the troposphere and completes a circuit of the earth every four to seven weeks. At the end of the first circuit lateral diffusion is very largely complete and subsequent observations of radio-activity over the United Kingdom show a substantial decrease of concentration with time even when allowance is made for the normal processes of radio-active decay. By contrast the observations from the Bismuth flights following the hydrogen bomb tests in the Pacific in the spring of 1954, show only a very slight decrease with time of airborne activity but, when the correction for decay is applied, a gradual increase in atmospheric concentrations is revealed.

Stewart *et al.* attribute these differences in behaviour of the two types of cloud mainly to the very slow rate of vertical diffusion at the tropopause and above. The effect on the atomic bomb cloud is to inhibit upward diffusion from the troposphere and so the steadily diminishing concentrations observed after lateral diffusion has been completed may be interpreted as showing the rate of removal of radio-active dust by deposition upon the surface of the earth. Viewed in this way, the observations suggest that half the material in an atomic bomb cloud settles out of the atmosphere within about three weeks. On the other hand the cloud from a hydrogen bomb penetrates many thousands of feet into the stratosphere and the particles of dust size diffuse downwards steadily but very slowly. Concentrations in the lower atmosphere are therefore reinforced continuously by diffusion from above to an extent which may offset the losses by deposition.

Researches such as those described by Stewart *et al.* are clearly of great potential value to the science of meteorology and also suggest how much more could be learned if similar observing programmes were carried out in many different parts of the world as a concerted attack upon the problem of atmospheric diffusion.

Meteorology and reactor siting.—In the past industrialists have not always acknowledged the importance of meteorology when deciding upon a location for a factory and all too often the meteorologist has been consulted at a late stage to explain why the site chosen has proved to be a bad one. More recently, however, at those factories where the waste products released to the atmosphere contain obnoxious gases or particles, meteorological factors have been given close attention in measures taken to reduce the damage likely to be caused by the chimney effluents. The operation of a nuclear reactor presents similar problems, but as has been explained already, in a more vital way and there is no question but that local weather conditions must be taken into account in site selection. The problem is essentially one of safety, hence its importance. It is known that in routine operation a minimum amount of radio-active material will be discharged from the chimney of the reactor which must therefore be sited so as to ensure that human life, either directly or indirectly, is not exposed to harmful concentrations. Moreover, should a major accident occur at the reactor, there would be an almost instantaneous release of a large amount of radio-activity and for some distance down-wind lethal or dangerous concentrations would occur near ground level. Thus although every precaution is taken both in the construction and in the operation of a reactor and one can say that the possibility of a serious accident is remote, there must be general agreement about the wisdom of building reactors at distances well removed from densely populated areas.

The meteorological problem in relation to the operation of nuclear reactors again consists very largely of estimating the diffusive properties of the atmosphere. For routine operations we are concerned with concentrations from a continuous source of radio-activity and the chimney is regarded as approximating to an elevated point source; in considering the effects of a disaster the source is an instantaneous one and can also be regarded as a point source without over-simplifying the problem. Wind speed, wind direction and atmospheric stability, as indicated by the vertical distribution of temperature, are the most important parameters governing dispersion in the atmosphere and these are incorporated in Sutton's theory of diffusion by means of which quantitative estimates can be made of concentrations likely to occur in varying conditions of weather and for specified strengths of source[6]. The application of this theory to problems of airborne radio-activity is treated in considerable detail in a handbook compiled by the United States Atomic Energy Commission[7]. Both in this country and in the United States much attention has been given to the values to be used for the diffusion parameters, e.g. n and C_z, which appear in Sutton's equations. n is a dimensionless number which is related to the vertical gradient of the horizontal wind and varies in value from zero in very turbulent or high lapse conditions to unity when there is little or no turbulence as in the case of strong inversions. When the potential temperature is constant with height the appropriate value of n is 0·25. The parameter C_z is a generalized diffusion coefficient which serves to indicate the vertical spread of the plume or cloud and is therefore of special importance when considering ground level concentration from elevated sources. Observations of C_z in different areas and over a wide range of conditions have shown only a fair measure of agreement. Some portion of the discrepancies can be attributed to local terrain and this emphasizes the importance of accumulating data on the micrometeorology of an area which may be under consideration as a reactor site. In applying Sutton's equations in a specific locality it is therefore advisable to bear in mind that the theory was originally developed for diffusion over a level surface in a neutral atmosphere and that when these conditions do not hold some departure of observation from theory must be anticipated.

Precipitation is another weather factor of importance in the reactor problem as well as in the case of fall-out. It is well known that rain or a shower clears the air of dust and would presumably also be effective in cleansing the lower atmosphere of any radio-active matter that is present. It will be apparent therefore that the onset of precipitation could upset estimates of concentration based on ordinary diffusion theory and in a question of this importance it is essential that as much information as possible should be obtained about the precise influence of rainfall upon airborne particles.

Radio-activity in meteorological research.—Systematic observations have served to indicate the rate at which radio-active matter released during weapons trials mixes with the atmosphere and have also given prominence to the possibilities of using harmless radio-active substances as tracers for meteorological research. An important advantage of radio-activity is that the most minute quantities can be readily detected by modern sampling and analysing techniques. Thus, as Machta has pointed out, it may be practicable in the near future to study problems of the large scale circulation by plotting the progress through the atmosphere of a few grams of a suitable radio-active substance released at a selected time and place.

Geophysical research has a long history of the application of natural and artificial tracers, the use of drift bottles by oceanographers being one of the best known examples. The eruption at Krakatao hurled large quantities of dust into the high atmosphere and enabled meteorologists to study mixing and other processes there. In recent years constant-level balloons have been used to track individual air parcels for many days at a time. Important natural tracers are water vapour and ozone, the latter having space and seasonal variations that appear to be closely connected with circulations above and below the tropopause. In many experimental studies of local or small scale meteorological problems, tracers such as smoke have been indispensable accessories. Meteorologists now hope that the use of radio-active substances as tracers may produce more complete data in the case of some of the older types of field experiment and may also make possible trials of a kind never before considered feasible. Many ideas have been put forward such as the use of radio-active tritium in association with water to study the formation of dew and to investigate the hydrologic cycle generally; the use of a special tracer to observe air trajectories in jet streams; as a control in rain making trials; and for the purpose of measuring diffusion rates at various levels in the atmosphere. All such experiments must, however, be very carefully planned and the meteorologist will need full co-operation from specialist physicists and chemists. The properties required of a tracer—insoluble in water, not liable to be washed out of the atmosphere by rain, etc.—must be carefully defined. Large scale problems will call for the closest international co-ordination and may involve a lengthy period of preparation in order to perfect the arrangements. These precautions are essential because a large scale tracer experiment cannot be repeated using a further quantity of the same material as tracer until the original amount has decayed sufficiently, a process that may take several years.

International collaboration.—For several years the United Nations, through an Advisory Committee and through the specialized agencies, has played a leading part in promoting international collaboration both in arriving at the best assessment of the possible dangers from the uses of atomic energy and in exchanging information concerning the many aspects of the application of atomic energy to peaceful purposes. The World Meteorological Organization, which is one of the specialized agencies of the United Nations, has clearly an important part to play in these questions and at the Executive Committee Meeting in April, 1956 resolved to co-operate fully with other international organizations as well as to provide expert advice to its own Members. The Executive Committee appointed a panel to study the meteorological aspects of atomic energy with a view to ensuring that new techniques arising from this field of activity may be used to assist the science of meteorology in every possible way, including the development of new instruments. In its first report the panel has made several recommendations covering the dissemination of information to Members and the organization of research projects.

Collaboration among meteorologists in atomic energy matters will be greatly helped by some developments in connection with the International Geophysical Year. The programme of the I.G.Y. was recently extended to incorporate measurements of nuclear radiation in precipitation and in the air. It is hoped therefore that during the next year a good network of stations, with uniform methods of collecting and analysing rain water and air samples for radio-activity, will be established throughout the world. This initiative on the part of the I.G.Y. is especially to be welcomed because a vast network of observing stations will be required for the successful prosecution of tracer studies into the general circulation.

The international collaboration that is being actively encouraged in the meteorological aspects of atomic energy needs no underlining because meteorologists have long been accustomed to think internationally in the interests of their science. Another form of close collaboration which is developing is that between meteorologists and specialists in other sciences. Where atomic energy applications are concerned, it will not be sufficient for the meteorologist merely to consult the physicist or chemist or biologist and then to make his own way in his particular problems. The subject is indeed so complex that collaboration must take place at every stage of meteorological research in this field and it is not the meteorologist alone who will benefit. Physicists and chemists are finding that for many problems in radio-activity the atmosphere forms a convenient and accessible laboratory. But it has curious properties which the meteorologist can help to explain and perhaps circumvent.

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THE DIURNAL VARIATION OF SURFACE WIND AND PRESSURE AT BERMUDA

By P. C. BARTRUM, B.A.

Introduction—Bermuda is well situated for obtaining observational data free from the complications caused by orography and large land areas. Situated between latitudes 32° and 33°N. it lies for the greater part of the year on the edge of the Azores–Bermuda anticyclone, the prevailing wind being south-west. It is not, however, free from the disturbing effects of passing depressions and anticyclones, especially in the winter months when gales from a direction between north and west are common. It is also liable to be affected by hurricanes in the latter part of the hurricane season (late August to October), but during the years 1935 and 1936, with which we are concerned, hurricanes did not come close enough to cause much disturbance to Bermuda's weather. The relative freedom of Bermuda from such disturbing influences makes it particularly suitable for the investigation of the diurnal variation of wind and pressure.

The anemometer and its exposure.—The wind was measured by a Dines Pressure Tube Anemometer set up at Fort George, St. George's, Bermuda, latitude 32°23′N., longitude 64°41′W. The anemometer is situated on a parapet of Fort George and the height of the mast is 40 ft. Fort George itself is built into the summit of a hill about 170 ft. high above sea level, and the parapet is 182 ft. above sea level, so that the vane is 222 ft. above sea level. The hill slopes steeply in all directions except to the west, where the slope is gradual. The anemometer, therefore, has a good exposure in all directions, but owing to its position on a local prominence the winds recorded may be expected to be somewhat stronger than they would be over level ground at sea level.

Bermuda itself (at the time) had an area of about 19 square miles, being surrounded by sea for at least 600 miles in all directions. The majority of the land mass of Bermuda lies to the south-west of the anemometer.

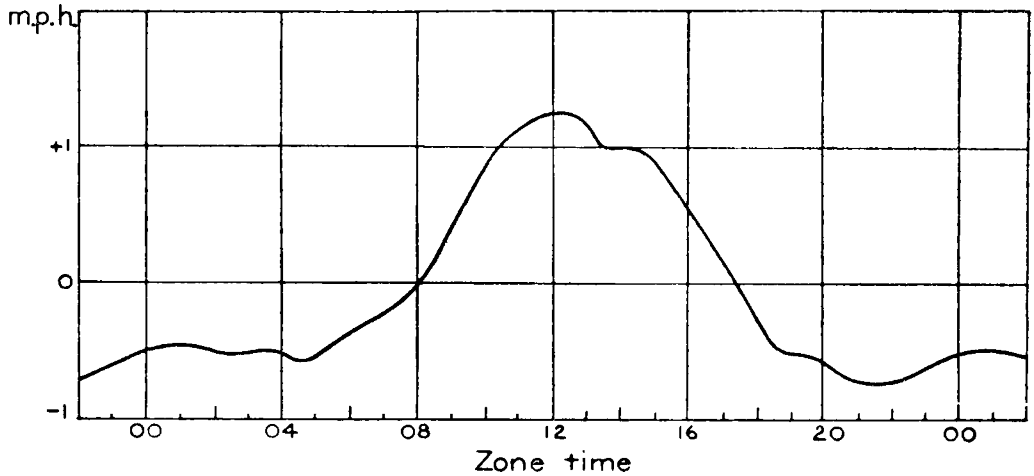

FIG. 1—DIURNAL VARIATION OF WIND SPEED AT ST. GEORGE'S, BERMUDA, 1935–36

Mean diurnal inequality for periods of an hour centred at each half hour.

Tabulation and analysis of wind data.—Mean wind speed and direction for hourly periods ending at the exact hour (zone time = G.M.T. − 4 hours) were read off the anemogram, speeds being estimated to the nearest mile per hour, and directions to the nearest of the 16 points of the compass (N, NNE, NE, etc.). These were tabulated by months for the two years 1935 and 1936. Vector components of wind from southerly and westerly directions were then calculated from the mean speed and direction over each hour. These were similarly tabulated by months. From these figures hourly diurnal inequalities of absolute speed, and the component velocities from west and south, were deduced for each month. The complete series of observations was used without any selection.

The monthly inequalities of each element were combined into three groups: Winter (Jan., Feb., Nov., Dec.), Equinoxes (March, April, Sept., Oct.) and Summer (May, June, July, August). Each of the resulting diurnal inequalities was therefore based upon about 240 readings. When these were plotted, random fluctuations of the order of 1/5 of the diurnal amplitude were in evidence. However, if all the data for the two years are combined together, the random fluctuations are reduced to reasonable proportions. The results are shown diagrammatically in Figs. 1 and 2.

Fig. 1 shows the diurnal variation of wind speed independent of direction. It is of the usual form with a maximum soon after 12 hr. due to the well known diurnal effect of temperature. The low value of wind speed between 13 and 14 hr. is apparently a real effect as it occurred in 15 of the 24 months (namely Jan., March, April, May, Aug., Sept., Oct., Nov. 1935 and Feb., April, May, June, Sept., Oct., Dec. 1936). This is perhaps a secondary temperature effect, due to the afternoon build-up of cloud.

The hourly diurnal inequalities, grouped into seasons, were also harmonically analysed and the first four harmonics deduced. As a check the diurnal inequalities based on the whole of the two years' data were also harmonically analysed. The harmonic components thus deduced were valid for mean values of the wind over an hour, centred at the half-hours. These were then corrected to give the harmonic components valid for instantaneous values commencing at 00 hours zone time. The method is given by Bilham[1].

The results are shown in Table I. In order to obtain local mean time from the zone time it is necessary to subtract 19 min. The phase angles are given with respect to zone time, so that to obtain phase angles valid for local mean time α_1 should be increased by 5°, α_2 by 9°, α_3 by 14°, and α_4 by 19°. In the case of the absolute wind speed the first harmonic has the largest amplitude, while in the case of the vector components the second harmonic preponderates. This is in accordance with what we should expect, the preponderance of the second harmonic in the wind components being connected with a similar preponderance in the diurnal variation of pressure.

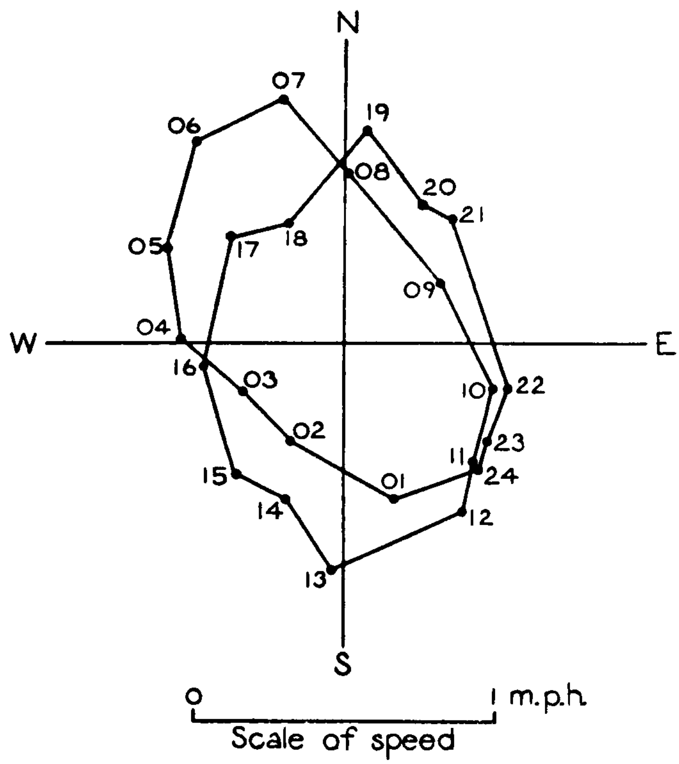

FIG. 2—DIURNAL VARIATION OF VECTOR WIND AT ST. GEORGE'S, BERMUDA, 1935–36
Mean diurnal inequality for periods of an hour, ending at the hour indicated (zone time). The wind is to be regarded as blowing *from* the appropriate point on the diagram *to* the origin.

The diurnal variation of pressure.—Owing to the interest in the relationship between the diurnal variation of the vector wind and the diurnal variation of pressure it was decided to analyse harmonically the latter for the same years, 1935 and 1936, at Fort George. The readings used were taken from a Short and Mason open scale aneroid barograph and adjusted to agree with the readings of the Kew Pattern mercury barometer, both at Fort George. Readings of the latter were made at 08, 14 and 20 hours, zone time. The results are given in Table II. The same adjustment must be made to the phase angles as in the case of the wind if values valid for local mean time are required.

TABLE I—HARMONIC ANALYSIS OF THE DIURNAL VARIATION OF SURFACE WIND AT ST. GEORGE'S, BERMUDA, 1935–1936

Absolute Speed (V)

	D_1	α_1	D_2	α_2	D_3	α_3	D_4	α_4	V_0
		°		°		°		°	
Winters ...	0·55	300	·22	055	·12	258	·07	090	18·4
Equinoxes ...	0·92	264	·35	055	·07	032	·09	225	15·6
Summers ...	1·33	250	·55	078	·10	050	·05	147	12·9
Years... ...	0·89	264	·37	066	·03	357	·04	162	15·6

Westerly Component (u)

	A_1	α_1	A_2	α_2	A_3	α_3	A_4	α_4	u_0
Winters ...	·34	002	·56	336	·22	183	·05	082	+2·9
Equinoxes ...	·17	284	·54	340	·01	157	·02	337	+0·1
Summers ...	·13	147	·45	320	·08	312	·08	280	+0·8
Years... ...	·09	342	·51	333	·06	200	·02	320	+1·3

Southerly Component (v)

	B_1	α_1	B_2	α_2	B_3	α_3	B_4	α_4	v_0
Winters ...	·33	013	·58	091	·03	234	·13	259	−0·4
Equinoxes ...	·33	140	·71	072	·07	203	·18	173	+1·4
Summers ...	·57	248	·62	075	·09	023	·08	329	+5·7
Years... ...	·09	240	·63	079	·01	276	·07	229	+2·2

The mean diurnal variations of wind are fitted to the forms:

$$V = V_0 + D_1\sin(\omega T + \alpha_1) + D_2\sin(2\omega T + \alpha_2) + \ldots$$
$$u = u_0 + A_1\sin(\omega T + \alpha_1) + A_2\sin(2\omega T + \alpha_2) + \ldots$$
$$v = v_0 + B_1\sin(\omega T + \alpha_1) + B_2\sin(2\omega T + \alpha_2) + \ldots$$

where T = zone time of 60°W.

and ω = angular velocity of the earth's rotation.

Wind speed in m.p.h.

If these are compared with the values for 1933 and 1934 given by Bartrum[2], it will be seen that there is close agreement, especially in the second harmonic. Simpson's empirical formula for the second harmonic[3] gives, for Bermuda, $c_2 = 0{\cdot}95$ mb., $\alpha_2 = 144°$. The phase agrees closely with the observed value, but the predicted amplitude is somewhat larger than that observed.

The observed relationships between the second harmonics of pressure and of the wind components are shown in Table III. The significance level of the other wind harmonics is probably too small to warrant detailed consideration.

Relation between diurnal variation of wind and pressure.—It is well known that the second harmonic of the diurnal variation of pressure is such that the maxima and minima occur roughly at the same local time everywhere in the world (Simpson, 1918). This may be regarded as due to the passage round the world from east to west with the sun of two shallow anticyclones separated by two shallow cyclones, having their centres somewhere near the equator, and superimposed on the ordinary relatively static pressure distribution. For a station in the northern hemisphere the centres would pass to the south and the expected result would be a wind, superimposed on the ordinary wind, which should veer clockwise round the compass twice in 24 hours. This is exactly what is found in Bermuda (as in other places).

TABLE II—HARMONIC ANALYSIS OF THE DIURNAL VARIATION OF STATION LEVEL PRESSURE (MB.) AT ST. GEORGE'S, BERMUDA, 1935–1936

Height of barometer cistern above mean sea level 158 ft.

	C_1	α_1	C_2	α_2	C_3	α_3	C_4	α_4	p_0
Winters ...	·13	293°	·71	155°	·21	351°	·09	197°	1012·3
Equinoxes ...	·20	271	·67	145	·05	029	·02	083	1012·3
Summers ...	·19	274	·54	141	·11	152	·02	098	1012·7
Years... ...	·17	278	·64	147	·05	013	·03	172	1012·5

The mean diurnal pressure variations are fitted to the form:

$$p = p_0 + C_1\sin(\omega T + \alpha_1) + C_2\sin(2\omega T + \alpha_2) + \ldots$$

where T = zone time of 60°W.

and ω = angular velocity of the earth's rotation.

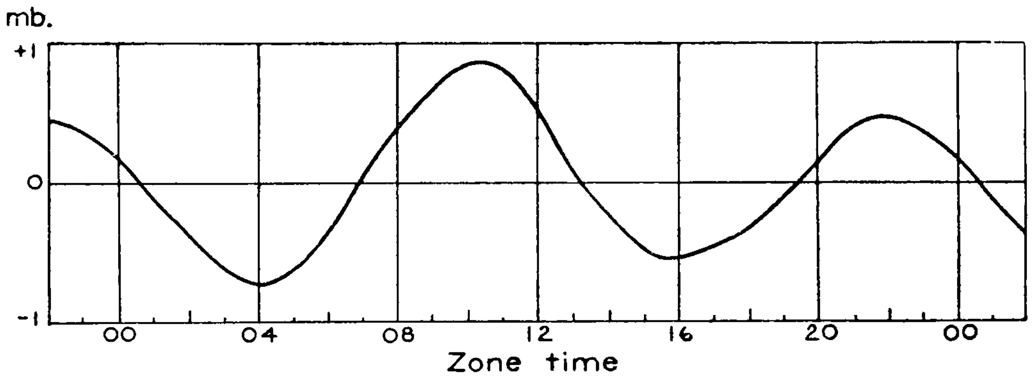

FIG. 3—DIURNAL VARIATION OF PRESSURE AT ST. GEORGE'S, BERMUDA, 1935–36

Mean diurnal inequality at each hour.

TABLE III—OBSERVED AND "IDEAL" VALUES OF PHASE DIFFERENCES AND RATIOS OF AMPLITUDE FOR THE SECOND HARMONICS

	Phase differences		Amplitude ratios		
	West–Pressure θ_2	South–Pressure ψ_2	West/South A_2/B_2	West/Pressure A_2/C_2 m.p.h./mb.	South/Pressure B_2/C_2 m.p.h./mb.
Winters	181°	296°	0·95	0·79	0·83
Equinoxes	195	287	0·77	0·81	1·32
Summers	179	294	0·74	0·84	1·13
Years	186	292	0·81	0·81	1·00
"Ideal"	180	270	1·07	0·95	0·89

Since the pressure systems are moving too rapidly we cannot make use of the geostrophic relation to estimate how the direction of the semi-diurnal wind should fit in with the maxima and minima of the semi-diurnal pressure wave. The problem was considered by Gold[4] who showed that if vertical motion and frictional forces are neglected, then for the semi-diurnal wave in the northern hemisphere the phase angle of the westerly component of wind should be 180° in advance of the pressure, and that of the southerly component should be 270° in advance of the pressure, i.e. the wind should be east at pressure maxima, west at pressure minima, and north or south when the pressure has its mean value in such a way that the wind vector rotates in a clockwise direction. Thus the wind should be in just the opposite direction to what we should deduce by a crude application of the geostrophic relation. Gold also deduced values for the amplitude ratios. These ideal relationships for the case of Bermuda are shown in the lowest row of Table III. It will be seen that there is general agreement, as can also be seen by comparing Figs. 2 and 3.

The formulae obtained by Gold gave waves of infinite amplitude at latitude 30°, and he therefore attempted to allow for frictional forces. He assumed a force proportional to the wind and in the opposite direction, a device having mathematical convenience but without satisfactory physical basis. The effect is to increase the phase differences θ_2 and ψ_2, and to decrease the amplitude ratios A_2/C_2 and B_2/C_2. When applied to the case of Bermuda these results did not give any marked improvement as regards agreement with observation.

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ESTIMATION OF THE FREQUENCY OF "RUNS OF DRY DAYS"

By E. N. LAWRENCE, B.Sc.

Part II

Persistence.—Throughout this study, the question of the effect of persistence occurs. In the geometric series it is assumed to be zero, i.e. no matter how long a spell lasts the chances of a further day remain constant. In the logarithmic series, a definite (positive) persistence is allowed for, but the persistence is forced into a special pattern. In the "Jenkinson-probability" series a "smoothed persistence", indicated by the value of σ_1/σ_2, is calculated for each site; a source of "error" here is probably the inherent assumption that one type of persistence exists throughout the range of lengths of run. In the "natural-persistence" series actual persistence values are introduced. It would appear that this achieves a greater accuracy than the other series when mean (area) values are assumed for the chances of a further day of the run. By considering totals of runs (spells) over a period or area, the "curves" of P_1, P_2, P_3, ... P_{15} against length of past run were constructed (see Fig. 7) for the months June, July, August and for the season, June to August inclusive, over the combined area of south-west, south-east and east England, showing the August and seasonal values for each of the three sub-areas, south-west, south-east and east England. These graphs suggest that, throughout the range of lengths of run, there are several "types" of persistence:

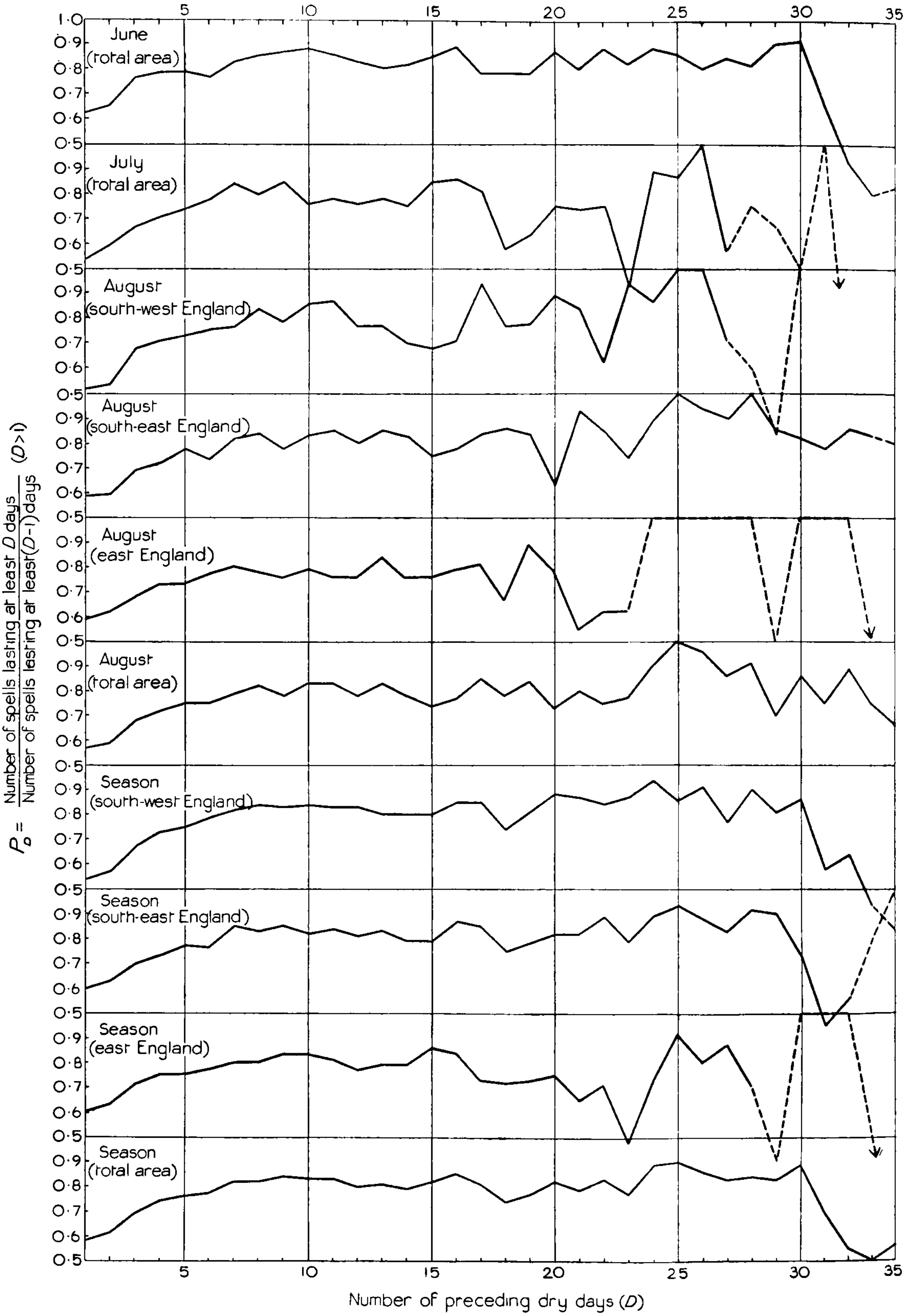

FIG. 7—VALUES OF P_D

(i) Up to run lengths of 8–10 days: positive persistence

(ii) From 8–10 days to 18–20 days: zero or slight negative or anti-persistence

(iii) From 18–20 days to about 25 days: zero or slight positive persistence

(iv) From about 25 days to about 30 days: slight negative or anti-persistence

(v) From about 30 days: negative or anti-persistence.

These properties may be illustrated also by graphs of length of run against cumulative frequency F plotted on a logarithmic scale, persistence and anti-persistence being revealed by the concavity or convexity, respectively, of the curve towards increasing F. It is interesting to note that Belasco[5] found that for anticyclonic days at Kew there was persistence in the range 3 to 20 days, and thereafter strong anti-persistence; this suggests that persistence of "dryness", under similar climatic conditions, would not become strongly negative until well after 20 days.

Similar data of runs of dry and wet days in Southern Rhodesia[6] were examined for runs of up to eight days and marked persistence was found up to about seven days. A range of the types of persistence present in an area may provide a useful measure in the study of climatic types. It is noteworthy that frequencies calculated from area values for the probabilities P_4 to P_{15} give remarkably good agreement with the observed cumulative series.

Conclusions.—The "natural-persistence" series with area probability values is the most convenient and accurate for calculating frequencies of runs of dry days. The logarithmic series also achieves a high degree of accuracy but is much less simple to compute. The geometric series does however provide reasonable estimates, though it is not quite so simple to compute as the "natural-persistence" series. The "Jenkinson-probability" series, which is specially suited to the frequencies of rarer runs, is not fully tested here for this quality.

The area probability values ("natural-persistence" method) are sufficiently different from month to month as to suggest that better frequencies could be calculated from a sliding scale of values, for each value of P_D, throughout the summer. These graphs would give, for each date and each area, the values of P_4 to P_{15} most appropriate to the calculation of frequencies of dry spells centred on that date.

The fact that area mean values of P_D give good approximations to run frequencies may be useful in deciding on "typical" sites or climatic regions for certain climatological variables or for comparing regions, in particular for the study of climatic types.

The value of persistence is not constant throughout the range of lengths of run. There is more than one "persistence régime", a fact which it may be necessary to consider in medium and long-range forecasting and allied problems.

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BRITISH OCEAN WEATHER SHIPS—10th ANNIVERSARY

By C. E. N. FRANKCOM

On 1st August 1947 *Weather Observer* sailed from London on her first voyage as an Ocean Weather Ship to Station "Juliett" in the North Atlantic (52°30′N., 20°W.)—thus being the first British Ocean Weather Ship to put to sea. On 5th August she took up duty for the first time at "Juliett" and sent her first radio weather message from that station to Dunstable and thereby inaugurated the United Kingdom's active participation in the North Atlantic Station Agreement, which had been signed in London in September 1946. (Her log-book shows that her first day on station was marked by westerly winds of force 4–5; air temperature being 65°F., dew-point 58°F. and sea temperature 67°F.)

Accordingly, August 1957 marks the tenth anniversary not only of *Weather Observer's* service as an Ocean Weather Ship, but also of British participation in this outstanding example of international co-operation.

Two of the other British Ocean Weather Ships complete ten years' service in the North Atlantic during 1957—*Weather Recorder* in October and *Weather Watcher* in November. *Weather Explorer* completes her tenth year of service in February 1958.

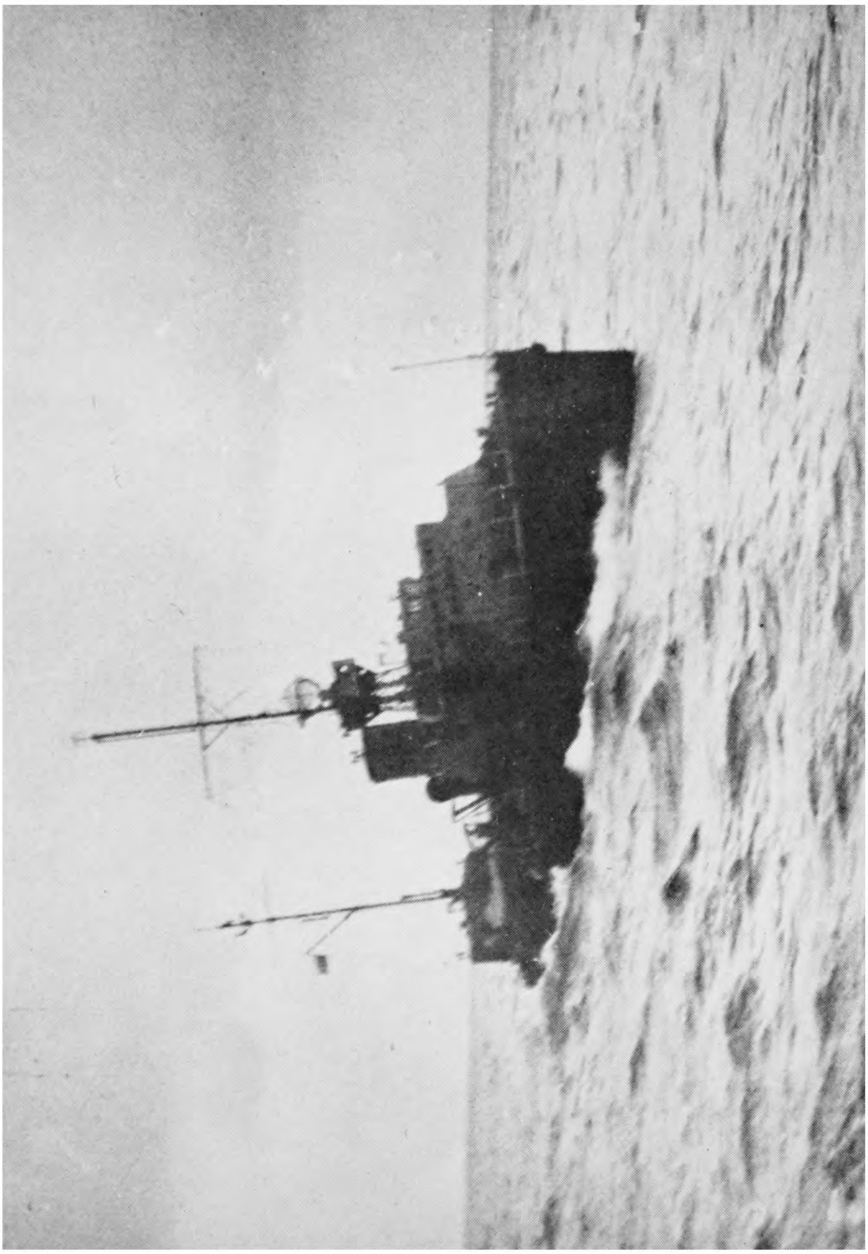
Weather Observer was primarily the "Flower" class Corvette *Marguerite*—a class of vessel which was made famous by Nicholas Monsarrat in his book *The Cruel Sea*. The other ships were previously named *Genista, Snowflake* and *Thyme* respectively.

Until January 1955 the four British ships, operating from their base at the Great Harbour in Greenock, confined their activities exclusively to Ocean Stations I and J. Subsequent to that date they have operated in rotation with French and Netherlands vessels at Ocean Stations A, I, J and K. (Norwegian vessels have also periodically done six monthly duty at Station A and have then returned to Station M which has been temporarily manned in the meantime by Netherlands ships.)

Considering the stormy conditions which so often prevail in the North Atlantic Ocean, these ten years have been strenuous not only for those who have served aboard the ships, but also for the vessels themselves. The meteorological statistics, published in the *Marine Observer*[1, 2, 3], aptly illustrate this point.

In addition to surface observations, upper air observations (radio-sonde and radar-wind) up to a height of about 50,000 ft. have regularly been carried out aboard the ships and the meteorologists, of whom there are seven in each ship, have

[*To face p. 304*



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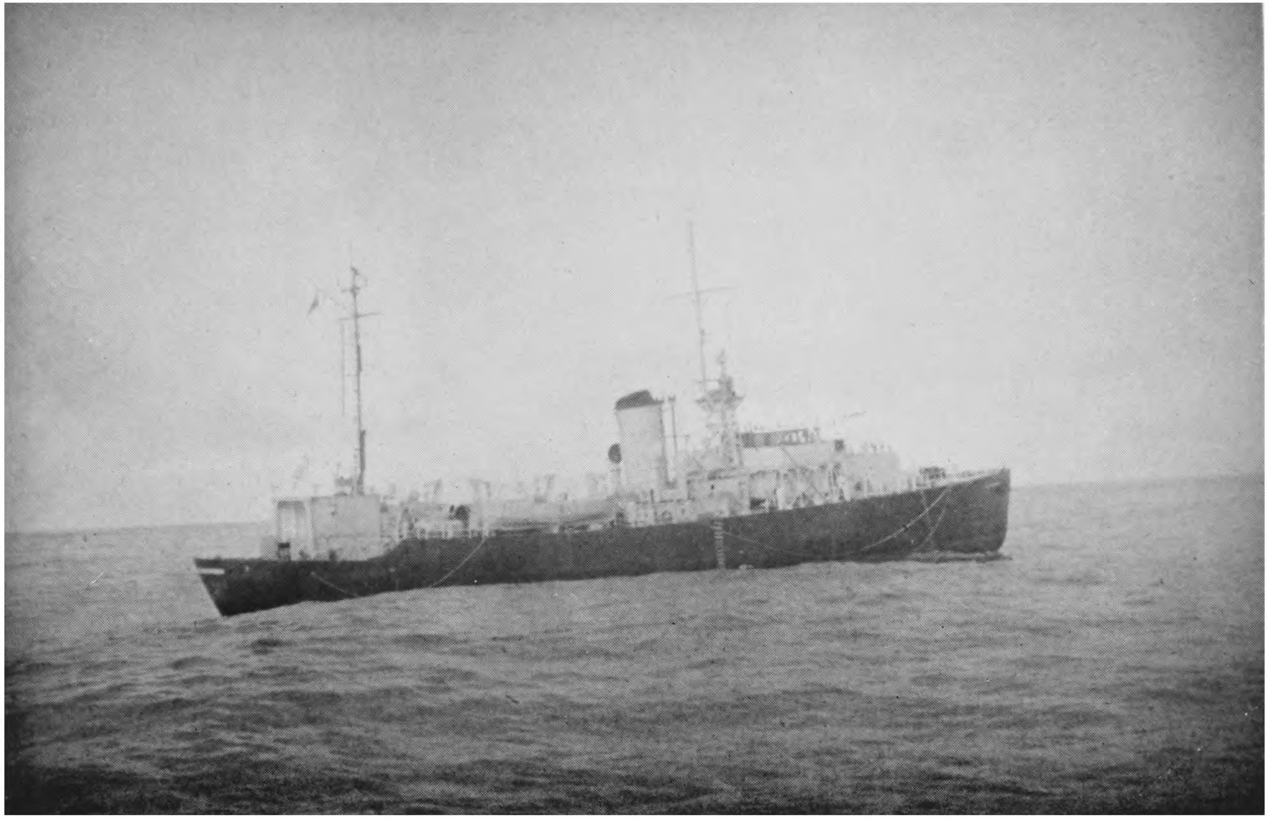
O.W.S. *WEATHER OBSERVER*

Photograph by D. Philips

O.W.S. *WEATHER EXPLORER*



Photograph by D. Philips

O.W.S. *WEATHER RECORDER*

Photograph by W. N. Burton

O.W.S. *WEATHER EXPLORER*

Meteorologists retrieving bathythermograph.

prided themselves upon the fact that it has been extremely rare for an upper air observation to be missed due to bad weather. Releasing the large balloon, with instruments attached ready for taking upper air observations, in a Beaufort force 11 wind aboard a small ship in mid-Atlantic is no easy task. When one considers that these meteorologists are not professional seamen one will realize what a fine job they have done.

For the upper wind observations aboard these ships a Naval-type radar has been used and the whole observations need constant visual attention and considerable skill on the part of the technicians operating the radar. This again is no easy job under heavy weather conditions. These technicians not only operate the radar but have maintained this apparatus as well as all the elaborate radio equipment aboard the ship in an admirable manner—often involving long hours of work in exposed and uncomfortable conditions.

Each individual aboard the ships—whether he be on Deck, in the Engine Room, in the Radio Office or in the Victualling Department—has played his part in the success with which the work of the British Ocean Weather Ships has been carried out during these ten years. One individual who certainly should not be forgotten is the cook aboard each of the ships, who has always managed to produce hot meals no matter how rough the weather has been.

Each of these ships carries a total crew of 53. The following are the names of those individuals who have served aboard the British Weather Ships throughout this ten year period:

Captain A. W. Ford	Master	Mr. A. J. Read	Chief Steward
Captain F. A. Elston	Master	Mr. A. M. Dunning	Chief Radio Technician
Captain H. Sobey	Master		
Mr. W. Oliver	Radio Overseer	Mr. R. H. Brass	Chief Radio Technician
Mr. T. Chadwick	Radio Overseer		
Mr. R. A. Gascoyne	Chief Steward	Mr. H. F. Clifton	Bos'n

The meteorologists normally serve a period of one year aboard a weather ship with the option of extending that period if they so wish. Mr. M. V. Dumphy has the distinction of having done the maximum number of voyages so far of any meteorologist i.e. 51 voyages (approximately six years). Mr. R. G. Findlay served for 45 voyages and Mr. W. N. Burton for 40 voyages. At the Base in Greenock Captain G. W. Steer, the Shore Captain, and Mr. F. W. Martin, Clerical Officer, have served throughout the ten years.

In addition to their meteorological duties, the Ocean Weather Ships provide navigational aids to aircraft in flight and air/sea rescue facilities and they also carry out certain oceanographical work on behalf of various authorities in the United Kingdom. All these activities add to the interest of life aboard the ships but they obviously involve much specialist work on the part of the individuals concerned. The Weather Ships have also provided a very convenient "platform" for special research and other activities to be carried out; e.g. these have included seismic experiments on behalf of Cambridge University; magnetic observations for the Admiralty; various experiments with new type inflatable life rafts and a considerable variety of meteorological experiments.

The existing ships were selected as most suitable for Ocean Weather Ships primarily on account of their excellent reputation for sea-worthiness as North Atlantic anti-submarine escort vessels during the war and also because they were surplus to naval requirements and were therefore acquired relatively cheaply. After all, this is an important consideration for the taxpayer. The ships have shown throughout these ten years what good sea boats they really are and they have fulfilled their task admirably. Their sea-worthiness and their eminent suitability for this work are largely related to their special design and their small size. They are, however, a little too small for the comfort of those who serve in them and, as the ships are now showing wear as a result of their strenuous ten years in the Atlantic, preceded by eight years even more strenuous war service, authority has now been obtained to replace one of these ships (*Weather Explorer*) by a "Castle" Class Frigate named *Oakham Castle* which has been transferred from the Admiralty to the Air Ministry for the purpose. *Oakham Castle* is now in the shipyard of Messrs. Lamont & Co. at Greenock for conversion to an Ocean Weather Ship. This is quite an extensive job and is expected to take about nine months. Steps are being taken with a view to replacing the other three ships after a little experience has been gained with *Oakham Castle.*

"Castle" Class Frigates are in fact the lineal successor to the "Flower" Class Corvettes. They are slightly larger (having a total length of 236 ft. compared with 205 ft.) and the accommodation aboard them will be considerably more roomy and comfortable than that aboard the existing ships.

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HELICOPTERS AND THE FORECASTER

By A. J. WILLIS

Helicopters are becoming increasingly numerous throughout the world and have a considerable operational future. Some forecasters may not, however, be quite as familiar with the operating characteristics of helicopters as with those of more conventional aircraft. The following notes have been compiled to help forecasters to give helicopter pilots the type of information most suited to their needs.

Wind.—*On the ground.*—When starting up or running down in gusty conditions the free-wheeling rotor blades are liable to "blade sailing". The blades are lifted violently upward when facing into wind and thrown downward as they face away from the wind. The vibrations thus set up in the rotor blades may so increase in amplitude as to cause the ends of the rotor blades to strike the rear of the fuselage with consequent damage. This effect may occur when surface winds exceed about 25 kt., and helicopter operators usually ask to be given a special warning when these conditions are expected. To reduce the risk of "blade sailing" some helicopters are fitted with "droop stops" which confine the vibrations to safe limits in winds up to about 40 kt.

During take-off.—Surface wind strength and direction may be of great importance when landing or taking-off in very restricted areas.

In flight.—Once the helicopter is airborne wind strength is important for two reasons:—

(i) With a cruising speed of only 60–80 kt. strong headwinds may make a point-to-point flight impracticable.

(ii) If for other reasons, e.g. low cloud, the helicopter has to be flown very close to the ground the turbulence associated with strong winds could be very dangerous.

Temperature.—Carburettor intake temperature is of extreme importance, especially on take-off, and over sun-heated concrete may be well in excess of nearby screen temperatures. Temperatures much above 80°F. may result in a drastic reduction of pay load.

Visibility.—*Forward visibility.*—Although the hovering capability of the helicopter is one of its most noted characteristics, flying at very low speeds greatly increases fuel consumption. Therefore visibility becomes of importance to the helicopter pilot if it causes him to reduce his speed to below 60 kt. for more than a limited period. In practice this means that for normal operation a forward visibility of not less than one mile is required although for short distances a visibility of much less than one mile may be accepted. It should be remembered that when surface visibility is reduced by smoke or haze beneath an inversion the haze may often be thicker near the inversion than at the surface. Thus the forward visibility for a helicopter pilot operating beneath the haze top at say 500–1,000 ft. may frequently be much less than that reported at the surface.

Air–ground visibility.—The oblique air–ground viewing angle of the average aircraft and of some helicopters makes visual contact with the ground more difficult to maintain than the surface observations would suggest. Some helicopters, however, allow a near-vertical air–ground viewing angle thus giving a much clearer view of the ground than would be afforded by a more oblique viewing angle.

Cloud.—Providing visual contact can be maintained with the ground, extremely low cloud bases represent in themselves no special problem but helicopter pilots generally try to avoid flying in cloud although limited flying in stable stratified cloud is practicable. Generally speaking there is no flying in very turbulent cloud and certainly no flying in cloud at temperatures below freezing point.

Precipitation.—Apart from freezing precipitation (see ICING), this represents only an indirect hazard to the helicopter pilot in that it may reduce visibility and so the safe cruising speed with a consequent rise in fuel consumption.

Icing.—This is the most serious of all the weather risks for the following reasons:—

(i) The helicopter has very high wing loading. For example the wing loading on a Sycamore helicopter is three times that on a Provost aircraft. Quite a small deposit of ice may therefore have a serious effect on the performance of the rotor.

(ii) Even a slight increase in weight on the rotor blades may cause an appreciable increase in the centrifugal reaction on the rotor head.

(iii) The rotor is very finely balanced and even slight irregularities of weight on the individual rotor blades will destroy the balance and set up severe vibration.

(iv) Ice accretion on the rotor head may interfere with blade control.

(v) As far as is known no British or American helicopter is at present fitted with de-icing devices although one Russian helicopter is reported to be fitted with a means of supplying de-icing fluid to the rotors.

Ground Ice Accretion.—It must be remembered that even on the ground ice formation can be a hazard to the helicopter operator. Ice forming on the blades while the helicopter rotor is turning may set up "ground resonance". This is a condition where vibrations due to the unbalanced rotor blades pass via the ground reaction to the undercarriage springing, where sympathetic vibrations may be set up of amplitude large enough to overturn the aircraft. Furthermore pieces of ice flying off rotor blades at speeds up to 400 kt. may also constitute a real danger to ground crew.

From the foregoing it is plain that even slight ice accretion is a grave danger to helicopters both in flight and while running-up on the ground. As helicopter pilots will normally avoid flying in cloud, the special hazards they may encounter are as under:—

(i) Freezing rain or drizzle.

(ii) Rime.

(iii) Wet snow at temperatures below freezing point. Dry snow is not a hazard.

Helicopter pilots expect these phenomena to be specially emphasized in briefing if they are expected.

Acknowledgement.—I wish to acknowledge the advice and co-operation in the preparation of these notes of Sqd.-Ldr. Dowling, Officer Commanding, Helicopter Squadron, Central Flying School.

WORLD METEOROLOGICAL ORGANIZATION

The meetings of the Aerological Commission and the Commission for Instruments and Methods of Observation, Paris, 1957

The second session of the Commissions for Aerology and for Instruments and Methods of Observation of the World Meteorological Organization took place in Paris, beginning on June 18 and ending on July 5 and 6 respectively. The meetings were held in the Hotel du Palais d'Orsay under the chairmanship of the Presidents, Prof. Dr. J. Van Mieghem (C.Ae.) and Mons. A. Perlat (C.I.M.O.). One of the Committees was a joint one; this dealt chiefly with upper air and radiation observations and instruments.

The functions of the Aerological Commission can be regarded broadly as falling into three groups.:

(*a*) to review developments in meteorological research and their international consequences,

(*b*) to provide the basis of international co-operation in regard to observations and other facilities required for meteorological research

and (*c*) to ensure that the technical procedures used internationally conform with current scientific knowledge.

All of these three aspects of the Commission's work were covered in the Paris session. The scientific aspects of meteorology which came under review included numerical forecasting, the artificial modification of cloud and rain, the jet stream, atmospherics, mountain waves, turbulent diffusion, aerological diagrams, ozone and atmospheric chemistry. It had been the practice to refer such subjects to small working groups which operate between sessions of C.Ae., and the reports of these groups were discussed in Paris. The groups were reconstituted to continue the study of these subjects, with the exception of the jet stream, on which a comprehensive report by the working group was submitted for publication by the W.M.O.

The second aspect of the Commission's work, the provision of the requirements for research, was prominent in the discussions of the final details of the organization of the International Geophysical Year, in the proposal to set up a network of stations for the chemical sampling of air and precipitation, and in the recommendation that the W.M.O. should assume responsibility for the network of ozone observations. Publication of aerological observations was also considered with a view to standardizing practices and the Commission expressed a desire for the continuance after the I.G.Y. of the centre set up by the W.M.O. to collect and publish I.G.Y. observations.

In regard to the third aspect of the responsibilities of the C.Ae., certain small changes in the definition of temperature scales were accepted to conform with the international practices in physics, but probably more interesting were the discussions regarding the jet stream and the tropopause. A definition of the "jet stream" has been recommended differing in detail from that recently adopted by the W.M.O. as a result of a postal ballot of Members. The definition of the tropopause in current use in the Meteorological Office was adopted by C.Ae., but a code was proposed for the further specification of the character of the tropopause and this, it is hoped, will go some way to overcoming the difficulties of classifying unconventional tropopause structures particularly in polar regions.

The terms of reference of C.I.M.O. cover the same ground as those of C.Ae., from the instrumental point of view. It is felt by some that the most valuable work that can be done by C.I.M.O. is that which appears in concrete form in the Technical Regulations or the Guide, and, as the President said in his report, the groundwork for this is done between sessions by the working groups, of which more than half the members in the present case were not serving on the Commission but were drawn from a wider sphere. C.I.M.O.–I appointed seven working groups, and one more was appointed by the President between the sessions. C.I.M.O.–II appointed eleven. Perhaps the most important new working group is that on Meteorological Instruments and Methods of Observation on Aerodromes, whose terms of reference include a study of possible ways of measuring "slant visibility".

The question of standardization of instruments was considered, but it was felt that the time was not ripe for any move in this direction. On the question of the standardization of accuracy of observations, a number of amendments to the Technical Regulations was recommended.

Various questions regarding the accuracy of radio-sonde and other upper air instruments were discussed by the two commissions jointly. Uncertainties regarding the accuracy and wide differences in the principles of operation of radio-sonde and upper wind equipment make the specification of generally acceptable standards a matter of difficulty. Little progress was made at the meetings towards the uniformity of the aerological network, but an attempt was made to present the results of the Payerne trials of 1956 in a form in which their usefulness could be tested on a synoptic scale. A working group on aerological measurements will continue the work of the former group on radio-sonde comparisons; although no further international trials on the Payerne scale are intended before the next session, it was felt desirable to keep the subject under review.

A report of the meetings would not be complete without a reference to the excellent entertainment provided by the hosts, the French Meteorological Service, for the enjoyment of the delegates between the meetings. These informal occasions gave many opportunities for the representatives of many different nations to get to know one another personally. Such contacts provided the opportunity for many exchanges of views which will no doubt be reflected in closer international co-operation on aerological and instrumental matters in the coming years.

The meetings also included a number of discussions of scientific papers and these occasions also provided opportunities for exchange of scientific knowledge of meteorology.

At the final session, Dr. R. C. Sutcliffe, Great Britain, was elected President of C.Ae. for the period until (and including) the next session. Dr. W. L. Godson, Canada, was elected Vice-President. The President and Vice-President of C.I.M.O., Mon. A. Perlat and Dr. L. M. Malet, were re-elected for a second term. In all the work of the Commissions, invaluable help was given by the representatives of the Secretariat, Dr. K. Langlo and Mr. O. M. Ashford.

NOTES AND NEWS

Meteorological Committee

The Secretary of State for Air announced in the House of Commons on June 29 that the Meteorological Committee of members nominated by other Departments, the Universities and Royal Society would be dissolved and be replaced by an advisory committee consisting of an independent chairman, two scientists and two laymen, all outside Government service. The chairman of the Meteorological Research Committee would serve *ex officio* as one of the two scientists and the other be appointed after consultation with the President of the Royal Society. He stated that Lord Hurcomb had accepted his invitation to become chairman. The function of the committee will be to keep under review the progress and efficiency of the meteorological services and the broad lines of current and future policy, the general scale of effort and expenditure devoted to the Meteorological Office, and the contacts between the Meteorological Office and those who use its services.

The membership of the Committee was completed in August as follows:

The Lord Hurcomb, G.C.B., K.B.E., (*Chairman*), Sir Austin Anderson, Sir David Brunt, F.R.S., Sir Charles Normand, C.I.E., Colonel N. V. Stopford Sackville, O.B.E., T.D.

In the course of his career as a Civil Servant Lord Hurcomb was Permanent Secretary of the Ministry of Transport and Director-General of the Ministry of War Transport. He is a member of the Nature Conservancy.

Sir Austin Anderson's interests are in shipping and insurance. He has been Chairman of the Orient Line since 1952.

Sir David Brunt and Sir Charles Normand need no introduction to readers of the *Meteorological Magazine*. Sir Charles is the present Chairman of the Meteorological Research Committee.

Colonel N. V. Stopford Sackville is Chairman of the Northamptonshire Agricultural Executive Committee and Liaison Officer of the Ministry of Agriculture and Fisheries for Northamptonshire and Leicestershire. He is a county Alderman and prominent landowner.

The Director-General of the Meteorological Office and a representative of the Permanent Under-Secretary, Air Ministry, will be in attendance at meetings of the Committee and the Secretary, Meteorological Office, will be its secretary.

Terminology in temperature forecasts for the British Isles

The terminology for temperature forecasts was changed on September 16, 1957, from the one given on pages 48 and 49 of *Your Weather Service* because the more extreme terms of the former table, e.g. very hot when temperature was expected to be more than 20°F. above normal, were little used.

The new definitions are as follows:

Departure from average °F.	Spring (mid-March to mid-May) Autumn (mid-Sept. to mid-Nov.)	Summer (mid-May to mid-Sept.)	Winter (mid-Nov. to mid-March)
+14	Very warm	Very hot	Exceptionally mild
+11 to +14		Hot	
+ 7 to +10	Warm	Very warm	Very mild
+ 3 to + 6	Rather warm	Warm	Mild
− 2 to + 2	Average	Average (or rather warm*)	Average (or rather mild*)
− 3 to − 6	Rather cold	Rather cool	Rather cold
− 7 to −10	Cold	Cool	Cold
−10	Very cold	Very cool or cold†	Very cold

* For the upper part of the range if desired.

† "Cold" for use when a marked fall in temperature is expected.

In addition to terms for temperature defined strictly as in the table, words such as "warm", "cold", "mild" will be used in forecasts in such phrases as "a cold easterly wind is spreading across the country".

The effects of wind and humidity on the human system will be taken into account by coupling the wind and temperature forecasts, when the forecaster considers it useful to do so, e.g. "rather cold with strong northerly winds", and by using the terms "close", "muggy" and "raw". These words are defined as follows:

Close: temperature average or above average for the time of year with high humidity, a cloudy or overcast sky and a calm or light wind; oppressive.

Muggy: warm damp air not necessarily oppressive.

Raw: cold damp air sometimes with fog.

In forecasting frost a special set of terms will be used, ground and air frost being treated differently.

Ground frost.—As the degree of severity of ground frost over a whole forecast region cannot be specified closely on account of topography and soil differences quantitative terms will not be employed in regional forecasts. In these the phraseology will be of the form "Ground frost will occur generally" or " Ground frost will occur in places". If it is thought that ground temperatures will fall to a low level, say below 20°F. in places the forecast will state that ground frost will occur and be severe in places.

In forecasts for one place, as distinct from an area, the forecaster may, when desirable, give the actual temperature likely to be reached in words such as "ground frost will occur with temperatures at the ground falling below 25°". The expression "sharp (ground) frost" will not be used.

Air frost.—The effects of frost at screen level are very dependent on the wind. This is reflected in the new terminology for air frost which runs:

Term	Corresponding screen temperature Wind speed less than 10 knots °F.	Wind speed 10 knots or over °F.
Slight frost	32–27	32–31
Moderate frost	26–21	30–28
Severe frost	20–11	27–23
Very severe frost	below 11	below 23

To assist users to exercise their judgment on the likely effects to themselves the forecasts will make clear the connection between the severity of the frost and the wind speed by the use of such phrases as "Very low temperatures such as occurred last night are not expected tonight but with 30°–27° in many places and a continuing moderate or fresh northerly wind, moderate or severe air frost may again be widespread."

A lightning stroke on a hillside

On the afternoon of April 23, 1957, Mr. A. P. Clark of Black Hope Farm, Midlothian, was on the hillside about half a mile north-east of his farm-house when a lightning stroke hit the ground about 60 yards from him making a crater about 5 feet long by 18 inches wide and more than a foot deep. Several hundredweights of earth were displaced and some heavy lumps of turf were thrown a distance of 20 or 30 yards but these were probably helped by the steep down slope. Mr. Clark was fortunately down the slope from the strike so that his head was appreciably lower than the crater. He says that he experienced a feeling as though the pressure had risen and then a very definite wave of heat. Mr. Clark got in touch with Mr. Wrigley, late of the Royal Observatory, Edinburgh, who kindly ran the writer out to Blackhope.

On account of the rarity of appreciable mechanical effects when lightning runs to earth the following notes are offered.

The national grid reference of the hole is 36/327522.

The height above sea level is 1,150 feet but within a mile are 3 peaks of between 1,400 and 1,500 feet. A wire fence runs along the skyline (about 1,500 feet) of the hill to the east and Mr. Clark tells me that the posts have, on several occasions, suffered lightning damage. The crater was not even on the highest point of its immediate surroundings but was just above the place where a very steep upward gradient gave place to a more gentle slope.

Thunder was reported from a wide area in Scotland but rainfall measurements in the near vicinity were suprisingly small. Amounts for the 24 hours measured at 9 a.m. next morning were:

Station	Distance and bearing of thunder miles	Rainfall inches
Gladhouse	3·1 west-north-west	·02
Portmore	5·5 west-south-west	·10
Rosebery	3·7 north-west	Nil
Stow	8·1 south-east	·09
Gorebridge	5·6 north	·04
Ford	8·0 north-north-east	·05
Newbattle	8·0 north	·01

Mr. Clark noticed that a small burn draining one or two hundred acres to the west came down in spate but the bigger Blackhope water draining a few square miles to the south-west was not noticeably affected by the rain. There were many lightning flashes during the storm but no estimate of number could be made. Fuses were blown on the telephone circuit in the farm-house about half a mile away.

R. A. WATSON

LETTER TO THE EDITOR

Torrential rainfall

In Mr. D. C. Mason's note[1] on an occasion of torrential rainfall at Tengah, Singapore, when 4·4 in. fell in 99 min. he talks of a "solid sheet of water" and this would seem a reasonable description to anyone who has seen such very heavy rainfall. It is interesting, therefore, that the calculated proportion, by volume, of water to air in this storm is only 1:265,000. (An average terminal velocity for the raindrops of 5m./sec. has been used.) This, of course, is the average over the whole 99 min. and there would have been instantaneous proportions considerably greater, but even they would have been surprisingly small.

Mr. G. S. P. Heywood, late Director of the Hong Kong Royal Observatory, has pointed out that the highest rate of rainfall ever recorded—1·02 in. in 1 min. in California—yields a proportion of water to air of only 1: about 12,000.

E. T. BAKER

Northolt. August 10, 1957.

REFERENCE

1. MASON, D. C.; Torrential rainfall at Royal Air Force Station, Tengah. *Met. Mag., London*, **86**, 1957, p. 187.

[The liquid water mixing ratio corresponding to a proportion of water to air by volume of 1/12,000 is, at 1,000 mb. and 20°C. 70 gm./Kg. and for a proportion of 1/265,000 is 3·2 gm./Kg.

The saturation water vapour mixing ratio at 20°C. is 14·2 gm./Kg. The rate of rainfall would thus have had to be over four times that quoted by Mr. Mason for the amount of liquid water to equal the amount of water vapour in the air. Ed. *M.M.*]

REVIEW

Hurricanes. Their nature and history. 9th revised edition. By I. R. Tannehill. $8\frac{1}{2}$ in. $\times 5\frac{1}{2}$ in., pp. x+308, *Illus.*, University Press, Princeton: Oxford University Press, London, 1956. Price: 36*s.*

The United States hurricane warning service, with its convincing demonstration of lives saved, is one of the proudest achievements of applied meteorology. In recent years losses of life in inland parts of North America, which are seldom visited by hurricanes and where people do not so readily heed the warnings, have exceeded the deaths in the worse affected coastal states. Damage to property is hard to avoid. Consequently the effectiveness of the hurricane warning service may be gauged by the reduced number of human deaths per ten million dollars of property damage; in 1926–30 there were 161 fatalities per unit damage in the United States: this figure steadily declined to 4 deaths per unit damage in 1941–45 and 0·4 in 1949.

The American hurricane warning service was started during the Spanish–American war. President McKinley said he was more afraid of one West Indies hurricane than of the entire Spanish Navy. Already from 1875 or earlier, however, a similar warning service with purely humane motives had been organized by the Jesuit Fathers at Belem, Havana. War and peace also enter the story at Apia, Samoa, in 1889, where American and German warships were preparing for hostilities, when all were wrecked by a tropical cyclone and the would-be belligerents became friends, rescuing each other in many acts of heroism.

This book is the new edition of a standard work, first published in 1938, by the man who was head of the synoptic division of the United States Weather Bureau with responsibility for the hurricane warning service during the period when the death roll was so happily cut down. Most of the new matter in this edition appears to be contained in a thirty-six page appendix.

Sections dealing with the dimensions, maximum wind speeds, geographical and seasonal distributions, tracks and life history of the Caribbean and North Atlantic hurricanes, contain a wealth of information in easily readable form which will be invaluable to all whose livelihood is affected by tropical cyclones. The reviewer knows of no such convenient compendium of information on hurricanes for shipping and travel directorates, insurance agencies and others concerned. Further chapters deal with the tidal waves which sometimes accompany these storms, with the procedures of the warning service and with precautionary measures. There is also a chronological list of all the storms known since Columbus' time and notes in some detail of the worst storms from about 1750 to 1955.

Revision has, however, produced an unevenly balanced book: a mine of factual data, invaluable to layman and meteorologist alike, but relatively weak and out of date on the theoretical side. Meteorologists will be disappointed to find no reference to Bergeron's work, nor to the later writings of Riehl. Interpretation of the hurricane circulation and development is still presented largely in the words of those who wrote on the subject in the 1920's; opposing view-points are stated unnecessarily on some aspects. Pages 58–62 on the "height of the tropical cyclone" ought surely to have been entirely re-written in the light of modern knowledge of the upper air circulation from radio soundings and aircraft reconnaissance, though this criticism is partly met in the appendix. This is not the only instance in which statements in one part of the book are corrected elsewhere. The world map of cyclone tracks on p.4 might be taken to imply that the north American region is the worst in the world for tropical cyclones, whereas the discerning reader will discover on p.116 that these storms are more frequent as typhoons in the western Pacific and in the southern Indian Ocean. On p.141 the storm of February 12, 1493, near the Azores is quoted as the first recorded West Indian hurricane, but the reader's suspicions that this was an extratropical polar-front depression are finally given the verdict on p.239. The words "South Atlantic" on p.56, where "southern North Atlantic" is meant, may confuse the layman who is elsewhere informed, correctly, that tropical cyclones are unknown in the South Atlantic. These are, however, minor pitfalls which will not deceive the careful user who reads right through the book.

The reviewer has found some interest in the very appreciable change of hurricane frequency in the North Atlantic in recent years. The increased incidence since 1931 giving a 25-yr. average of 9 a year against 6 a year for the first 30 yr. of the century is noted in rather vague terms by Tannehill on p.110 and attributed by him largely to improved facilities for reporting; indeed he assumes, in a remark on p.143, that the frequency should have remained unaltered in each century since Columbus. The reviewer believes these conclusions to be false. Tropical storms in the Atlantic were more frequent in 1887–1896 with an average of 8·4 yearly, than in the later period to 1930. The long period of minimum frequency, 1897–1930, coincided with the minimum gradient of ocean surface temperature between the tropics and the Iceland region, a time of decreasing Arctic ice and relatively low temperature of the warmest parts of the Atlantic. This arrangement would discourage convection phenomena by reducing both instability and moisture content in the tropical zone.

There was another period of "remarkable scarcity" of tropical storms in the mid-nineteenth century between about 1843 and 1870, especially 1857–66; this too coincided with a minimum of Arctic ice, though nothing seems to be known about the temperature of the tropical Atlantic at that time.

The following table, based on Tannehill's data, shows the gradual increase of reported storms over the centuries; it also indicates superimposed variations which may deserve attention in connexion with climatic variation. Indeed some aspects of the over-all trend are probably real, notably the decrease from the 1500's to 1600–1650 and, perhaps, much of the increase from 1800 to the present day.

TABLE I—FREQUENCIES OF REPORTED ATLANTIC HURRICANES IN HALF CENTURIES AND VARIOUS SHORTER PERIODS

Period	Total number of tropical storms	Average yearly number
1501–1550	13	0·26
1551–1600	13	0·26
1601–1650	8	0·16
1651–1700	33	0·66
1701–1750	41	0·82
1750–1759	...	2·0
1751–1800	123	2·46
1780–1788	...	4·6
1789–1810	...	2·5
1801–1850	198	4·0
1811–1825	...	4·3
1826–1840	...	4·2
1841–1855	...	3·7
1851–1900	228	4·6
1856–1870	...	1·6
1871–1886	...	5·4
1887–1896	...	8·4
1897–1930	...	6·0
1901–1950	375	7·5
1931–1955	...	9·0

Bergeron has pointed out that tropical storms only form where the following three conditions are satisfied:

(i) very extensive areas of water with surface temperatures over 27°C. (which is nearly the maximum temperature at present found in the oceans),

(ii) sufficient depth of thermally unstable air, and

(iii) where the intertropical convergence zone is rather far displaced north or south of the equator.

It would seem inevitable from (i) and (ii) and, perhaps, from (iii) also, that the frequency of these storms must be very sensitive to climatic trends.

H. H. LAMB

OFFICIAL PUBLICATION

The following publication has recently been issued:

GEOPHYSICAL MEMOIRS

No. 99—*Tornadoes in England: May* 21, 1950. By H. H. Lamb, M.A.

Close examination of the trails of devastation left by the main tornado and two subsidiaries over south-eastern and eastern England on May 21, 1950 reveals a good deal of detail about their behaviour through many successive pulses of activity. Estimates of the magnitude of the greatest wind speeds, shear and suction effects (pressure reduction) are derived; the extreme winds probably exceeded, and perhaps considerably exceeded, 100 kt. at certain brief phases of the activity of the main tornado, but speeds of this order were only attained over a width of a few feet, sometimes only a foot or two.

These particular English tornadoes were clearly attributable to a complex of factors: they occurred, as is usual, in a severe thunderstorm, but the evidence shows that the instability cannot have attained the extreme values possible in England nor have extended through the greatest depth of the atmosphere ever occurring here. A low condensation level contributed to great potential instability in the lower layers, so that strong vertical currents could be formed near the ground in spite of only moderate to rather low afternoon temperatures. Close study of the terrain over which the tornadoes passed in relation to the main surface wind currents on May 21, 1950 suggests that a vital initial twisting impulse was supplied by a sudden local increase of the surface north-easterly wind immediately in front of the tornado cloud advancing south-south-west, just as it came clear of various obstacles such as various north-east : south-west ridges of hills with small cross valleys in which there was little or no wind. This was the setting where each of the main bursts of activity began.

Smaller obstacles on the ground, such as dense coppices and conglomerations of buildings, also obviously affected the behaviour of the tornado, causing it to lose energy, wander up to a couple of hundred yards aside of its track or break up, though they themselves sustained considerable damage.

Both frontal and topographical shears seem to have been present, though not in a very pronounced degree, and the frontal situation, which could be followed in some detail, proved interestingly fluid in a manner associated with intense convection and local modification of air masses by heavy rainfall.

A deduced pressure profile through these tornadoes is presented, and some more theoretical discussion shows how samples of the wide variety of velocity profiles occurring may be constructed.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Dr. F. J. Scrase, O.B.E.*, Senior Principal Scientific Officer, retired on August 15, 1957. After service in the Special Brigade, Royal Engineers during the First World War he joined the Office in August 1920 as a Junior Professional Assistant at Kew Observatory. In 1921 he was posted to Porton, but he returned to Kew Observatory in 1926 and he remained there for 10 years. In 1937 after a short period at Croydon Airport he was posted to Gibraltar as Senior Meteorological Officer. On his return in 1939 he was appointed Head of the Instruments Branch and from 1948 until his retirement he was Assistant Director (Instrument Development). Dr. Scrase was appointed an Officer of the Order of the British Empire in the New Year Honours List of 1948 and he was awarded the L. G. Groves Memorial Prize for Meteorology in 1955.

At a ceremony at Harrow on August 15, the Director-General presented Dr. Scrase with a cheque subscribed by his colleagues.

Dr. Scrase has accepted a temporary appointment in the Meteorological Office.

Mr. H. W. Davis, Senior Experimental Officer, retired on August 16, 1957. He first worked at the Royal Observatory, Greenwich, and after service in the Royal Field Artillery in the First World War, he joined the Office in August 1919 as a Technical Assistant. Apart from short periods in 1937–38 in the Instruments Division and the Forecast Division at Headquarters, his 38 years' service has been spent at army and aviation outstations, including a tour of duty in the Middle East. From 1949 until his retirement he served at South Cerney.

Sports activities.—*Athletics.*—Senior Aircraftman C. W. Fairbrother who is at present serving in Western Germany was selected to represent Great Britain and Northern Ireland in the High Jump event in the Amateur Athletics

Association match against France at the White City on August 3 and 5. He was placed second, jumping the same height as the winner, 6ft. 3in. Earlier in the year in Western Germany he won his Group and Command high jump competitions establishing in the latter a record for the event with a jump of 6 ft. 2 in.

WEATHER OF AUGUST 1957

As in the previous month, August was marked by a fair degree of mobility, the depression track across the Atlantic being notably variable. Consequent upon the general variability, pressure anomalies were, on the whole, rather small. The Azores anticyclone was a little stronger than normal, whilst further north from Greenland to Spitsbergen, pressure anomalies were 2 to 3 mb. below normal. The general zonal flow across the Atlantic was thus stronger than normal. Perhaps as a result of this, depressions from the Atlantic penetrated well eastwards being frequently located over the North Sea–Denmark region where pressure was again 2 to 3 mb. below the normal for the month. Pressure was slightly above normal over a very wide area including most of Asia, The Pacific and North America, the greatest anomalies being over Canada where anticyclones had repeatedly moved in from Alaska. Pressures were low in the polar basin, however, as had been the case in the previous month.

Temperatures were below normal over much of France, Italy and Germany, being 2 to 3°C. below the August normal in Southern Germany. These regions were affected by frequent northerly winds from the North Sea. Temperatures were also below normal in Japan and Manchuria whilst positive temperature anomalies reaching +4°C. were reported in Cyprus and Northern Siberia.

Rainfall was above normal over most of Northern Europe and also in the west Mediterranean but was below normal in Southern France and Northern Italy and in Southern Spain, Morocco and Algeria. The rainfall distribution over North America was rather patchy but a region of above normal rainfall roughly along latitude 40°N. marked a region of frequent cyclonic activity.

Pressure was high over the British Isles at the beginning of the month and weather during the first few days was warm and sunny, with afternoon temperatures reaching 80°F. locally and with many places recording more than 13 hr. of sunshine daily. On the 4th, however, a shallow trough of low pressure, accompanied by outbreaks of rain, approached from the south-west and during the following two days thunderstorms developed fairly widely over the country. Many of the storms were severe and reports of storm damage and extensive floods were common, with rain in some places of very rare intensity. During a severe storm at Bwlchryllan, Cardiganshire on the 5th, Bank Holiday Monday, 3·43 in. of rain was recorded in 2 hr. while on the same day at Clifford, Herefordshire 4·11 in. fell in 90 min., the second heaviest fall on record for that period in the United Kingdom. The 8th to the 12th was a period of intense cyclonic activity over the British Isles with widespread thundery rain and frequent thunderstorms often accompanied by unusually heavy downpours of rain or hail. One such occurred at Llansadwrn, Anglesey, on the 10th when 5·38 in. of rain fell in 2 hr. Noteworthy falls occurred in and around London on the 12th and 13th, especially in the Kingston–Teddington area, where there was considerable flooding. The 12th was the wettest August day at Kew since records began nearly 100 years ago. Floods, owing to heavy rain, were also reported from many other parts of the country, notably from Bath, Salisbury and Oxford. In the north rainfall amounts were mostly small until on the 14th a deep depression moved east across Scotland bringing outbreaks of rain, heavy locally, to all districts of the British Isles and gales to exposed northern coasts. During the next few days depressions passed well to the north of Scotland and from the 16th to the 22nd weather was quieter and drier, and although rain or drizzle occurred at times, it was mostly slight, except in the north. On the 21st an anticyclone, moving in from the Atlantic, gave the sunniest day in the British Isles for nearly three weeks. A depression which developed off the west of Ireland on the 22nd heralded another period of stormy weather. This depression gave widespread and locally heavy rain on the 23rd, with strong winds and gales in exposed places, as it moved toward northern Scotland, and was noteworthy for its unusual depth for the time of year. Early on the 24th barometric pressure in the extreme north of Scotland fell to 976·8 mb. at both Sule Skerry and Cape Wrath, the lowest pressure ever recorded in the British Isles during August. By this time winds had reached gale force in all western and northern districts and the following day gales extended to the whole country and were severe in exposed places. As the depression moved slowly toward Scandinavia the north-westerly winds over the British Isles moderated gradually to give rather cool weather during the last week of the month, with showers which became progressively less frequent.

The month as a whole was rather cool and, except for the first week, there was a marked lack of warm days. In the second half of the month temperature rarely reached 70°F. Sunshine was below the average generally, although in southern England it was somewhat above the average for the period during the latter half of the month. Rainfall was the most outstanding feature of the month owing to its local intensity, but less than half the monthly average occurred over most of East Anglia and the East-Midland counties of England. The sunshine at the beginning of the month rapidly ripened grain and harvesting was well under way, particularly in southern England, until heavy rains and the gales of the 23rd and 24th caused widespread damage and put a stop to operations. Reports of damage by storms and flooding to stooks, standing crops, top fruit, hops and small buildings have been received from districts as far apart as Cardigan and Kent. Diseases such as potato blight and mildew on apples have become serious threats to yields in the wet humid weather, but some vegetable crops, such as runner beans and sugar beet, have responded well to the abundant rainfall.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	84	34	−0·7	121	+2	85
Scotland	80	30	−0·3	128	0	87
Northern Ireland ...	73	38	0·0	113	+1	87

RAINFALL OF AUGUST 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	2·64	119	*Glam.*	Cardiff, Penylan ...	3·39	80
Kent	Dover	2·41	104	*Pemb.*	Haverfordwest ...	2·48	59
,,	Edenbridge, Falconhurst	3·08	118	*Radnor*	Tyrmynydd	8·66	161
Sussex	Compton, Compton Ho.	3·59	116	*Mont.*	Lake Vyrnwy	8·18	153
,,	Worthing, Beach Ho. Pk.	1·97	87	*Mer.*	Blaenau Festiniog ...	11·39	102
Hants.	St. Catherine's L'thouse	1·98	103	,,	Aberdovey	4·81	108
,,	Southampton (East Pk.)	3·49	133	*Carn.*	Llandudno	5·62	199
,,	South Farnborough ...	1·46	66	*Angl.*	Llanerchymedd ...	4·53	125
Herts.	Harpenden, Rothamsted	2·14	84	*I. Man*	Douglas, Borough Cem.	3·02	79
Bucks.	Slough, Upton	2·00	92	*Wigtown*	Newton Stewart ...	3·37	81
Oxford	Oxford, Radcliffe ...	3·77	165	*Dumf.*	Dumfries, Crichton R.I.	3·69	91
N'hants.	Wellingboro' Swanspool	2·39	100	,,	Eskdalemuir Obsy. ...	6·63	129
Essex	Southend, W. W. ...	2·00	109	*Roxb.*	Crailing...	3·80	129
Suffolk	Felixstowe	1·41	81	*Peebles*	Stobo Castle	4·86	137
,,	Lowestoft Sec. School...	1·74	79	*Berwick*	Marchmont House ...	4·99	151
,,	Bury St. Ed., Westley H.	3·03	117	*E. Loth.*	North Berwick Gas Wks.	4·20	135
Norfolk	Sandringham Ho. Gdns.	2·59	96	*Midl'n.*	Edinburgh, Blackf'd. H.	2·90	90
Wilts.	Aldbourne	3·31	119	*Lanark*	Hamilton W. W., T'nhill	4·16	122
Dorset	Creech Grange... ...	3·39	119	*Ayr*	Prestwick	4·14	130
,,	Beaminster, East St. ...	3·91	125	,,	Glen Afton, Ayr San. ...	6·85	127
Devon	Teignmouth, Den Gdns.	2·10	93	*Renfrew*	Greenock, Prospect Hill	4·40	86
,,	Ilfracombe	4·57	127	*Bute*	Rothesay, Ardencraig ...	6·56	166
,,	Princetown	7·28	107	*Argyll*	Morven, Drimnin ...	5·73	109
Cornwall	Bude, School House ...	3·45	122	,,	Poltalloch	5·28	108
,,	Penzance	4·64	146	,,	Inveraray Castle ...	7·34	112
,,	St. Austell	4·45	123	,,	Islay, Eallabus	...	...
,,	Scilly, Tresco Abbey ...	2·76	100	,,	Tiree	3·69	88
Somerset	Taunton	2·09	88	*Kinross*	Loch Leven Sluice ...	5·40	141
Glos.	Cirencester	3·82	123	*Fife*	Leuchars Airfield ...	3·07	100
Salop	Church Stretton ...	8·00	240	*Perth*	Loch Dhu	5·99	89
,,	Shrewsbury, Monkmore	5·54	200	,,	Crieff, Strathearn Hyd.	4·40	105
Worcs.	Malvern, Free Library...	4·88	169	,,	Pitlochry, Fincastle ...	3·47	98
Warwick	Birmingham, Edgbaston	4·23	141	*Angus*	Montrose Hospital ...	4·00	143
Leics.	Thornton Reservoir ...	2·93	105	*Aberd.*	Braemar	4·52	133
Lincs.	Boston, Skirbeck ...	1·88	79	,,	Dyce, Craibstone ...	4·64	153
,,	Skegness, Marine Gdns.	2·56	105	,,	New Deer School House	4·33	146
Notts.	Mansfield, Carr Bank ...	3·83	137	*Moray*	Gordon Castle	4·99	157
Derby	Buxton, Terrace Slopes	6·95	159	*Nairn*	Nairn, Achareidh ...	4·55	187
Ches.	Bidston Observatory ...	2·99	97	*Inverness*	Loch Ness, Garthbeg ...	6·45	198
,,	Manchester, Ringway...	3·51	107	,,	Loch Hourn, Kinl'hourn	8·67	106
Lancs.	Stonyhurst College ...	6·66	132	,,	Fort William, Teviot ...	6·09	98
,,	Squires Gate	3·78	111	,,	Skye, Glenbrittle ...	...	...
Yorks.	Wakefield, Clarence Pk.	4·28	165	,,	Skye, Duntulm... ...	5·90	133
,,	Hull, Pearson Park ...	3·10	107	*R. & C.*	Tain, Mayfield... ...	4·17	154
,,	Felixkirk, Mt. St. John...	5·06	178	,,	Inverbroom, Glackour...	7·49	179
,,	York Museum	5·11	203	,,	Achnashellach	7·80	124
,,	Scarborough	2·56	92	*Suth.*	Lochinver, Bank Ho. ...	5·57	167
,,	Middlesbrough... ...	2·04	74	*Caith.*	Wick Airfield	5·13	187
,,	Baldersdale, Hury Res.	5·90	178	*Shetland*	Lerwick Observatory ...	3·17	105
Norl'd.	Newcastle, Leazes Pk....	3·29	117	*Ferm.*	Crom Castle	5·10	123
,,	Bellingham, High Green	3·71	105	*Armagh*	Armagh Observatory ...	5·56	154
,,	Lilburn Tower Gdns. ...	6·50	230	*Down*	Seaforde	4·83	129
Cumb.	Geltsdale	4·83	117	*Antrim*	Aldergrove Airfield ...	4·19	116
,,	Keswick, High Hill ...	7·53	144	,,	Ballymena, Harryville...	3·44	81
,,	Ravenglass, The Grove	3·62	79	*L'derry*	Garvagh, Moneydig ...	4·05	103
Mon.	A'gavenny, Plâs Derwen	3·38	102	,,	Londonderry, Creggan	3·88	84
Glam.	Ystalyfera, Wern House	7·25	117	*Tyrone*	Omagh, Edenfel ...	5·13	120

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ANTICYCLOGENESIS IN RELATION TO A PARTICULAR THICKNESS PATTERN

By C. HAWORTH and J. HOUSEMAN

Summary.—It is shown that a combination of a diffluent ridge and a confluent trough on the 1000–500-mb. thickness chart will give rise to sustained anticyclogenesis and, under certain conditions, to the formation of a new anticyclone.

Introduction.—Sutcliffe[1] has shown that development can be related to vorticity gradients indicated by the surface pressure and a thickness pattern representative of the horizontal temperature gradient in the troposphere. The 1000–500-mb. thickness chart is normally used in British practice and it has been shown that when:—

$$-\mathbf{V}'\frac{\partial}{\partial s}\left\{l + \zeta' + 2\zeta^{\circ}\right\} > \text{or} < 0$$

where $\mathbf{V}'$ = the thermal wind vector from 1000–500 mb.,

ζ' = the vorticity of the thermal wind for the 1000–500-mb. layer,

ζ° = the vorticity of the geostrophic wind at 1000 mb.,

l = the Coriolis parameter, $2\,\omega \sin \phi$

and $\frac{\partial}{\partial s}$ = differentiation along a thickness line,

then the situation favours either cyclogenesis or anticyclogenesis respectively. In a later work, Sutcliffe and Forsdyke[2] apply this to a study of the geometry of the thickness chart in a baroclinic atmosphere. Two of the patterns, the "diffluent ridge" and the "confluent trough" are shown in Figs. 1 and 2 respectively. The regions of maximum development are indicated by A for anticyclogenesis and C for cyclogenesis. If these two patterns are combined together as shown in Fig. 3 it will be noted that in the area between the trough and the ridge there is a region of anticyclogenetic tendency on both the warm and cold sides of the pattern. This common diffluent region will be referred to as the A–A region in the ensuing discussion. It is in this region that conditions favour the formation of an anticyclone.

The association of the rear of a confluent trough on the thickness chart with a surface ridge of high pressure is a common occurrence but, as Sutcliffe and Forsdyke[2] have mentioned, difficulty is usually experienced in deciding how great the ridge development will be. We suggest that a combined diffluent-ridge confluent-trough pattern on the thickness chart in conjunction with the appropriate surface pattern will usually lead to the formation of a new anticyclone and in any event to large-scale ridging.

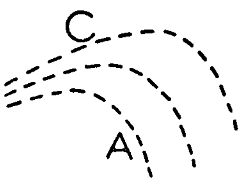


FIG. 1—DIFFLUENT RIDGE

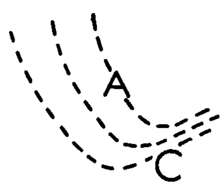


FIG. 2—CONFLUENT TROUGH

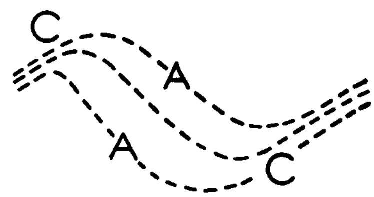
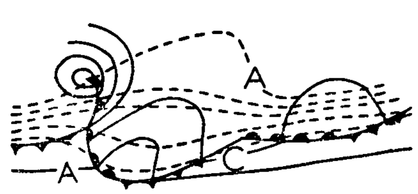
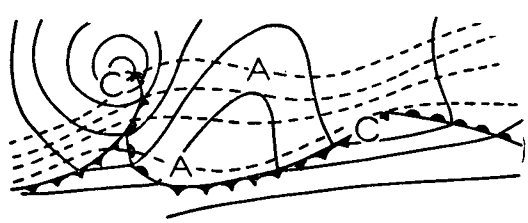


FIG. 3—COMBINED DIFFLUENT RIDGE AND CONFLUENT TROUGH



—surface isobars - -thickness lines

FIG. 4—DIFFLUENCE IN A WEST TO EAST DIRECTION



— surface isobars - -thickness lines

FIG. 5—DEVELOPMENT OF A DIFFLUENT RIDGE AND CONFLUENT TROUGH FROM THE DIFFLUENCE IN THE THERMAL STREAM

In the classical model of the general circulation of the atmosphere a sequence of depressions moves uninterruptedly from west to east in the unsettled westerly belt of temperate latitudes with inadequate room for new anticyclones to develop. Only temporary ridges are allowed for between successive depressions. In order to have anticyclogenesis of appreciable magnitude, it is essential to find some mechanism whereby this series of depressions can be interrupted[3]. The interruption is achieved by the combined diffluent-ridge confluent-trough pattern, since depressions associated with it are steered so that the distance between them is increased as the pattern develops. Space and time are thus available for the new anticyclone to form.

The developing pattern.—The pattern will form provided that there is a temporary diffluence in a strong west to east baroclinic zone, with depressions developing at the left exit of the western jet and the right entry to the eastern jet illustrated in Fig. 4. Subsequent advection and deepening of the depressions will bring into existence a model pattern shown in Fig. 5. With these requirements present the pattern will develop satisfactorily and produce an anticyclone if the conditions set out for its continuance are fulfilled.

Conditions for continued existence and development.—The important factors in the development process in this particular model are:—

(i) advection,

(ii) intensity of the pattern, $\mathbf{V}'\frac{\partial \zeta'}{\partial s}$ in the development inequality

and (iii) Coriolis effect, $\mathbf{V}'\frac{\partial l}{\partial s}$ in the development inequality.

Advection.—If the diffluent-ridge confluent-trough pattern is to produce a surface anticyclone it is vital that the advection of the air should be such as to maintain the pattern for a fair period of time, say 24 hr. The process is best illustrated with diagrams as in Figs. 6 and 7.

Low *a* shown in Fig. 6 has developed on the warm side of the confluent trough and moved quickly north-east, advecting cold air southwards and accentuating the confluent trough. A ridge has developed behind the depression in the rear of the confluent trough. This is the ridge which is often the problem in the determination of future development. Low *b* is in a tight thermal gradient approaching an area of diffluence. Therefore the tendency will be for it to swing to the left, but this will not occur if the advection is not suitable as will be seen from later considerations.

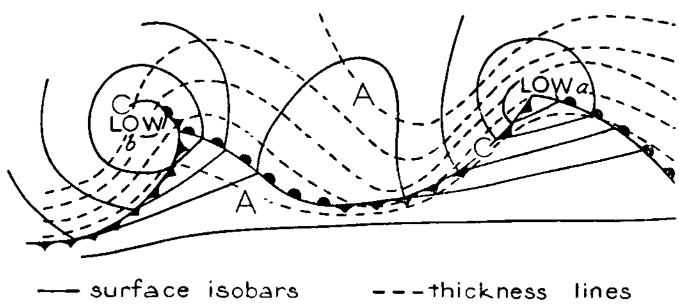


FIG. 6—INITIAL STAGE OF ANTICYCLONIC DEVELOPMENT

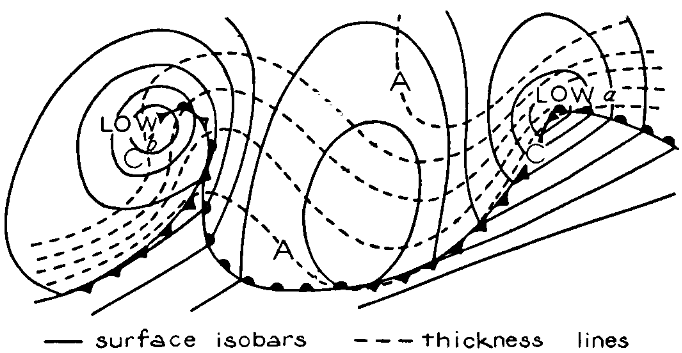


FIG. 7—DEVELOPMENT OF A SURFACE ANTICYCLONE

Low *b* shown in Fig. 7 is deflected to the left in the thermal diffluence on the west side of the diffluent ridge, low *a* continues to move quickly north-east in the strong thermal gradient of the confluent trough. This widens the gap between the two depressions giving an area A–A where anticyclogenesis—or more strictly negative relative divergence, subsidence and probably anticyclogenesis—has time and space to exert itself, giving rise to further ridge development and eventually to an anticyclone. It should be noted that there is no restriction made on the deepening of lows *a* and *b*. The anticyclone, having developed in an already weak thermal field, will soon tend to become warm and barotropic and in many cases will bring about a change of type from changeable westerly to settled anticyclonic.

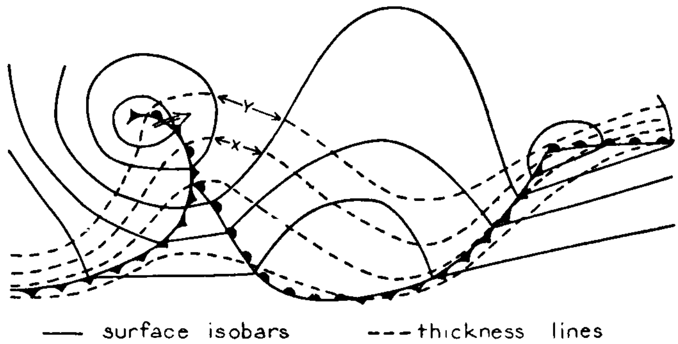


FIG. 8—TYPE OF ADVECTION LEADING TO CONFLUENCE OF THE THERMAL RIDGE

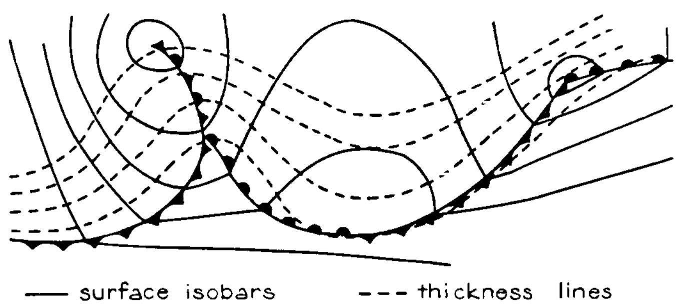


FIG. 9—RESULTING MOTION OF DEPRESSION ROUND THE PEAK OF THE CONFLUENT RIDGE

The deepening low *b* will advect warm air to high latitudes thus maintaining the strong thermal gradient on the western side of the thermal ridge. The deepening low *a* will maintain cold air advection southward on the eastern side of the confluent trough so that the A–A region will be maintained in the slacker thermal gradient between the ridge peak and the trough line. Once the high has developed it becomes an anticyclonic involution as described by Sutcliffe and Forsdyke[2]: the end result is a barotropic high with semi-permanent features.

Advection between the two depressions does not necessarily maintain the required thickness pattern. Only if the southerly gradient ahead of the western depression is tight will this occur. If the surface gradient is slack the ensuing advection will tend to lead to an extension of the thermal ridge peak eastwards rather than northwards as shown in Figs. 8 and 9.

In fact, adverse advection may cause the thickness pattern to resolve into a confluent-ridge confluent-trough or a confluent-ridge diffluent-trough. In Fig. 8 advection at X is greater than at Y. This, coupled with cooling due to northward motion, will give rise to a tightening thermal gradient ahead of the depression which will then continue north-eastwards causing the surface ridge to collapse in the north as it proceeds. Eventually the thermal ridge will become confluent and the western depression will either turn the peak of the thermal ridge and move quickly south-east or become slow-moving with the formation of warm-front or warm-occlusion secondary depressions as described by Sawyer[4]. In the first case the southward advection of the cold air behind the depression will quickly cause the thermal ridge to collapse along with any associated anticyclone. In the second case the developing secondary depressions will move quickly towards the surface ridge producing a collapse in this manner. If the diffluent thermal ridge moves towards an area covered by snow the movement of the thickness lines will be retarded at the edge of the snow[5]. The thermal gradient will be increased since the lines of higher value will continue to be advected until they also approach the snow surface and the ridge will become confluent with resulting destruction of the anti-cyclogenetic pattern.

If southward advection of cold air in the confluent trough is not sufficiently great to keep the tight thermal gradient on its eastern side in existence, the pattern will be destroyed by the trough becoming diffluent and the essential A–A region being removed. Consequently, over the north-east Atlantic, it frequently happens that confluent troughs moving southwards do not persist due to the large amount of heating of the cold air in transit[6]. A similar effect is produced over the European continent in summer when surface heating is high. Occasionally, however, the advection of warm continental air north-wards along the eastern side of a confluent trough helps to maintain it.

Advection of the right sort is therefore necessary to maintain the pattern. Ideally a strong south to south-east gradient should develop ahead of the western depression, low *b* in the diagrams, while a strong northerly gradient is maintained behind the eastern depression, low *a*.

If the confluent trough weakens after the surface anticyclone has formed, the A area on the cold side of the pattern vanishes and the anticyclone retreats south-westwards to the warm side leaving only a weakening ridge to the north-east. This corresponds closely with type IV of Sawyer's classification of anti-cyclones[7]. If the diffluent ridge becomes confluent the pattern is destroyed with resulting increased cyclonic activity as described above.

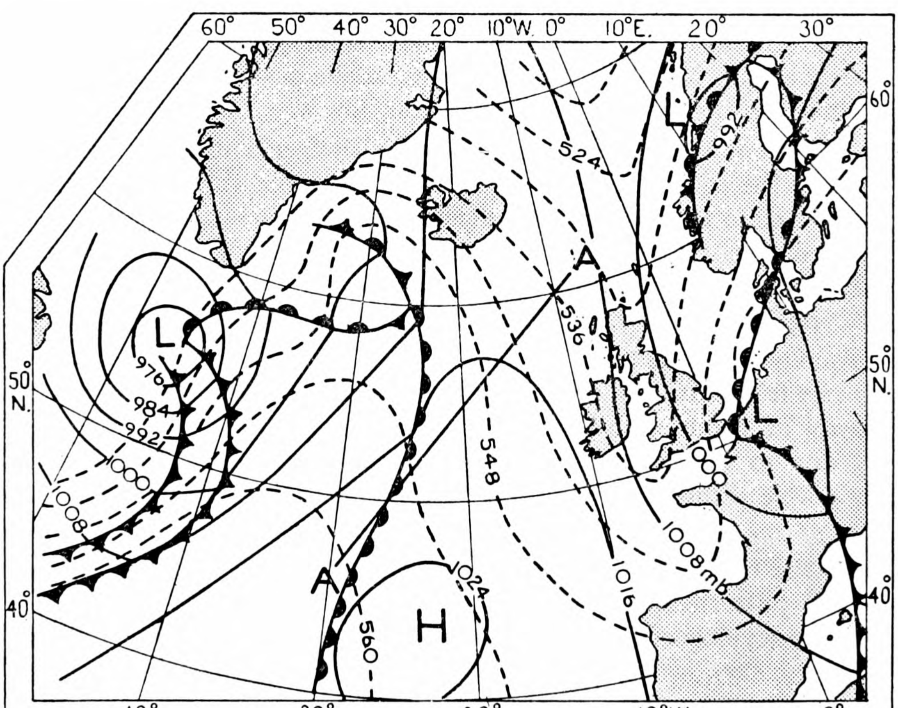
Development of a further depression on the warm side of the confluent trough is not frequent. Any depression which does develop will fill and move slowly away at right angles to the thermal stream over its centre. This is probably due to the large amount of subsidence in the cold air creating a vertically stable atmosphere in which small disturbances cannot develop[8].

Intensity of the pattern.—The amount of anticyclogenesis depends on the strength of the thermal wind, $\mathbf{V}'$, and the gradients of thermal vorticity. A well defined pattern with moderate wind speeds is therefore necessary for significant anticyclogenesis.

Coriolis effect.—From the development inequality it can be seen that the effect of the Coriolis term, $-\mathbf{V}'(\partial l/\partial s)$, on anticyclogenesis is to reduce it when the A–A region has thickness lines orientated north to south and to increase it when the thickness lines are south to north, because $\partial l/\partial s$ is negative in the former case and positive in the latter. Since the latitude changes covered by the pattern can be very large then the Coriolis term will play an important part in the development of surface features. In this particular pattern the effect is almost always one of reduction and can be large when the orientation of the thickness lines in the A–A region is north to south or when the pattern covers large latitude differences.

Assuming that the effect of the Coriolis term is sufficiently large to be worthy of consideration, since it is a reducing effect on anticyclogenesis, the smaller the Coriolis term, the greater will be the resulting development. The two things to be taken into account to reduce the value of the term are the mean latitude of the pattern and the orientation with respect to the earth's surface. Since $\partial l/\partial s$ is smaller in high latitudes than in lower latitudes a high mean latitude is to be desired for the greatest anticyclogenetic effect. If the thickness lines are orientated in a west to east direction the effect of the Coriolis term is zero, hence orientation in this direction of the thickness lines in the A–A region will be most favourable for the greatest anticyclogenetic effect. As the situation develops and the orientation is gradually changed from the most favourable to the least favourable with the A–A region lying north to south, there will be a period when the anticyclone will either decline slightly, or, at best, only maintain its intensity without further building until the thickness lines in the A–A region are orientated in the reverse direction at an appropriately small angle when further building will take place.

Steering.—The thermal wind over the new anticyclonic centre is usually not large and the thermal steering results only in a transfer of the larger pressure rises somewhat downstream along the thickness pattern.



— Isobars (1000-mb. contours) — — 500 - 1000 - mb. thickness lines

FIG. 10—CHART FOR OCTOBER 21, 1955 AT 0300 G.M.T.

Practical application to forecasting.—To use the diffluent ridge confluent trough for forecasting the formation of a new anticyclone, the following factors must be kept in mind:—

(i) Advection such as to keep the pattern in existence over a sufficiently long period.

(ii) Sharp diffluence on the ridge and confluence on the trough with sharp ridge and trough lines.

(iii) Orientation of the thickness lines in the A–A region should be near to the west-east direction and the thickness lines in the C areas should be near to the south-north direction.

(iv) The whole pattern should have a high mean latitude, say above 50°N.

If any one of the above conditions is not fulfilled, the intensity of the resulting anticyclogenesis will be reduced. A new anticyclone will not usually develop unless conditions (i), (ii) and (iv) are fulfilled, but other symptoms of anticyclogenesis, e.g. filling depressions, weakening fronts, will be manifest.

Characteristics of the development of anticyclones.—

(i) A depression on the thermal ridge is deflected to the left with much deepening, advecting warm air northwards.

(ii) A depression on the confluent trough moves north-east, advecting cold air southwards.

(iii) Any new depression developing on the confluent trough moves south-east at right angles to the thermal pattern and fills.

(iv) An anticyclone develops with marked tendency for two ridges orientated from A to A a little down the thermal pattern from the A–A axis.

(v) The large-amplitude pattern so generated gives a slight weakening of the anticyclone and then a re-build.

(vi) If a new model pattern is generated on the western side of an old high with a weakening pattern, then the tendency is for the centre to be transferred to the new A–A in the next 24 hr. and for this to become the major system.

(vii) The orientation of the A–A axis governs the future shape of an existing high even when a decline is indicated.

(viii) If the confluent trough weakens or the diffluent ridge becomes confluent the pattern is destroyed and the anticyclogenesis will be markedly reduced.

Examples of the use of the pattern in practice.—We give a number of examples of the various types of development in the synoptic situation which followed the appearance of a diffluent-ridge confluent-trough pattern on the 1000–500-mb. thickness chart. The developments which the foregoing theoretical discussion would have led one to expect, are given.

Development and orientation of a simple surface ridge.—On Friday October 21, 1955 at 0300 G.M.T. Fig. 10 shows a confluent trough lying from north to south over the British Isles backed by a large-scale diffluent ridge over the Atlantic, to the south-east of Greenland. There were depressions in the colder air to the west of the diffluent ridge and to the south-east of the confluent trough, while a ridge of high pressure extended from the warm air in the south-west across the baroclinic thermal pattern into the cold air in the north.

Expected development.—The region of greatest anticyclonic vorticity is marked A–A. The surface ridge is expected to swing so as to orientate itself along the line A–A and at the same time to move south-eastwards, broadside to the thermal flow. The depression in the west should swing to the left and deepen, that over Norway move rapidly north-east and the one over northern France move slowly south-east.

In Fig. 11 the chart for 0300 G.M.T., Saturday October 22, 1955 shows that these expectations would have been largely fulfilled.

Development of a new anticyclone.—The chart for 0300 G.M.T. on March 3, 1955 shown in Fig. 12 reveals the dominant surface feature to be a large anticyclone centred over Denmark. Over the central Atlantic is a weak ridge while a deep trough just east of Newfoundland is moving rapidly east. Ahead of this trough and over the ridge lies a well defined thermal diffluent-ridge confluent-trough pattern.

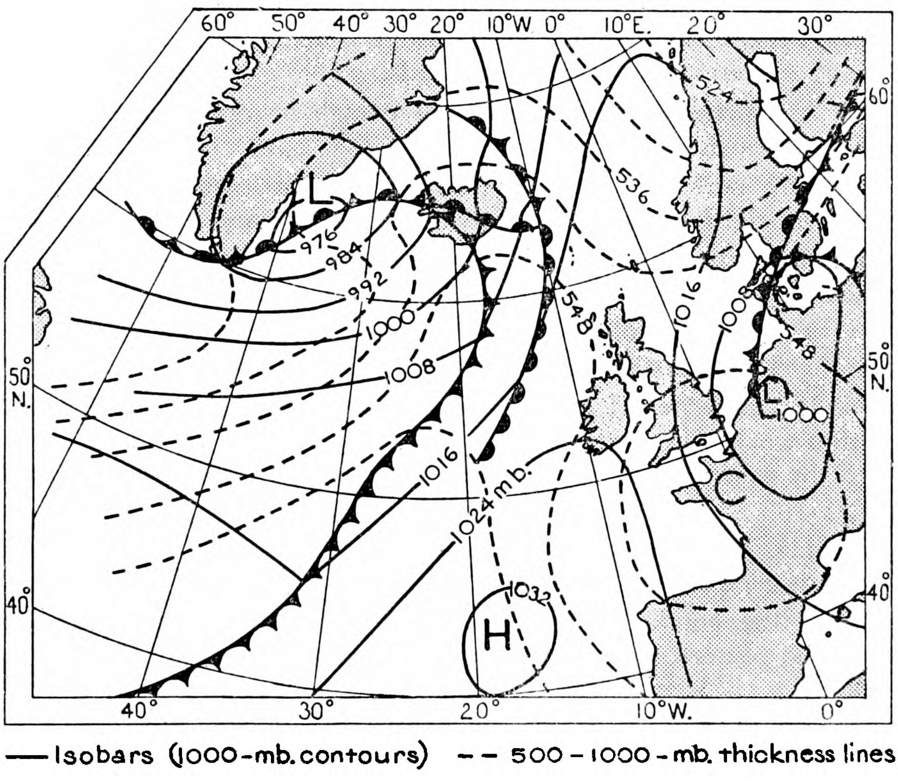
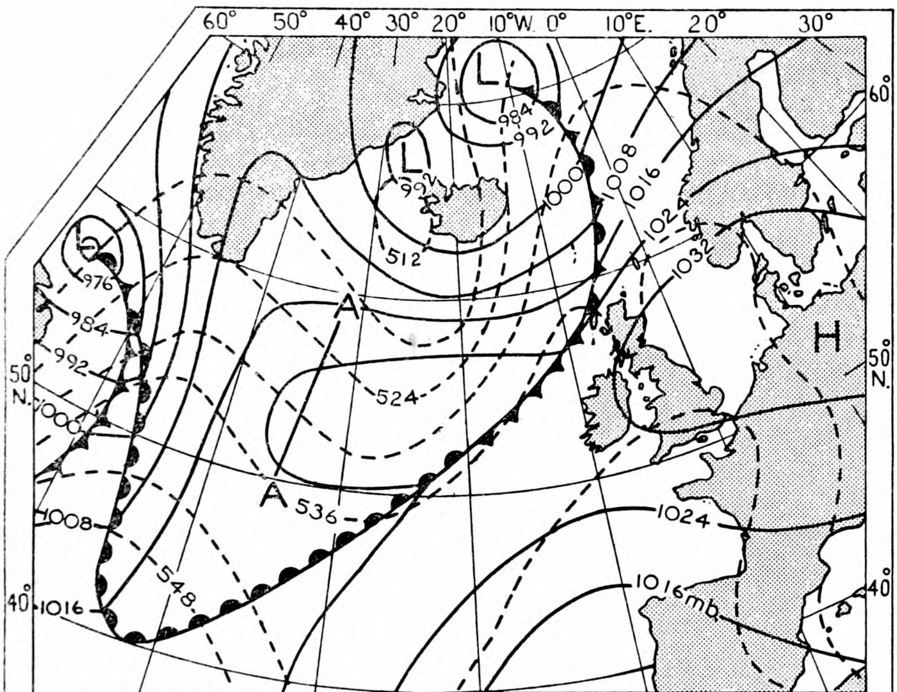


FIG. 11—CHART FOR OCTOBER 22, 1955 AT 0300 G.M.T.

Expected development.—The ridge should build and tend to orientate its axis more in the south-west to north-east direction. Since the ridge is in a different air mass from the anticyclone over Denmark it seems likely that large-scale ridging will lead to the formation of a new, detached, anticyclonic cell. While developing, this cell should move slowly east-south-east with the thermal wind across its centre.

In Fig. 13, the chart for March 4, 1955 shows that the expectations have been realized but that the diffluent-ridge confluent-trough pattern is no longer in existence, the confluent trough having become diffluent. Normally this should lead to the rapid destruction of the anticyclone. In the present instance, however, pressure rises have been so large that the consequent subsidence-warming has transformed the thermal pattern over the centre of the anticyclone into a barotropic region. Consequently an almost stationary, warm anticyclone results with depressions moving round it in the tight outer thermal gradient.

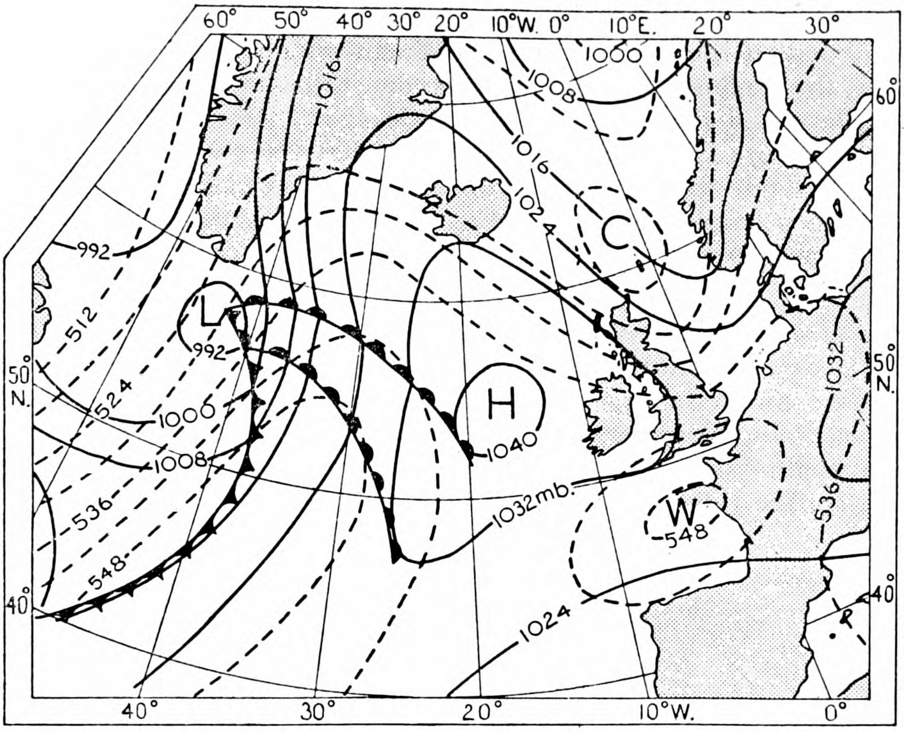
Filling of an advancing depression.—The large anticyclone, the formation of which was described in the previous paragraph, is shown in Fig. 14 to be still in existence on March 7, 1955. Its western lobe was at that time being approached by a depression to the east of Newfoundland. The thickness chart shows a small scale diffluent-ridge confluent-trough between this depression and the surface ridge.



—— Isobars (1000-mb. contours) — — 500 - 1000-mb. thickness lines

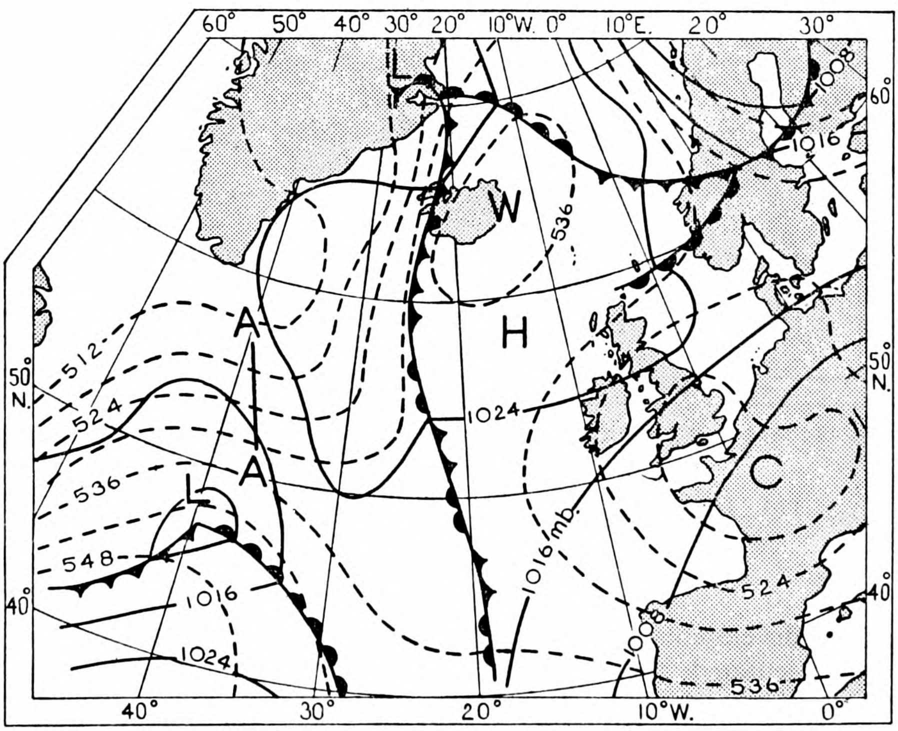
FIG. 12—CHART FOR MARCH 3, 1955 AT 0300 G.M.T.

Expected development.—Although the pattern in the thermal field is small it is well orientated, the thickness lines between confluence and diffluence lying almost along the west to east direction. Consequently, although heavy and prolonged pressure rises cannot be expected, definite development of the ridge should take place. The depression is on the warm side of the main baroclinic zone and so cannot well turn left., It must therefore fill up.



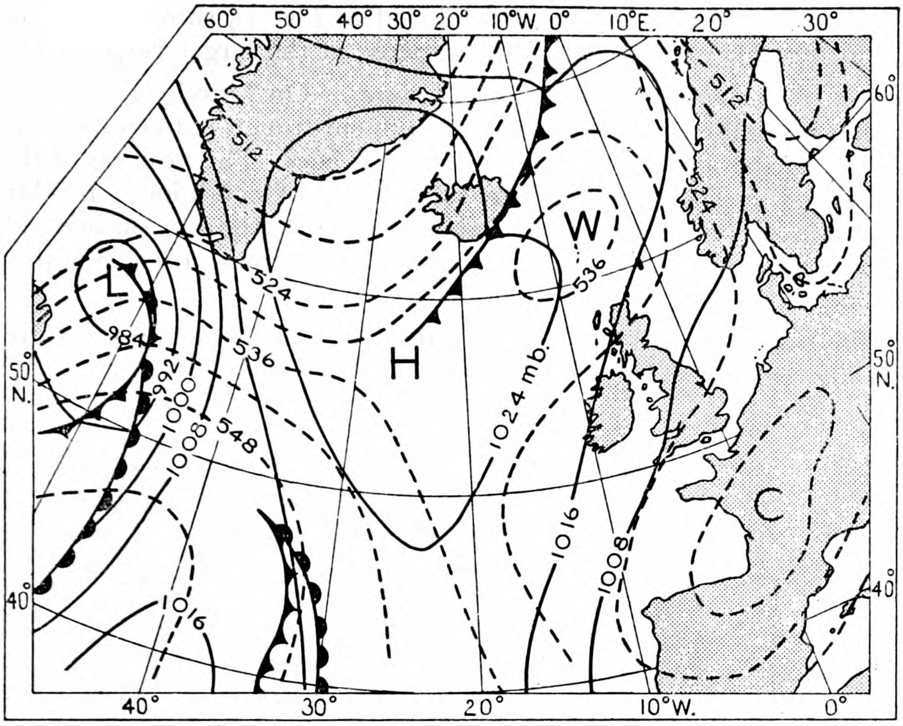
— Isobars (1000-mb. contours) – – 500–1000-mb. thickness lines

FIG. 13—CHART FOR MARCH 4, 1955 AT 0300 G.M.T.



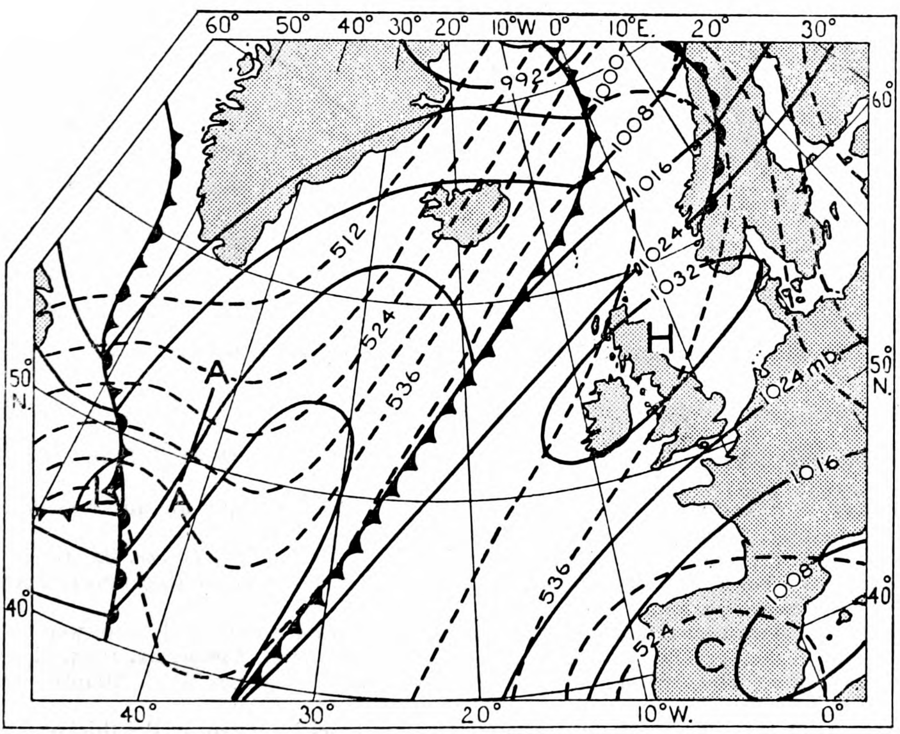
— Isobars (1000-mb. contours) – – 500 – 1000-mb. thickness lines

FIG. 14—CHART FOR MARCH 7, 1955 AT 0300 G.M.T.



— Isobars (1000-mb. contours) – – 500 – 1000-mb. thickness lines

FIG. 15—CHART FOR MARCH 8, 1955 AT 0300 G.M.T.



— Isobars (1000-mb. contours) – – 500 – 1000-mb. thickness lines

FIG. 16—CHART FOR MARCH 11, 1955 AT 0300 G.M.T.

The chart for March 8, 1955 reproduced in Fig. 15 shows the depression filled and the ridge developed at the expense of the larger ridge to the east.

Transfer of the main anticyclonic centre westwards.—On March 11, 1955, Fig. 16 shows that a small-scale diffluent-ridge confluent-trough pattern has appeared to the west of the anticyclone over the British Isles. The position of this and the associated surface situation are reminiscent of conditions on March 7, 1955. Again therefore we would expect the west-Atlantic surface ridge to strengthen and the nearby depression, which lies on the warm side of the baroclinic zone, to fill.

The final development is shown on the chart for 0300 G.M.T., March 12, 1955 in Fig. 17.

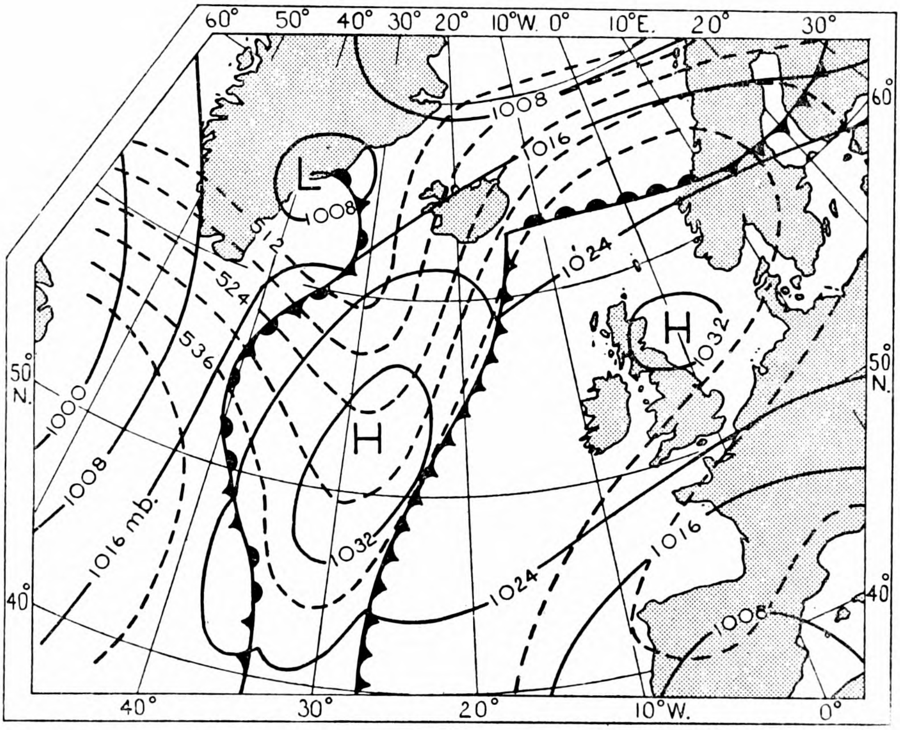


FIG. 17—CHART FOR MARCH 12, 1955 AT 0300 G.M.T.

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A SECOND REPORT ON FOG AT LONDON AIRPORT

By D. C. EVANS

Introduction.—Nearly seven years ago N. E. Davis[1] published a note on Fog at London Airport, based on the first four years of observations there. Ten years of observations are now available and a review of the preliminary appreciation has been made. As the diurnal variation of fog during the summer months is not a significant problem, only the months October to March are considered here.

Histograms of fog frequencies.—Hourly observations of visibility less than 1,100 yd. have been used to construct histograms in Fig. 1 which show, for each month, the distribution of four ranges of visibility hour by hour. The ranges of visibility are less than 220 yd., less than 440 yd., less than 880 yd. and less than 1,100 yd.

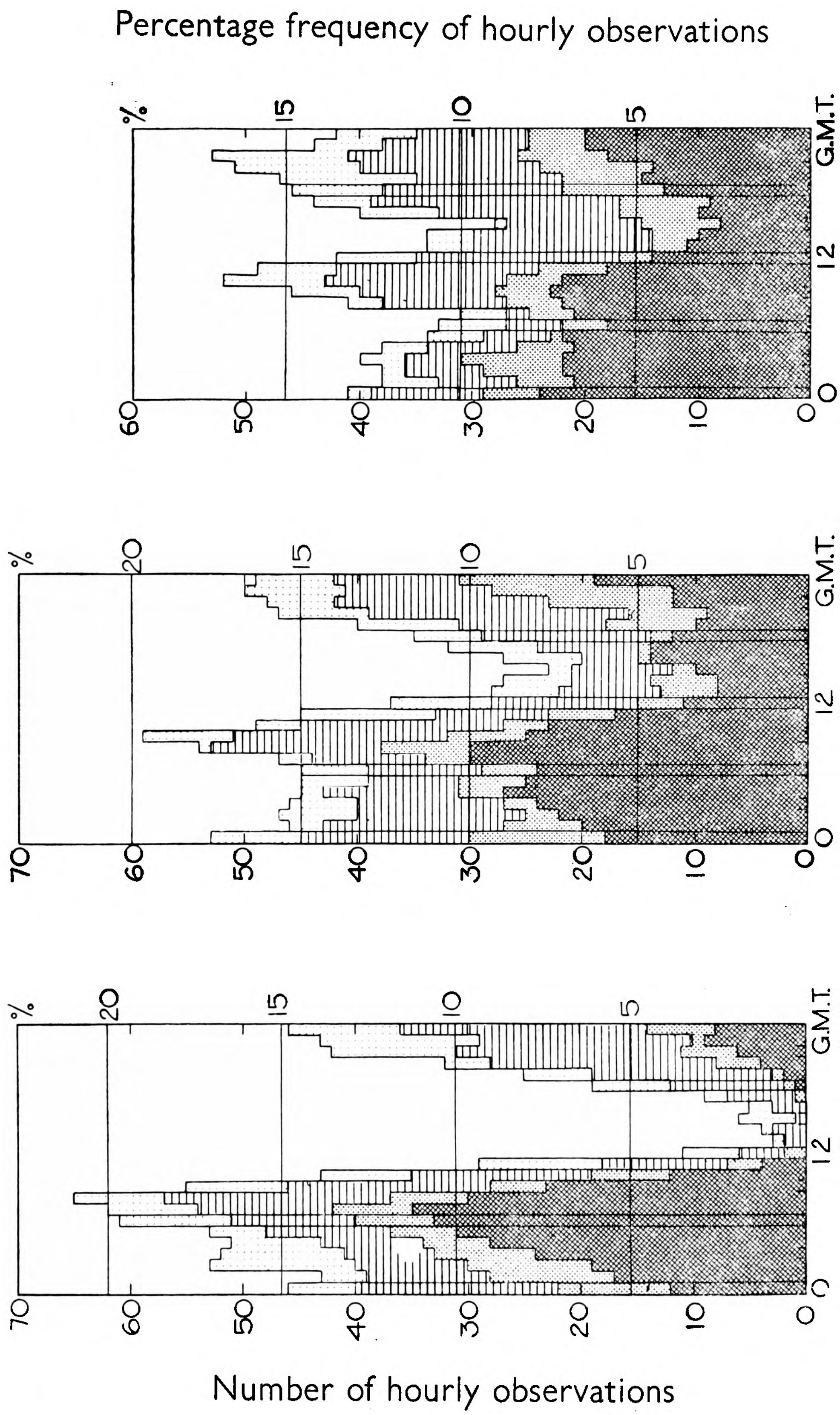
Copies of Fig. 1 are displayed in the forecast room at London Airport and are used by the forecasters when fog formation seems a probable development of the synoptic situation. Assessments are made of the fog point, the rate of cooling, the wind drift and other relevant factors, but the histograms give some indication of the probable range of visibility at certain times and help the forecaster to translate his general assessments into visibilities, times and probabilities, which, in spite of their wide margin of error, are of value to the operating companies. Similarly in forecasting the diurnal changes of visibility in fog or its dispersal these diagrams give a valuable summary of past experience.

Monthly totals.—Table I gives the monthly totals of hourly observations of visibility within the four ranges used in the construction of the histograms in Fig. 1. The corresponding percentage frequency is also given.

TABLE I—MONTHLY TOTAL OF HOURLY OBSERVATIONS OF VISIBILITY WITHIN CERTAIN RANGES

	Visibility							
	<220 yd.		<440 yd.		<880 yd.		<1,100 yd.	
	No. of hourly Obs.	Frequency	No. of hourly Obs.	Frequency	No. of hourly Obs.	Frequency	No. of hourly Obs.	Frequency
1946–55		%		%		%		%
October	298	4	408	5	689	9	858	12
November	424	6	568	8	880	12	1,020	14
December	418	6	555	7	845	11	986	13
1947–56								
January	340	5	464	6	720	10	861	12
February	127	2	219	3	496	7	620	9
March	169	2	251	3	523	7	673	9

Major periods with high frequency of fog.—The salient points in the variation of fog at London Airport, which were deduced from the first four years of observations by Davis, are fairly well confirmed by the additional data now available. The frequency and persistence of fog in November is not as outstanding as it was in the first four years but Table I confirms that


Percentage frequency of hourly observations
October 1946-55
November 1946-55
December 1946-55
G.M.T.
%
0
12
5
10
15
20
0
10
20
30
40
50
60
70
Number of hourly observations

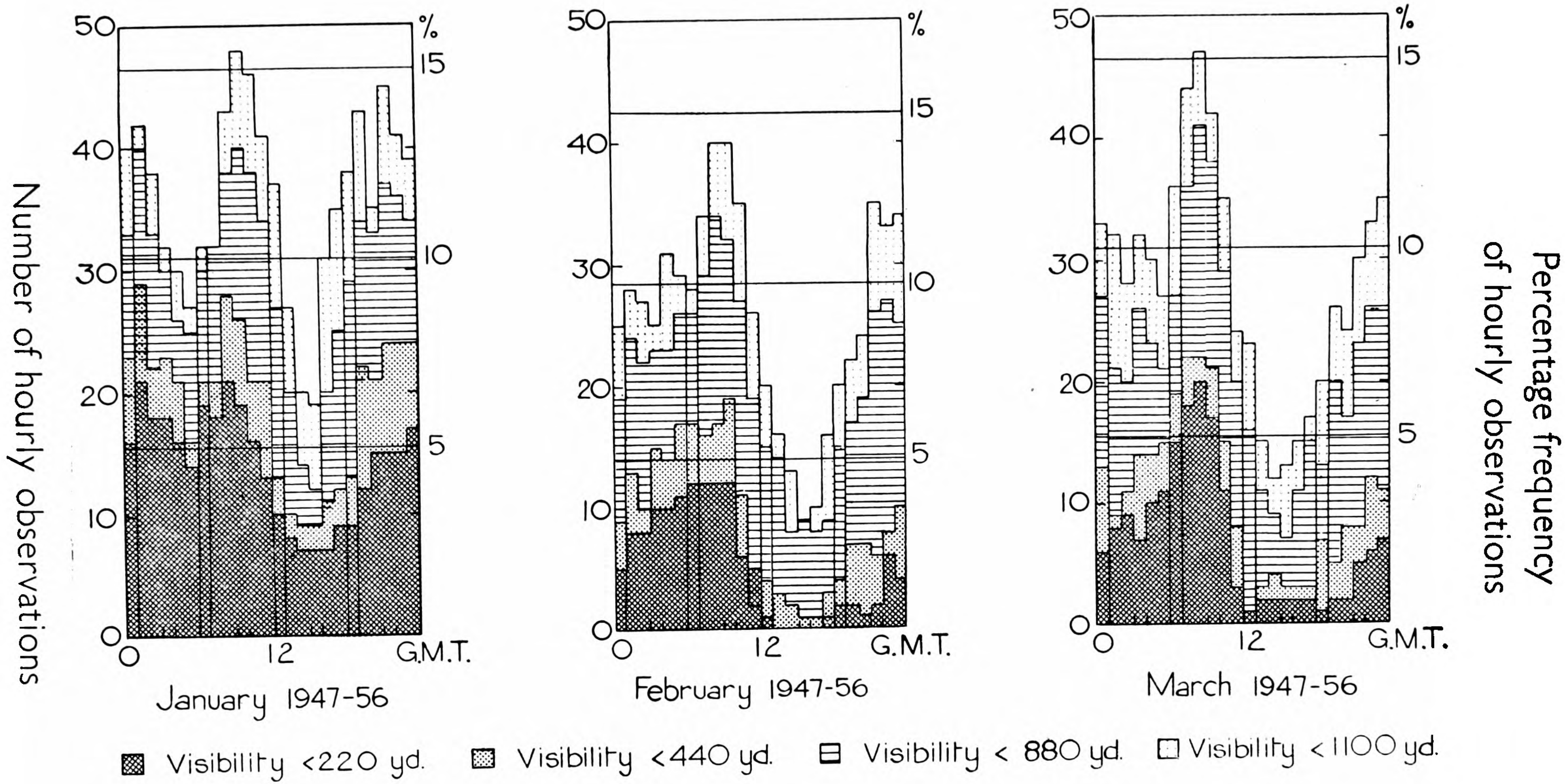


FIG. 1—HISTOGRAMS OF FOG FREQUENCIES AT LONDON AIRPORT

November is the foggiest month although December is now shown to be only a little less foggy than November. The high frequency of fog on October mornings is confirmed. The highest frequency of the whole year occurs at 0700 and 0800 G.M.T. in October when the frequency of fog with visibility less than 220 yd. is over 10 per cent. and with visibility less than 1,100 yd. is over 20 per cent.

General pattern of diurnal variation.—It can now be assumed that the general structure of the diurnal variation of the frequency of fog in winter contains two maxima, one at about one hour after sunrise and another about midnight. The main minimum occurs about 1500 G.M.T., with a secondary minimum about 0500 G.M.T. It should be noted that on Sunday mornings the poorest visibilities occur an hour or more later than on week-days which suggests that local domestic smoke is a considerable factor in the thickening of morning fogs, the implication being that local domestic stoking takes place later on Sunday mornings than during the week.

Tendency for smoke fogs to disperse late in the evening.—In spite of the general deterioration of visibility from 1500 G.M.T. to midnight there is often a marked improvement between 2100 and 2200 G.M.T probably due to the decrease of local domestic smoke production. This improvement is partly obscured in the histograms in Fig. 1 by the onset of radiation fog at this time on other occasions, but it took place on about 50 per cent. of the occasions when the visibility at 2100 G.M.T. was between 330 and 1,100 yd. When the visibility at 2100 G.M.T. was less than 330 yd. an improvement within the next hour was observed on only 9 out of 44 occasions.

TABLE II—PERCENTAGE FREQUENCIES OF VISIBILITIES FOLLOWING ZERO HOUR FOR OCTOBER (0700 G.M.T.), FEBRUARY (0800 G.M.T.) AND MARCH (0700 G.M.T.)

Visibility<220 yd. at zero hour

Visibility	Hours after zero 1	2	3	4	5	6
yd.	*Percentage*					
<220	88	76	38	9	0	0
<440	91	79	59	24	6	3
<660	91	79	68	35	15	12
<880	97	82	71	41	21	12
<1,100	100	88	74	50	24	12

Clearance of thick fog during daylight.—One of the most critical problems connected with the diurnal variation of fog is the timing of an expected clearance of thick fog during the forenoon or early afternoon under the influence of purely diurnal changes. The following analysis was made to assess the degree of probability of various diurnal improvements in winter. Zero hour for improvement was taken as about one hour after sunrise and occasions with visibility less than 220 yd. at that hour were tabulated with regard to subsequent changes in visibility in Tables II and III. The winter months have been divided into two groups as the three months grouped together gave similar results.

No attempt has been made to exclude from these tables improvements which were not of a diurnal character. Assuming that only a small percentage of the improvements were due to changes in the synoptic situation, it is possible to

Map reference SX(20) 105836

Photograph by Dermott P. Fitzgerald

INN YARD AT CAMELFORD

(see p. 341)

Map reference SX(20) 115837

Photograph by Dermott P. Fitzgerald

TREGOODWELL BRIDGE FROM THE SOUTH-EAST BANK OF THE RIVER

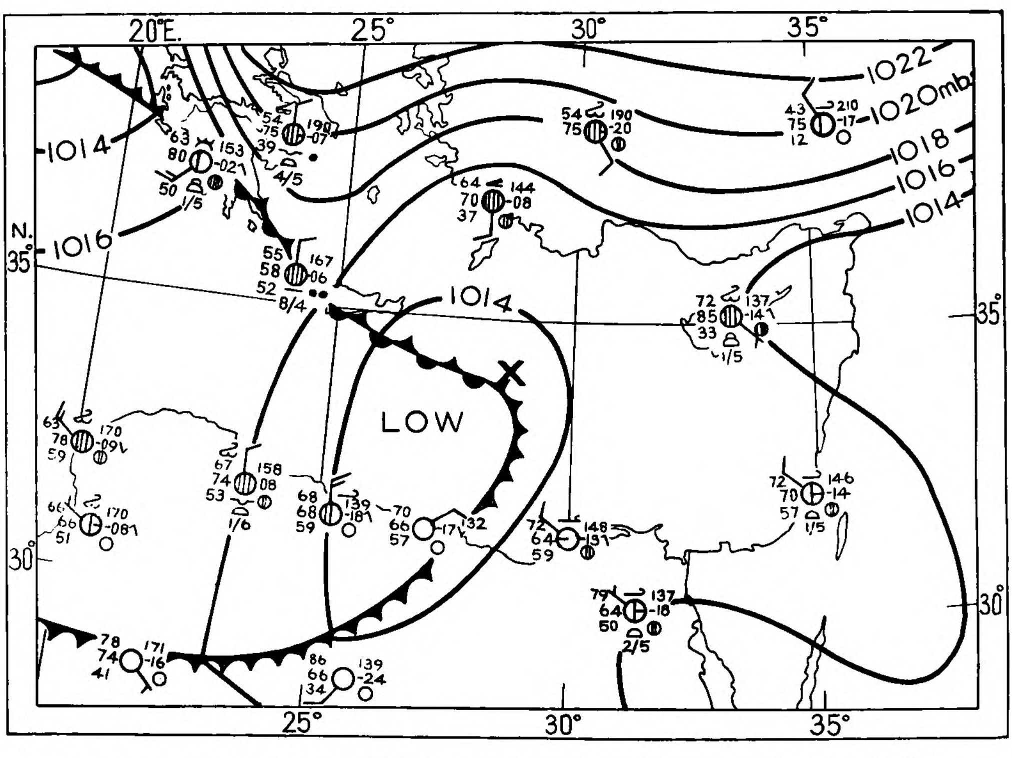
(see p. 342)

Map reference SX(20) 115837 *Photograph by Dermott P. Fitzgerald*

TREGOODWELL BRIDGE FROM THE NORTH-WEST BANK OF THE RIVER

(see p. 342)

Photograph by T. A. M. Bradbury



CLOUD PATTERN AND 1200 G.M.T. CHART OVER THE MEDITERRANEAN

(see p. 347)

assess the probabilities of improvement from the above tables, on occasions when no change in the synoptic situation is expected. For example, if visibility is less than 220 yd. at 0900 G.M.T. on a morning in December there is more than a 50-per-cent. probability that the visibility will be less than 660 yd. at 1300 G.M.T.

The earlier improvement, relative to sunrise, of the low visibilities in Table III is attributed to the poorest visibility being associated with the initial lighting and stoking of domestic fires which, in midwinter, occurs earlier relative to sunrise.

Comparison of two four-year periods.—One of the most striking features of the four years previously examined was the high frequency of fog in November, but it will be seen in Table IV that in the next four years December had a frequency of fog which was almost as outstanding.

The increase of fog in December was partly due to the disastrous fog of December 5 to December 9, 1952, which accounted for 107 almost consecutive hourly observations, 77 of which were of visibilities less than 220 yd. However, if all these observations are subtracted from the 1950–53 totals, December still had more fog than November during this period.

TABLE III—PERCENTAGE FREQUENCIES OF VISIBILITIES FOLLOWING ZERO HOUR FOR NOVEMBER (0800 G.M.T.), DECEMBER (0900 G.M.T.) AND JANUARY (0900 G.M.T.)

Visibility <220 yd. at zero hour

Visibility	Hours after zero 1	2	3	4	5	6
yd.	*Percentage*					
<220	80	66	41	29	22	24
<440	85	76	54	39	37	34
<660	100	85	68	51	44	41
<880	100	93	76	68	56	44
<1,100	100	95	83	74	66	54

TABLE IV—TOTAL NUMBER OF HOURLY REPORTS OF VISIBILITY FOR PERIODS CONSIDERED

	1946–49	1950–53		1947–50	1951–54
	Number of observations			*Number of observations*	
October			January		
<220 yd.	122	135	<220 yd.	135	108
<1,100 yd.	395	380	<1,100 yd.	369	271
November			February		
<220 yd.	261	107	<220 yd.	68	59
<1,100 yd.	553	298	<1,100 yd.	345	254
December			March		
<220 yd.	141	221	<220 yd.	92	75
<1,100 yd.	370	496	<1,100 yd.	314	333

Some climatological means and fog frequencies.—Table V was prepared to illustrate the differing climatic conditions in the months of November and December in the two four-year periods considered above.

A fairly close correlation appears between the calms and the observations with visibility less than 1,100 yd. Mean temperatures, vapour pressures and wind directions do not show as much correlation with the frequency of fog as might be expected. The readings for December 1950 and December 1952 demonstrate these points as follows:—December 1950 and December 1952 are similar in temperature and vapour pressure, which are both below average, but December 1952 had a higher percentage of calms which was paralleled by a higher percentage of fog. The larger percentage of easterly winds in December 1950 did not produce the larger number of occasions with thick smoke or fog which would be expected. This feature of calms being more significant than easterly winds in producing fog is further demonstrated by the figures for November and December 1953, which are similar under most headings but the much higher percentage of easterly winds in December is associated with only a relatively small increase in fog.

TABLE V—CLIMATIC CONDITIONS DURING PERIODS CONSIDERED

	Percentage of 3-hourly observations			Means of all 3-hourly observations		Percentage of hourly observations	
	Winds					Visibility	
	E'ly NNE.–SSE.	1–10 kt.	Calm	Vapour pressure	Dry-bulb temperature	< 220 yd.	< 1,100 yd.
				mb.	°F.		
1946–49 November	18	56	13	9·3	45·5	9	19
December	25	57	10	7·9	41·7	5	13
1950–53 November	21	50	10	9·0	44·9	4	10
December	20	58	17	7·8	40·3	8	17
1950 December	29	66	10	6·2	34·9	1	10
1952 December	8	53	23	6·8	37·3	15	23
1953 November	11	51	21	10·0	47·3	7	16
1953 December	31	68	21	9·8	45·7	9	19

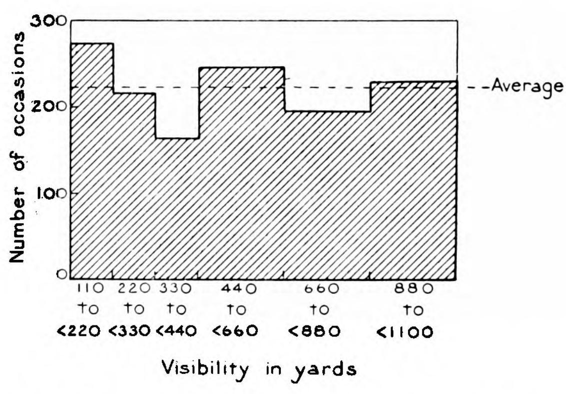


FIG. 2—HISTOGRAM OF FOG FREQUENCY AT LONDON AIRPORT DURING THE WINTER MONTHS OCTOBER 1950 TO MARCH 1956

There were 683 occasions with visibility less than 110 yd., but this column is omitted.
The pecked line is the average number of observations per 110-yd. step from 110 yd. upwards.
The totals for the 220-yd. steps have been halved to compensate for the doubled range of visibility.

Distinction between smoke and water fogs.—At Cardington, K. H. Stewart[2] found that visibilities in fog were almost invariably less than 200 yd. and that other visibilities within the fog range only occurred in the transitional stages of formation or dispersal. At London Airport there is a frequency of intermediate visibilities which cannot be only transitional but must be attributed to smoke pollution. It was thought that the range of visibilities used in producing Fig. 1 might be large enough to obscure a lack of observations somewhere between 110 and 550 yd., therefore the occasions with fog during the winter months from October 1950 to March 1956 were divided into twice as many groups, using 110-yd. steps up to 440 yd. and then 220-yd. steps up to 1,100 yd. The total numbers of observations of visibility within each of these steps has been found and the histogram in Fig. 2 obtained. Apart from the visibilities less than 110 yd., all columns contain a fairly uniform number of occasions, though there is a noticeable minimum in the range 330–440 yd. This can be taken as the division between water fogs and smoke fogs, though bonfire and pyrotechnic smoke on Guy Fawkes night, November 5, 1954, was sufficient to reduce the visibility to 300 yd. Other occasions of visibility less than 440 yd. in smoke have been caused by very high concentrations of smoke which have built up over the metropolitan area and have subsequently been brought to the airport by the onset of a light easterly drift.

As the minimum visibility in smoke is near the minimum visibility at which many aircraft are operated, it is helpful to distinguish between thick smoke and water fog by using the term smoke and not fog when there are no water droplets present or expected. This distinction conveys to the recipient valuable information and can sometimes give confidence in what would otherwise be a discouraging situation.

Conclusion.—It is hoped that the above survey of fog at London Airport will be of use to forecasters in their daily forcasting work, and to the operating companies and others in their long-term schedule planning. It is thought that the ten-years' data now presented, are unlikely to be changed significantly by the accumulation of further data.

REFERENCES

1. DAVIS, N. E.; Fog at London Airport. *Met. Mag., London*, **80**, 1951, p. 9.
2. STEWART, K. H.; Radiation fog: investigations at Cardington, 1951–54. *Met. Res. Pap., London*, No. 912, 1955.

RAINFALL AT CAMELFORD, CORNWALL, ON JUNE 8, 1957

By A. BLEASDALE, B.A.

A very intense fall of rain, accompanied by unusually heavy hail, occurred at Camelford, Cornwall, on Saturday, June 8, 1957. This was the outstanding event amongst the widespread thunderstorms of the Whitsun weekend.

The largest amount of rain fell probably about a mile east by north of Camelford, over the drainage area of a tributary of the River Camel. The largest actual measurement was made at Camelford (Roughtor View) where the reading for the rainfall day was 7·09 in. At another rainfall station, Camelford (Advent), 1½ miles to the east, the amount measured was 6·33 in. The previous largest fall in a rainfall day known to have occurred in Cornwall was 4·53 in. at Liskeard (Penmilder) on October 5, 1929, though there have been falls of 9 in. or more on four known occasions in the nearby counties of Devonshire, Somerset and Dorset, and falls in the range from 6 in. to more than 8 in. on several occasions across the Bristol Channel in South Wales.

A full account of the rainfall and flooding has been received from Mr. C. H. Archer of Wootton Courtenay near Minehead, who visited the area twice to investigate the damage caused and search for evidence to amplify the data obtained from rainfall stations in the neighbourhood. Mr. Archer acknowledges his great debt to Mr. D. W. Bogle, Honorary Secretary of the Cornwall Rainfall Association, who made the measurement of 7·09 in. with his own rain-gauge at Camelford and had already, before the first visit, assembled much

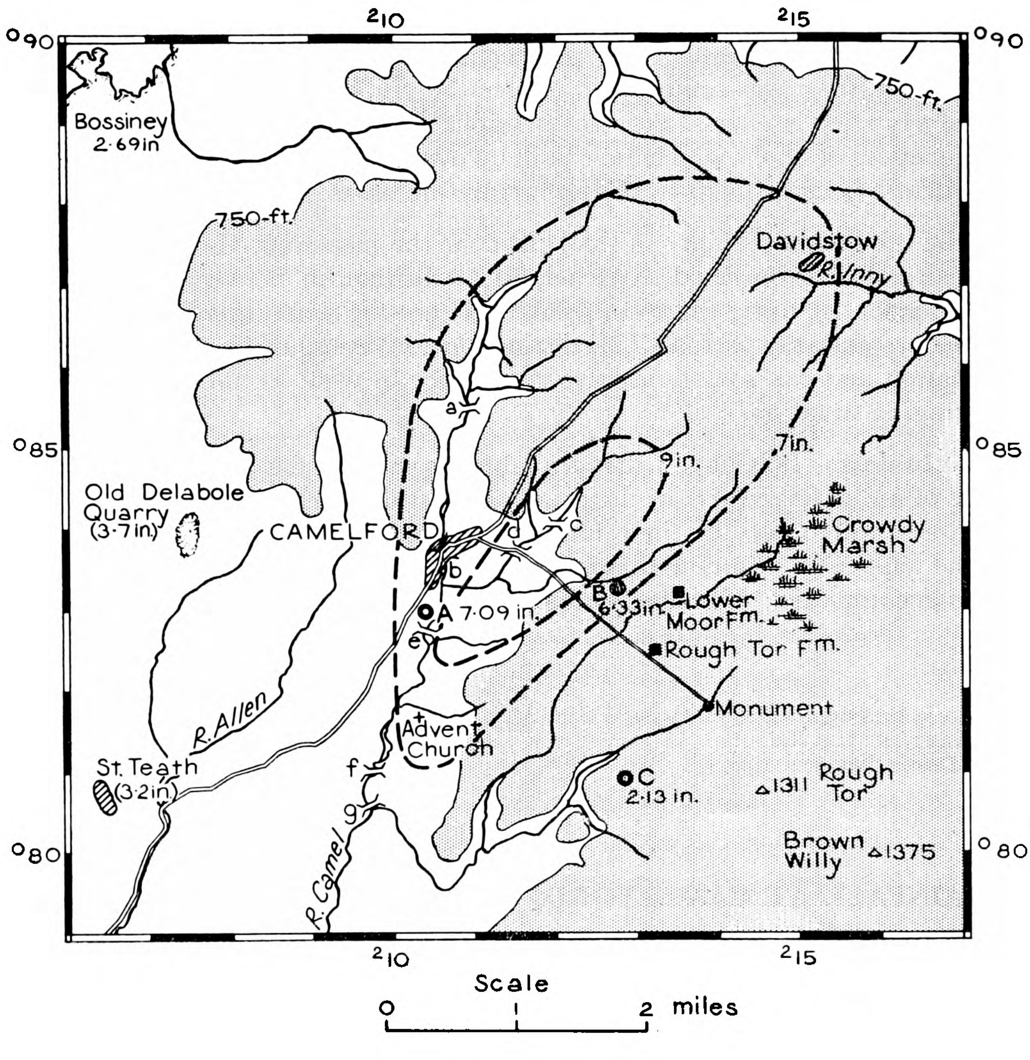


FIG. 1—RAINFALL DISTRIBUTION OVER THE CAMELFORD NEIGHBOURHOOD, JUNE 8, 1957

Rain-gauges.—A, Roughtor View; B, Advent; C, Stannon Clay Works.
(Values as read, excluding hail)

Bridges.—

a, Slaughterbridge
b, Camelford Bridge
c, Tyland Bridge
d, Tregoodwell Bridge
e, Fonteroon Bridge
f, Kenningford Bridge
g, Trecarne Bridge

of the other information available. Discussions were also held with Mr. B. Pepper, Engineer, Cornwall River Board, and Mr. R. R. Haylett, Surveyor, Camelford Rural District Council, who were directly interested, in their official capacities, in the effects of the rainfall. This note is intended to provide only a brief review of some of the main conclusions of Mr. Archer's account. Copies of the full report are available from the author.

Before dealing with the areal distribution of the rain, the report discusses the evidence regarding the timing of the fall and the severity of the hail. At Camelford several separate measurements were made with the rain-gauge and these showed that the greater part of the rain, 5·43 in., fell within 2½ hr. from 1230 to 1500 G.M.T. Though there were no separate measurements within this period there seems no doubt, from all accounts of the rainfall and flooding, that more than half of the amount fell during the first hour. The exceptionally high intensity thus indicated is nevertheless an underestimate since it was also during this first hour that the heavy showers of hail occurred and little of this was measured by the rain-gauge. It was unfortunately difficult to form any accurate estimate of the amount of hail. The total duration of the showers, which included hailstones up to the size of large peas, was "variously estimated at from twenty minutes to an hour". Mr. Bogle, inspecting his rain-gauge after a very heavy shower for fear that the funnel would be choked, found that very little hail had been retained. There was other evidence that hailstones bounced 3 ft. in height and more than 12 ft. horizontally. On the other hand, there was no possibility of estimating the average depth of hail on the ground, as masses of hailstones, some of them congealed into large blocks, were washed about by the flood waters. The photograph facing p. 336 shows the result in one place in Camelford, the inn yard, where the hail was piled almost knee-deep.

Mr. Archer's estimate is that very nearly an inch of equivalent rain may have been lost from the rain-gauge measurement during the hail showers. Though, in the circumstances, the actual amount is speculative, the estimate does not seem to be a gross exaggeration. Mr. Archer's conclusions are, first that the fall at Camelford in one hour from 1230 to 1330 G.M.T. must have reached approximately 4 in., including the hail; and secondly that the fall for the rainfall day at Camelford must have reached 8 in.

A fall of 4 in. in one hour is not known to have been actually measured in Britain. The value which has been accepted as the largest amount yet measured within this time was 3·63 in. at Maidenhead (Lowood) on July 12, 1901, though the original Report in *British Rainfall* 1901 used the phrase "in little more than an hour". On June 26, 1953, 3·54 in. fell in 55 min. at Eskdalemuir Observatory, an amount which included 3·15 in. in 30 min., details of the fall being available from the chart of the rain recorder. A further example, more directly relevant to the Camelford estimate, is provided by the observations from Hewenden Reservoir, Bradford Waterworks, for June 11, 1956, where a fall of 6·09 in. within 1 hr. 45 min. was measured; on this occasion at least 3·48 in. must have fallen within one hour and unless the rainfall intensity was remarkably uniform over the full period, it is probable that 4 in. or even a little more fell within an hour. At Camelford, whether the estimate of 1 in. for the hail is fully or only partially accepted, the midday fall was probably very close to the greatest hourly intensities yet known or estimated for this country.

With regard to the second conclusion, Mr. Archer uses the estimate of 8 in. for the rainfall day at Camelford in conjunction with other data and his survey of the ground, in order to draw a map of the rainfall distribution. This map has been used as the basis for Fig. 1 which reproduces the 9-in. and 7-in. isohyets as drawn on the original. The 3-in. isohyet, which is not shown, enclosed most of the ground covered by Fig. 1 except for areas of a few square miles in the north-west and south-east corners. There are three main points of interest. It is estimated that the fall to the east of Camelford must have exceeded 9 in. over an area of more than 1 square mile; this area lies almost entirely within the drainage basin of the small tributary flowing into the Camel about a third of a mile down-stream of Camelford Bridge (b). Secondly, the rainfall gradient to the south-east of this area must have been extraordinarily steep; the readings of 6·33 in. at the Advent rain-gauge (B in Fig. 1) and 2·13 in. at Stannon Clay Works (C) indicated a gradient of 4·2 in. in little more than 2,000 yd.; the rapid decrease of erosion along the road leading south-east to the monument at NGR SX(20)138817 was among the features which strongly reinforced this evidence and suggested a large decrease in rainfall in the first 300 yd. south-east of the Advent gauge, so that the 3-in. isohyet must have been very close to the 7-in. isohyet in this direction. Finally, in the relatively broad area to the north-east of Camelford in the upper Camel valley, shown as receiving upwards of 7 in. of rain, the timing of the rainfall was very different from that in Camelford; the fall was less intense but more prolonged and reached its greatest intensity between 1700 and 1800 G.M.T. in what must have been in some respects a separate fall.

The description of the flooding which occurred is closely linked with these three characteristics of the rainfall distribution. The four bridges marked c, d, e and f in Fig. 1 were either destroyed or damaged. The photographs between pp. 336–337 show two views taken from opposite directions of Tregoodwell bridge at d after the main flood had subsided. Though the bridge was still passable the damage was severe—"one of its main members, a rectangular granite block measuring 9 ft. by 3 ft. by 1 ft. was lifted up, torn from its railing, and hurled transversely across the stream". But the bridges at a and b were not damaged, as the flood from the upper Camel valley was much less violent. Trecarne bridge at g and others down-stream of this point were also not damaged. The very rapid decrease of rainfall to the south-east was further confirmed by the lack of significant flooding in the tributary which joins the Camel at Trecarne after flowing past Devil's Jump. At Camelford there were two floods separated by about 3½ hr. The first was due to the intense rain at midday in Camelford and the near neighbourhood. It reached its peak within an hour and this was followed after 1330 G.M.T. by a substantial fall. During this flood, water flowing down the main road from the north-west, with a depth of 3 to 6 in. right across the road, flowed over Camelford bridge and into h e houses beyond. The second flood came down the River Camel from the upper valley, with a peak corresponding to the maximum rainfall intensity between 1700 and 1800 G.M.T. in that area.

The report contains much other interesting information, including a comparison with the rainfall at Cannington, Somerset, of August 18, 1924, to which the Camelford fall bears a close resemblance with respect to the areas covered, the maximum measured or estimated falls, and peak intensities.

There is also a discussion of previous floods at Camelford, in particular that of August 30, 1950, which was much more serious than the 1957 flood though the rainfall was very much less and did not give rise to any measured fall of as much as 2 in. The conclusion reached is that if the location of the heaviest rainfall on June 8, 1957, had been displaced by only 1 to 2 miles to the north-west or north, the damage in Camelford itself would have been disastrous and might have been accompanied by serious casualties or loss of life. It is stated that improvement works are already in hand to give greater protection against future floods in this valley.

CHARLES SUMNER DURST, O.B.E., B.A.

Mr. Durst retired on September 6, 1957, after 38 years' service in the Meteorological Office.

After graduating in mathematics at Pembroke College, Cambridge, in 1910, Mr. Durst spent several years in the Malay States as a Surveyor and during the First World War was commissioned in the Royal Engineers and served in Gallipoli, Palestine and the Western Desert. After demobilization in 1919 Mr. Durst turned his attention to meteorology and entered the Office as a Junior Professional Assistant. A few months later he was promoted and joined M.O.1 under the late Commander Brooke-Smith who was then the Marine Superintendent. Mr. Durst remained in M.O.1 for seven years and during that time played a major part in the introduction of the punched card system for the analysis of meteorological statistics and also wrote a study on *The doldrums of the Atlantic* which was published as *Geophysical Memoirs* No. 28.

From 1928 to 1932 Mr. Durst was one of the group of meteorologists who carried out a massive programme of experiments at the Royal Airship Works, Cardington, on the structure of wind in the lowest two hundred feet or so of the atmosphere. The results of these experiments are contained in *Geophysical Memoirs* No. 54 which is still regarded as a mine of fundamental data on atmospheric turbulence. A separate section of this Memoir is devoted to a presentation of a theory of eddies which Mr. Durst developed during the progress of the work at Cardington.

From Cardington Mr. Durst was posted to headquarters and until 1940 served in the Forecast Division. The 1930's saw much pioneer work in the development of Empire Air Routes and many of the famous aviators of those days had occasion to draw upon Mr. Durst's extensive knowledge of world meteorology.

The outbreak of the Second World War in 1939 laid heavy requirements upon the Meteorological Office and among them was a need expressed by military planners for climatological appreciations covering many areas of the world and written from the aviation standpoint. In 1940 therefore Mr. Durst took charge of a new branch for Special Investigations, and in that capacity he was frequently consulted by such bodies as the Chiefs of Staff Committee. With his assignment to Special Investigations full scope was given Mr. Durst to exploit his scientific ability in the application of meteorological data to a wide variety of problems. There followed and has continued a steady output of papers on such diverse topics as the variation of wind with time and distance, the meteorology of airfields, the accuracy of route-wind forecasts for aviation, the calculation of geostrophic trajectories, the importance of jet streams to air navigation, surface friction and turbulence in the ocean, pressure changes and the efflux of gas in mines—to give just a selection. In the re-organization of the Meteorological Office in 1948 Mr. Durst's post was upgraded and he was appointed Assistant Director (Special Investigations). He retired from this post in October 1953, but remained in the Office a further four years and was able to complete a number of investigations as well as to launch out on some new ones.

It is pleasant to recall as milestones in a career of such distinction that Mr. Durst's merits have received public recognition several times. In 1937 he was awarded the Buchan Prize of the Royal Meteorological Society; in 1946 he was made an Officer in the Civil Division of the Order of the British Empire; in 1949 he was awarded the Groves Memorial Prize for Meteorology by the Air Ministry; in 1950, and again in 1956, he was awarded the Bronze Medal of the Institute of Navigation.

Mr. Durst's career in meteorology has spanned nearly four decades and almost throughout that time he has been in the front rank of meteorologists and has retained a freshness and originality of thought that many would be glad to possess for a short period at the height of their powers. Retirement is a term which seems only remotely applicable to Mr. Durst and indeed he fully intends to continue his studies into the many meteorological problems of air navigation. Both in his own work and in the inspiration he has given to others Mr. Durst has made a host of friends who will wish him many years of happiness in which leisure may gradually attain precedence over meteorology.

NOTES AND NEWS

Meteorological Magazine: increase in price

We regret that owing to further increases in the cost of printing and publication it has become necessary to again raise the price of the *Meteorological Magazine*. The price will be 2*s*. 6*d*. an issue with effect from the January 1958 number. The net annual subscription will become 32*s*. including postage. Present subscribers will remain on the existing rate until renewal of their subscriptions is due.

Some remarks on lightning flashes and ball lightning

A number of scientists (G. C. Simpson, C. T. R. Wilson, W. Findeisen, J. Küttner etc.) have studied the electrification of thunderclouds and arrived at important conclusions concerning the distribution of positively and negatively charged parts of the thunderclouds. Their figures show more or less regular patterns of positive and negative signs throughout the cloud. I refer to Schonland's book "The flight of thunderbolts"[1] and Hann-Süring's "Lehrbuch der Meteorologie"[2]. All investigators agree that the primary thunderstorm condition is unstable warm air rising upward with great speed. In the up-draughts the raindrops are charged with electricity in different ways to an amount that is "quite enough to account for all lightning from the thundercloud and for other less spectacular electrical effects as well" (Schonland,[1] p. 122).

There is, however, one important effect I should like to emphasize: what happens in the tremendous down-draught process when the up-draught comes to an end so that all the rain and hail particles gathered up to great heights must fall down? The fact is illustrated by Schonland[1] in his figure 27C and he adds: "At the present time nothing is known with certainty as to the electrical conditions in the down-draught region" (p. 133). Yet we must consider that this down-draught represents a state of instability surpassing to an extremely high degree that of the up-draught before. The temperature in the region where hail and heavy rain are falling out is much lower than that of the surroundings and the downward-directed air streams must reach enormous speeds.

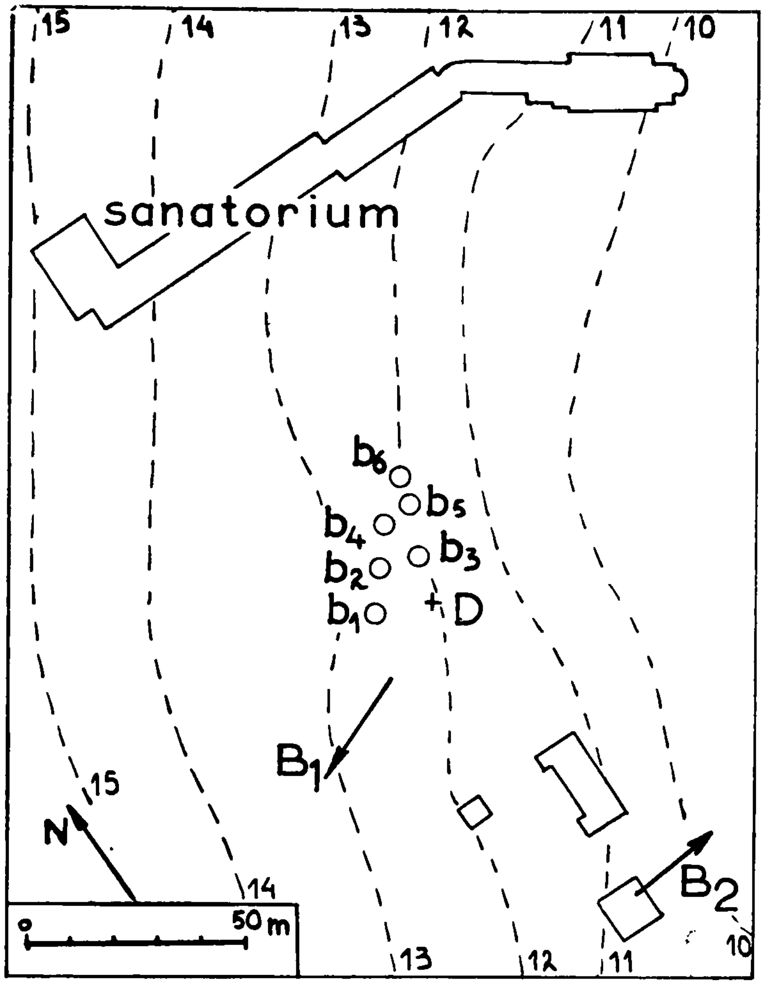


FIG. 1—PLAN OF THE NETHERLANDS STUDENTS' HEALTH RESORT AT LAREN

Fig. 1, taken from my article on the event in *Hemel en Dampkring*[3], shows the plan of the sanatorium grounds. The broken lines are contours of height in metres. The cross D shows where Mr. Dik was standing and B_1 the direction in which he saw the ball move. B_2 shows the direction in which Mev. Van Erp saw another ball explode. The oaks b_1 and b_2 were struck by lightning. b_3 and b_4 are also oaks and b_5 and b_6 are acacias.

Moreover thousands and thousands of tons of hail and water come down in a short time. All these effects are well known. The electricity-generating processes must increase during the fall up to amounts considerably higher than during the up-draught. I dare to presume that the principal electrical activity must be found in this second part of the thunderstorm phenomenon. Here the friction of ice and water particles (Sohncke, Küttner) and especially the "waterfall" electricity (Lenard, Simpson) must be extremely important. With regard to Lenard's phenomenon I should like to point to a possible effect. A large drop falling down will tend to break up. When break-up occurs, the small drops falling with less speed must be captured by the following large drops. Then these drops will also break up and so on. There must occur a chain process of collisions with a rapid increase in the number of electrically charged particles. In a short time interval a lightning flash must follow. Both Schonland[1] (p. 127) and Süring[2] (p. 1006) discuss the well-known effect of a flash preceding the rain and both consider the rainfall to arise from the action of the lightning flash. Schonland suggests the raindrops were supported by an electric field destroyed by the flash so that the rain falls out of the cloud following this "cutting of the strings of the electric parachute", as Schonland puts it. The above sketched development of electricity may point to the contrary action: the rain produces the flash. Indeed the flash will be seen at the same moment that it has taken place, and the thunder follows immediately, but the rain needs some time to come down and therefore the observer does not realize that nevertheless the rain has been the cause of the flash.

Concerning the occurrence of ball lightning, Schonland doubts its reality. He refers to an investigation by the American meteorologist W. J. Humphreys. I am sure that by far the most meteorologists disagree with this view. The observations of ball lightning all over the world show a good many common features. They are not caused by optical illusion. They are not observed by men "hardly in a position to give a reliable account of what happened" (Schonland p. 51). The numerous records in the Netherlands and elsewhere have by no means been "given by observers involved in thunderstorms on high mountains like the Alps". "The stories of fire-balls passing down chimneys and bouncing round the house with a sulphurous smell must be treated"—in all seriousness and then reveal their reality.

As to the cause of ball lightning we may accept that at the high temperature of the electrical discharge a number of chemical actions occur forming, as suggested many years ago by Th. Neugebauer, a mixture of electrically positive and negative gases. Dust and smoke particles, soot, and water droplets may take part in the process. This mixture is stable at the high temperatures concerned. When the ball cools the chemical balance may change either gradually or rapidly. In the first case this balance is maintained and the ball disappears noiselessly; in the second case, however, the mixture becomes unstable.

I had the good opportunity to verify the reports of two observations of ball lightning occuring just after one very near lightning flash, striking two trees and damaging the telephone cables in the grounds of the Netherlands Students' Health Resort at Laren near Hilversum, October 25, 1956 at 20hr. 15 min. Fig. 1 is a plan of the grounds. Mr. Dik, Chief of the Technical Department, did not see the flash because he was looking in another direction but he saw a large ball moving away from the trees and exploding at some distance. Mev. Vann Erp also did not see the flash but observed outside her house a ball appearing and exploding. Both observations were quite independent and related to two different fire-balls. The inhabitants of the resort heard a rather long clap of thunder and some of them were surprised when they heard that the strike was at no greater distance than about 80 metres. In fact there were three thunder claps caused by the close flash itself and the two exploding balls, with an appreciable time difference.

Mr. Dik did not see the flash, and he did not even hear the thunder. Only the following morning he realized that he had been at a distance of only 14 metres from the trees which had been struck!

The fact is known. Schonland mentions it but he is inclined to doubt it and to think "that in such cases the sound it too weak in intensity to be noticed in the general upset caused by a near discharge. Weak thunder of a special type is to be expected from such discharges, since they often consist entirely of a series of flickering tongues or streamers, each moving forward a little farther than its predecessor, and since they are not followed by the rapid and brilliant, and noisy return discharge which produces the characteristic whip-like crack of a flash to ground". This brilliant and noisy part of the flash was without doubt present in the Laren case! Mr. Dik did not give the impression of having been panic-stricken at the moment of the discharge in his immediate neighbourhood. I shall be glad to receive reports of other reliable observations of the same character.

S. W. VISSER

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2. HANN-SÜRING (newly written 5th edition by SÜRING, R.); Lehrbuch der Meteorologie. Part 9. Leipzig, 1951.
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Rainfall at Christmas Island (1°57'N. 157°27'W.)

A notable feature of the rainfall at Christmas Island is its extreme variability. In 1905 the annual rainfall was 298 in. whereas in 1917 only 10 in. was recorded. During the five and a half months from October 15, 1956 when the Meteorological Office station was opened, to March 18, 1957 the total rainfall was only 0·87 in. and then, in just over two hours on March 29, 1·82 in. fell. Another heavy fall occurred on April 3. Although at the official recording station there was only 1·05 in. between 9 a.m. and 9 p.m., at the airfield four miles away the rain was very much heavier, an unconfirmed report giving 12 in. during the day. Half an empty oil drum, cut off to form a cylindrical vessel about 12 in. deep, had been cleaned out and left in the open at 8 a.m. and by 5 p.m. was seen to be overflowing. Close questioning of the "observer" left little doubt that there had been a genuine rainfall of 12 in. in about nine hours. Certainly the flooding which occurred at the airfield was very much worse than that at the meteorological office site. Such high rates of rainfall, though for shorter periods, have been confirmed by the readings of the official rain-gauge. On May 26, 1957, 2·82 in. fell in 2 hours 10 minutes, the great bulk occurring in a period of 1 hour 24 minutes during which the average rate was probably about 1·8 in. per hour. On this occasion the airfield had much less rain.

M. H. FREEMAN

Cloud Pattern over the Mediterranean

Details of the photograph (facing p. 337) are as follows: date, March 26, 1957; time, 1010 G.M.T.; position, 34°10'N. 28°30'E. (shown by cross on chart facing

p. 337); height, 41,500 feet, indicated on a QFF setting of 1013 mb.; direction of view was south-south-east. It was taken from the rear window of a Transport Command Comet.

The cloud is stratocumulus, probably at a height below 5,000 feet. This is indicated by the shadows visible on the sea in the right-hand lower part of the print. The interesting feature is the way the cloud pattern suggests cyclonic circulation. The 1200 G.M.T. chart on that day indicates that a depression was in fact centred near this position. The centre of the circulation at cloud level may well be some distance from the surface centre, which in this case could not be accurately located.

Previous history showed that a cold front had crossed the Malta area the previous day. This front had since travelled very rapidly eastwards. Marked subsidence of the cold air had made the front very weak indeed in the region south of the centre, and no convective clouds were seen over the sea.

Two distinct bands of cloud were observed from the air, both were narrow and were spaced about a hundred miles apart. The photograph shows the most easterly band.

This area had been crossed at 0910 G.M.T. on a parallel track a little further south, and at that time the stratocumulus had a fan-shaped pattern, with the wider arc of the fan facing roughly south-east. There was no other low cloud within 50 miles of the area photographed, but an extensive cover of cirrostratus extended over the greater part of the Eastern and Central Mediterranean.

T. A. M. BRADBURY

REVIEW

Année Géophysique Internationale. International Geophysical Year. 1957–1958. OMM/WMO—No. 58. AGI/IGY 2. 24 mm. × 16 mm. World Meteorological Organization, Geneva, 1957. Price: Sw. fr. 8.

This publication has been prepared by the World Meteorological Organization to enable all concerned to ascertain which meteorological stations will be making observations of any type during the International Geophysical Year. Stations are listed under the eight headings, surface synoptic observations, upper air, radiation, atmospheric ozone, atmospheric electricity, sferics, nuclear radiation and atmospheric chemistry. Over 2,000 stations are listed under the first category and 650 under the second. Details of the type of instrument used are stated for upper air, radiation and ozone stations.

The booklet, compiled with the clarity and ease of reference always associated with W.M.O. publications, will be indispensable to all users of the observations made during the Year.

G. A. BULL

OFFICIAL PUBLICATION

The following publication has recently been issued:—

Annual Report on the Meteorological Office. April 1, 1956–*March* 31, 1957.

This Report is an account of the year's activities of the Meteorological Office as the State Meteorological Service. The new features introduced last year, cover design and illustrations and presentation mainly in the continuous narrative form, have been continued.

The provision of meteorological services for the general public, for aviation and shipping, for agriculture, industry, commerce and public utilities has continued to develop. The provision in the London area of an automatic dialling telephone service for the issue of forecasts to the public was, in collaboration with the General Post Office, extended during the year to Liverpool, Manchester, Birmingham, Glasgow, Belfast and Cardiff. Much consideration was given to the possibility of using mechanical and electronic methods for the recording and processing of meteorological data both for the improvement of information services and for meteorological research. The preparation of forecasts both for the general public and transatlantic air routes has been aided by the introduction of a direct teleprinter link on the transatlantic cable between this country and Canada; this ensures the prompt and regular reception of meteorological reports from North America and has eliminated the difficulties formerly caused by radio fade outs.

Much effort was devoted on the research side to numerical forecasting whereby forecast pressure maps are produced by calculation. An electronic computer, primarily for this work but also for other problems involving complex calculations is expected to be installed by the end of this year. Work continued on a series of controlled trials on the possibility of inducing rain artificially. The Meteorological Research Flight has continued its high altitude research which has a special significance in view of the increasing heights at which aircraft operate.

During the year under review the decision was taken to unite the Headquarters divisions now situated in London, Dunstable and Harrow at a new headquarters at Bracknell, Berkshire.

METEOROLOGICAL OFFICE NEWS

Retirements.—*Mr. C. A. Jupp*, Experimental Officer, retired on September 13, 1957. After service in the First World War from 1916 to 1919 and later for six years in the Royal Air Force, he joined the Office in July 1927 and spent his first five years at aviation outstations. Since 1932, apart from a period between 1945–1948, he has served successively in the Forecast, Marine and General Services Divisions.

Mr. H. A. Curtis, Senior Assistant (Scientific) retired on September 30, 1957. He served in the First World War from 1916 to 1919 and joined the Office from the Air Ministry in March 1929. He was posted to Croydon Airport. In 1935 he was transferred to the Forecast Division at Headquarters and since 1939, until his retirement, he has served continuously in the London Forecast Office. He was awarded the British Empire Medal in the New Year's Honours List of 1955. Mr. Curtis has accepted a temporary appointment in the Meteorological Office.

Academic successes.—The following members of the staff have been successful in recent examinations. We offer them our congratulations.

B.Sc. (General): J. D. Perry, P. J. Wiggett.

B.Sc. (Special): R. Baker, P. Menmuir (2nd Class Honours).

General Certificate of Education (Advanced Level): A. R. Belton, B. A. Cope, M. F. Gaskin, R. P. Healey, D. E. Lantry, Miss M. J. Llewelyn, Miss E. M. Walsh, D. Y. Warne.

Higher National Certificate: A. McEwen.

WEATHER OF SEPTEMBER 1957

In the British Isles the synoptic situation was changeable throughout the month with any particular pattern rarely persisting for more than a few days.

The month opened with fine sunny weather in Scotland and the north of England, but in the south it was changeable with periods of rain. Troughs, associated with a deep depression near Iceland, gave widespread rain on the 4th as they moved eastward across the country. Another depression deepened off the west of Scotland on the night of the 5th–6th and the following day was generally wet with heavy local rain and gales over the north-western part of the country. The 8th was sunny and dry apart from a few scattered showers, chiefly in Scotland, but weather was generally unsettled during the following week. A slow-moving frontal system, followed closely by a wave depression on a trailing cold front, reached western Ireland from the Atlantic late on the 8th and rain became widespread and locally heavy on the 9th and 10th. Pressure remained low over southern Scandinavia during the next five days; from the 11th to 13th there was rain in most parts of the British Isles with scattered thunderstorms and strong winds which reached gale force locally in northern districts. Gales and squally showers continued in the north of Scotland throughout the 14th and 15th, but further south the weather slowly improved. The next three days were mostly fine in the south and Midlands but still rather changeable in the north. Temperatures were somewhat below the average until the 18th when they rose to the upper sixties in the south of England and reached 70°F. at Mildenhall. Generally dull wet weather returned on the 20th, with a broad frontal belt lying roughly east to west across the country, and persisted for several days. An intense depression, the remains of an old tropical storm, arrived off south-west Ireland on the 23rd and in its circulation a broad area of rain spread northwards across England and Wales into Northern Ireland. The rain was heavy in places and thunderstorms developed over East Anglia and the Midlands; during one of these storms a miniature tornado occurred over Lincolnshire. Meanwhile colder air, preceded by outbreaks of rain, was spreading southwards from Scotland and by the 24th had reached the Midlands and the London area; the maximum temperature on that day was only 50°F. in North Wales, contrasting sharply with a south-coast maximum of 70°F. An anticyclone in the eastern Atlantic increased in intensity on the 26th and 27th and the following day cold air spread south-east over the whole country bringing mainly bright and showery conditions for the remainder of the month. Slight air frost occurred in a few places early on the 30th.

Temperatures were generally below normal in all parts of the country with day maxima 2–3°F. below the September average. Sunshine totals were deficient for most parts of the country some places having only about half their normal September amount. Rainfall was 198 per cent of the average in England and Wales but only 98 per cent in Scotland. More than twice the average was recorded over most of Wales and much of England north of the Thames, except in the north-east. Three times the average was exceeded in Nottingham.

The rain delayed harvesting and in some areas it has been estimated that as much as half the crops have been lost. Toward the end of the month, flood water following heavy rain caused even greater chaos especially in the Midlands where fields became unworkable and autumn ploughing was brought practically to a standstill. Potato blight caused serious losses as also did "virus yellows" in sugar beet which followed heavy aphis infection earlier in the year. Flower crops suffered in the wet weather, but grass and green vegetables continued to be healthy and plentiful.

Over most of the northern hemisphere the circulation was decidedly weaker than normal. The Indian monsoon appeared to have ended early and this also applied to the summer-time extension of the monsoonal low pressure towards north-east Asia. Pressure anomalies were positive over more or less all Asia, actually from Ceylon to beyond the North Pole in Greenland and Alaska: the anomaly reached +5 mb. in central Asia and at Spitsbergen. Pressure was 5 to 7 mb. above normal in Iceland. The subpolar low-pressure belt was displaced south in all sectors, but most in the Atlantic–European sector where pressure was lowest over south Norway and Sweden (1005 mb., greatest anomaly −9 mb.) instead of in the usual trough from south-west Greenland to Bear Island. There were smaller negative anomalies over northern Canada in another low-pressure cell displaced well to the west.

The lowest pressures in the Atlantic sector were actually several millibars above the usual minimum for September. The Azores high-pressure belt was also weaker than usual (highest monthly mean pressure 1020 mb., about 2 mb. below the usual maximum pressure) and several degrees south of the normal position except in the Bay of Biscay. Mean pressure gradients were weaker than usual except in two regions: over the Canadian Prairies and near the British Isles, where the month was notably windy. There was also a pronounced gradient for northerly winds in the Norwegian Sea.

The Rocky Mountains region was 2 to 3°C. warmer than normal and in a narrow zone over the Prairies the mainstream of the circulation appears to have been somewhat north of normal with pronounced north-westerly gradient winds. Above-normal temperatures were also noted over most of the Atlantic seaboard of North America (anomaly +4°C. over southern Baffin Land) and over a broad belt from the Red Sea to north-west Siberia and north Russia (anomalies up to +3°C. in several areas). The month was notably cool over most of the United States of America, Europe and east Asia (anomalies reaching −3°C. locally in each region named).

Rainfall exceeded twice the normal September totals at many places in north-west and central Europe and was locally over three times the normal. With the early cessation of the monsoon most of India was notably dry.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	73	29	−1·8	195	+5	85
Scotland	69	23	−2·0	99	+2	105
Northern Ireland ...	67	31	−1·2	170	+5	90

RAINFALL OF SEPTEMBER 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ...	2·48	136	*Glam.*	Cardiff, Penylan ...	5·07	166
Kent	Dover	3·35	145	*Pemb.*	Haverfordwest ...	8·70	245
,,	Edenbridge, Falconhurst	3·16	139	*Radnor*	Tyrmynydd	11·27	292
Sussex	Compton, Compton Ho.	3·85	138	*Mont.*	Lake Vyrnwy	9·30	258
,,	Worthing, Beach Ho. Pk.	3·13	146	*Mer.*	Blaenau Festiniog ...	14·69	186
Hants.	St. Catherine's L'thouse	4·16	174	,,	Aberdovey	8·72	273
,,	Southampton (East Pk.)	2·65	122	*Carn.*	Llandudno	5·57	262
,,	South Farnborough ...	2·88	151	*Angl.*	Llanerchymedd ...	6·83	232
Herts.	Harpenden, Rothamsted	3·07	157	*I. Man*	Douglas, Borough Cem.	6·38	195
Bucks.	Slough, Upton	2·52	143	*Wigtown*	Newton Stewart ...	4·51	132
Oxford	Oxford, Radcliffe ...	3·99	233	*Dumf.*	Dumfries, Crichton R.I.	3·78	139
N'hants.	Wellingboro' Swanspool	4·42	246	,,	Eskdalemuir Obsy. ...	4·27	115
Essex	Southend, W. W. ...	2·62	158	*Roxb.*	Crailing...	2·04	100
Suffolk	Felixstowe	2·45	148	*Peebles*	Stobo Castle	3·02	120
,,	Lowestoft Sec. School...	3·29	168	*Berwick*	Marchmont House ...	2·57	107
,,	Bury St. Ed., Westley H.	4·48	225	*E. Loth.*	North Berwick Gas Wks.	1·50	73
Norfolk	Sandringham Ho. Gdns.	4·00	193	*Midl'n.*	Edinburgh, Blackf'd. H.	1·53	75
Wilts.	Aldbourne	3·77	179	*Lanark*	Hamilton W. W., T'nhill	2·98	111
Dorset	Creech Grange... ...	3·95	144	*Ayr*	Prestwick	3·60	140
,,	Beaminster, East St. ...	4·30	169	,,	Glen Afton, Ayr San. ...	3·49	89
Devon	Teignmouth, Den Gdns.	2·24	114	*Renfrew*	Greenock, Prospect Hill	3·80	85
,,	Ilfracombe	6·57	244	*Bute*	Rothesay, Ardencraig ...	4·14	102
,,	Princetown	10·32	202	*Argyll*	Morven, Drimnin ...	4·40	78
Cornwall	Bude, School House ...	3·72	151	,,	Poltalloch	4·23	93
,,	Penzance	4·34	148	,,	Inveraray Castle ...	5·07	79
,,	St. Austell	4·04	127	,,	Islay, Eallabus... ...	4·47	107
,,	Scilly, Tresco Abbey ...	2·04	80	,,	Tiree	2·94	79
Somerset	Taunton	2·67	135	*Kinross*	Loch Leven Sluice ...	1·81	70
Glos.	Cirencester	4·73	207	*Fife*	Leuchars Airfield ...	1·45	75
Salop	Church Stretton ...	5·94	282	*Perth*	Loch Dhu	5·99	105
,,	Shrewsbury, Monkmore	4·77	293	,,	Crieff, Strathearn Hyd.	3·19	112
Worcs.	Malvern, Free Library...	4·64	240	,,	Pitlochry, Fincastle ...	1·91	76
Warwick	Birmingham, Edgbaston	5·10	259	*Angus*	Montrose Hospital ...	1·50	75
Leics.	Thornton Reservoir ...	5·17	286	*Aberd.*	Braemar	2·57	102
Lincs.	Boston, Skirbeck ...	4·44	252	,,	Dyce, Craibstone ...	2·26	93
,,	Skegness, Marine Gdns.	4·21	233	,,	New Deer School House	4·04	160
Notts.	Mansfield, Carr Bank...	4·51	245	*Moray*	Gordon Castle	1·97	79
Derby	Buxton, Terrace Slopes	10·09	311	*Nairn*	Nairn, Achareidh ...	1·29	61
Ches.	Bidston Observatory ...	5·60	232	*Inverness*	Loch Ness, Garthbeg ...	2·81	91
,,	Manchester, Ringway...	6·21	274	,,	Loch Hourn, Kinl'hourn	10·27	115
Lancs.	Stonyhurst College ...	8·32	218	,,	Fort William, Teviot ...	5·12	80
,,	Squires Gate	4·55	168	,,	Skye, Glenbrittle ...	...	...
Yorks.	Wakefield, Clarence Pk.	3·29	206	,,	Skye, Duntulm... ...	3·95	86
,,	Hull, Pearson Park ...	3·46	201	*R. & C.*	Tain, Mayfield... ...	1·05	46
,,	Felixkirk, Mt. St. John...	3·25	179	,,	Inverbroom, Glackour...	6·36	144
,,	York Museum	3·16	194	,,	Achnashellach	8·72	127
,,	Scarborough	3·01	168	*Suth.*	Lochinver, Bank Ho. ...	4·58	132
,,	Middlesbrough... ...	2·64	159	*Caith.*	Wick Airfield	3·25	130
,,	Baldersdale, Hury Res.	3·82	149	*Shetland*	Lerwick Observatory ...	4·19	139
Norl'd.	Newcastle, Leazes Pk....	3·69	186	*Ferm.*	Crom Castle	3·74	134
,,	Bellingham, High Green	2·40	100	*Armagh*	Armagh Observatory ...	3·87	157
,,	Lilburn Tower Gdns. ...	2·55	108	*Down*	Seaforde	5·11	186
Cumb.	Geltsdale	4·46	159	*Antrim*	Aldergrove Airfield ...	4·71	190
,,	Keswick, High Hill ...	6·70	158	,,	Ballymena, Harryville...	5·52	177
,,	Ravenglass, The Grove	7·20	214	*L'derry*	Garvagh, Moneydig ...	5·34	180
Mon.	A'gavenny, Plâs Derwen	6·65	260	,,	Londonderry, Creggan	6·27	190
Glam.	Ystalyfera, Wern House	11·13	255	*Tyrone*	Omagh, Edenfel ...	4·47	147

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METEOROLOGICAL OFFICE

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WORLD METEOROLOGICAL ORGANIZATION

Ninth Session of the Executive Committee

By SIR GRAHAM SUTTON, C.B.E., D.Sc., F.R.S.

The Ninth Session of the Executive Committee of W.M.O. took place at the Palais des Nations, Geneva, from September 24 to October 14, 1957. With the exception of Dr. Solotoutkhine (U.S.S.R), for whom Dr. M. A. Ivanov deputized, all members were present for most of the meetings. In addition, Professor J. van Mieghem, Monsieur A. Perlat, Mr. H. Thomson and Mr. R. G. Veryard attended some of the meetings in their capacities as Presidents of Technical Commissions.

The agenda was heavy, and already Third Congress, to be held in 1959, is casting long shadows. The Executive Committee had before it the herculean task of examining the entire internal staff rules of the Organization, and the approval of the recommendations of CAe, CIMO, CMM and CCl, as well as many procedural items relating to Congress. In accordance with custom, the work was divided between the two Standing Committees, on Programme under Dr. M. A. F. Barnett (New Zealand) and on Administration and Finance, under Professor H. A. Ferreira (Portugal). By eschewing most delights and living laborious days and nights the work was accomplished in time, the budgetary statement being completed only in the early hours of the morning of the final day.

There were many items of interest, which can be studied fully only when the Abridged Report is published, but one or two are sufficiently important to be singled out here. Perhaps the most significant of these is that relating to hydrology. The Executive Committee decided to support strongly the proposal of its Panel on Water Resources Development that W.M.O. should assume responsibilities in hydrology similar to its present responsibilities in meteorology. This implies the preparation of Technical Regulations, Guides and Yearbooks in hydrology, and the development of international standards for observations and networks, arrangements for exchange of data and the preparation of codes. Such a resolution cannot be implemented without changes in the W.M.O. Convention, which require the assent of Congress. The Secretary-General has been instructed to address a circular letter to all the Member countries of W.M.O., asking for comments on the resolution of the Executive Committee. If the replies indicate a substantial measure of support for the change, the

Executive Committee will have the task of drawing up draft amendments to the Convention at its next Session (April–May, 1958).

Another important resolution reflects the coming of jet aircraft into civil aviation on a wide scale. Already, I.C.A.O. has set up a Jet Operations Requirements Panel, which has produced a provisional list of requirements in meteorology. Many of these are very exacting, and in view of the importance and urgency of the problem the Executive Committee decided to establish a Panel of Experts to examine the implications for meteorology of future requirements for the routine commercial operation of jet aircraft and the extent to which existing techniques and facilities will allow these to be met. In addition, the Panel is asked to define any short-term developments in techniques and facilities that may be required, and to report to the Executive Committee at its next Session.

Among other matters, the Executive Committee considered the problems arising in the collection of data for the I.G.Y. and decided that the Geneva Centre must continue to operate on a self-financing basis, and that the other two centres (at Washington and Moscow) should be asked to pay for any microcards they may require. The Committee also examined the present position of the plans for the erection of a permanent building for W.M.O. in Geneva, and decided, in view of threatened delays, to ask the President and the Secretary-General to pursue the matter with vigilance.

Each Congress lays down a programme for the next four years, and decides upon a limit of expenditure. It is the duty of the Executive Committee to supervise the carrying out of the programme and to see that the maximum permissible expenditure is not exceeded. The general rise in costs throughout the world since 1955 has made this task impossible, and it was decided to ask Members to approve a supplementary estimate for the remainder of the present financial period.

It is clear that the volume of international work in meteorology is increasing rapidly, and as a consequence, the burden on the national services is becoming very heavy. Meteorologists must now rival diplomats in the number of journeys abroad they have to make, and it is remarkable that so much of the work of the Organization still continues to be on a "voluntary" basis. The spirit which led to the institution, over a century ago, of international co-operation in meteorology is still very much alive.

TELEVISION FORECASTING BY THE BRITISH BROADCASTING CORPORATION

By J. S. FARQUHARSON, M.A., D.Sc.

Many millions of people in this country have by now seen the television forecaster on their screens. They can probably be divided into two almost equal classes. One class likes Mr. A, and the other class dislikes him, Mr. A being any one of the forecasters who do this work. In fact, however, the scope for the development of personality is restricted, not only because of the shortness of the period of the broadcast, but also because an exact routine has to be observed when it is made. Whereas the usual television personality goes on the air after a considerable period of rehearsal, the television weatherman just steps in front of the camera as part of his day's work, with no rehearsal. His day begins about 12 noon in the London Forecasting Office when one of his first tasks is to study the typescript of the recording of the previous evening's broadcast, and to compare the forecast then made with the weather that actually occurred. In the event of there being any important divergencies he prepares a short explanation. The 0600 G.M.T. chart is copied on the special card made for the B.B.C. and if the weather is behaving in any way abnormally, past weather records may have to be studied. Letters from fans, critics and just thirsters after knowledge have to be dealt with. But the main task of the television forecaster is to get his ideas into shape about the weather of the following day and to consider appropriate captions for the (fair copy) forecast chart. The writing of captions can be most difficult as may be realized when it is recalled that one chart is used to depict the entire weather of the period from 8 a.m. to midnight for the whole of the British Isles.

The time of the broadcast being now about 6 p.m., it is not possible for the forecaster to complete the preparations for his task in the London Forecasting Office. This has to be done at the Lime Grove studios. So at 4 p.m., with his "Atlantic" chart and two blank charts of the British Isles under his arm, the forecaster sets off for the studios. One of the charts has to be used for the prebaratic or forecast map, the other for the caption chart. By 4.30 p.m. the senior forecaster at Dunstable has completed the forecast chart and as soon as it is received at the London Forecasting Office, the details of it are telephoned to Lime Grove, together with the general synoptic review which, in effect, indicates the lines along which the thoughts of the senior forecaster are running. After drawing the forecast chart on the blank he has brought with him, the television forecaster considers it in the light of the general synoptic review and rings up the senior forecaster about 5.10 p.m. for a final discussion. By 5.45 p.m. the caption chart is completed and final touches having been given to the forecast map, both are passed into the studio for line-up.

On the air, the forecaster, after greeting his audience, first demonstrates the general situation by reference to what he calls the "Atlantic" chart for 0600 G.M.T. of that day. It shows the main features of the pressure distribution over the Atlantic and Western Europe. Following on from this, the 1200 G.M.T. prebaratic of the following day is slid into view, the synoptic developments on this chart being dealt with as a sequence from the earlier chart. Area forecasts for broad areas of the British Isles are given, the areas depending on the current synoptic situation. A "further outlook" is given and after bidding his audience good night, the forecaster leaves a fair copy of tomorrow's forecast chart on the screen for about 15 seconds, the whole broadcast being timed to last 3 minutes. Later in the evening, at the end of the day's broadcasting, a fair copy chart is again shown while an appropriate script is read by an announcer. This occurs just before a special chart for coastal shipping is televised.

As regards the substance of the broadcast, forecasters are so often victims of the human memory that they almost regard this as an occupational hazard. The memory of the good-old-days type and of the type which insists our weather is changing because we no longer have Dickensian Christmasses are familiar. But the vagaries of the human mind do not end there. There are some who think, for example, that the television weather forecaster on the B.B.C. "starts nearly every night with an apology". This was alleged early in June 1957 and, in fact, examination of the records of the television broadcasts showed that what might be taken as apologies were made on May 7, 9, 14, 16, 22 and 29. Certainly that is rather a large number. But included among them is the apology: "Eastern and central districts had rather more cloud than I suggested last night . . ." and that is an admission of a relatively minor error. To address an audience of millions and convey the impression it is desired to convey is a tricky business. The forecaster on television sets himself the task of putting his audience in the same position as himself as regards knowledge of current and expected weather. If his task were perfectly performed so that his audience envisaged the probabilities as he does himself there would be no need for apologies. However, nothing is more irritating to the intelligent listener when, and if, a gross forecasting error has been made than for the forecaster blandly to carry on as though no error had been made. It is a concession to the intelligence and interest of the audience that efforts are made from time to time to explain the causes of error. But this must be done very carefully in order to avoid confusing the audience. In assessing the merits of the television forecast it is essential to remember that an absolute time limit of three minutes is imposed on the forecaster. Obviously if too much of this very brief period were given up to explanations the audience tuned in to receive a forecast might well be confused.

The forecasts given on television are for all practical purposes identical with those broadcast by the B.B.C. on sound radio at 5.55 p.m. In principle the television forecasts cover the period from 8 a.m. to midnight tomorrow while the 5.55 p.m. sound broadcasts on the B.B.C. cover the period of 24 hours from 6 p.m. In fact, however, the television forecaster can hardly escape mentioning any important phenomenon, such as frost or fog, which may be expected during the night. It is reasonable then to suggest that any checking or verification of the 5.55 p.m. forecast broadcast by the B.B.C. would be equivalent to checking or verifying the television forecast broadcast in the early evening. For over two years, from November 1954 onwards, two subjective methods were used to obtain a general indication of user reaction. In the first a number of geographically representative schools, scattered throughout the British Isles, was asked to listen daily to the forecasts broadcast by the B.B.C. (sound only) in respect of their area and to assess them either as "mainly right" or "mainly wrong", on the basis of the actual weather subsequently experienced. Over the period from May 1956, inclusive, average figures for all schools show that out of 100 forecasts, 90 were "mainly right".

A parallel scheme of slightly more rigorous kind consisted of having assessments made on the same forecasts by meteorological offices distributed over the British Isles so that at least one was in each B.B.C. region. In other words, on each B.B.C. regional forecast broadcast at 5.55 p.m. there was at least one report by Meteorological Office staff in the appropriate region. The forecasts were checked under four headings: (i) wind, (ii) weather, (iii) state of sky and (iv) temperature, and certain criteria were agreed where checking was not merely a matter of comparing an actual with a forecast reading. The forecast of each element was assessed as good, indifferent, or bad with marks 2, 1, and 0 respectively. A good forecast of all four elements would thus earn the maximum mark of 8. For the fourteen months from November 1955 to December 1956 the average score was 6·1 or 76 per cent, the lowest being 5·7 or 71 per cent in September 1956 and the highest 6·4 or 80 per cent in November 1956.

Neither of these systems of checking is objective, but they have some value as an indication of the impression made on the mind of a careful listener by comparing actual and forecast weather. They show that there is no foundation for sweeping statements about the poverty of the forecasting service. Indeed they indicate that the careful listener may well derive valuable assistance from them. This confirms the general impression made by such correspondence as is received in the Meteorological Office about forecasts and forecasting. To people who make use of the forecasts real help is given. The number of such users may be relatively small but that does not invalidate the fact. A clue may be given to this number by some information picked up about B.B.C. televiewers. Out of every hundred in the audience probably 40 never take any interest in the television forecast. Of the remaining 60 half don't pay much attention to the forecast while the remaining 30 per cent of the total potential audience constitute the body of opinion on which an appropriate policy could be based. But of these thirty very few have sufficient interest or drive to comment when comment appears to be called for. The result of this is to cause exaggerated importance to be given to individual letters which may be received. Such exaggeration is justified by the facts so far as we know them and is not merely owing to the reason that comment is usually favourable.

The difficulty of applying a yardstick to forecasting so as to measure its success is one that has never been overcome, except for specialized forecasts specially designed for the purpose of being checked. A comparable difficulty exists in assessing the impact on the audience of the forecast as presented by the forecaster on television. An audience research questionnaire may be sent to ascertain views from a cross-section of the audience but the mere receipt of a request for an opinion is probably sufficient of a goad to jolt the particular individual into thinking of the programme in a novel way. Now this is not what is required—but rather the ordinary reactions of an ordinary audience writing or reporting under the ordinary stimulus, namely the initiative with which they were born. In my opinion the invited intrusion of the television forecaster into millions of homes has brought about a number of things which are all good for meteorology. To the relatively few keen meteorologists it has seemed to provide an esoteric discourse which they alone could fully appreciate and use, and to the interested amateur it has provided a stimulus. And for the professional in his seclusion at the Central Forecasting Office it has advertised that he can be a good mixer and indeed is quite glad to mix. Aloofness is not a choice but an accident, in his case.

Various suggestions have been made for improving the presentation of the television weather forecasting programme. One writer asks if it would be too expensive to have a permanent television link between Central Forecasting Office and the studios. The answer to this is emphatically affirmative. It has also been said that the charts used are merely simplified versions of the synoptic chart, showing abstractions but not a direct representation of the weather. Obviously the writer in this case is not familiar with the limited resolving power of the television camera, and the method of writing captions on a map is at the best a makeshift. "Gimmicks" such as stipple-rollers and prepared arrowheads to be used in the illustration of points made have been tried and abandoned in favour of the simple straightforward presentation. The bulk of interested viewers, after all, want to know simply what tomorrow's weather is going to be in their area. If we can answer that question clearly against a background for the specialist then probably this is about the most we could hope to achieve in the limited time made available to the forecaster. It is perhaps a measure of the success of the method that it is copied in the only weather programme under the Independent Television Authority where personal presentation of the forecast is made.

Summing up then, it can be said that the personal presentation of the forecast by a forecaster on B.B.C. television has established a valuable link between producer and interested user of forecasts. At its lowest valuation it has taught many people that such a science as meteorology exists and that its practitioners are very worthy people.

RECENT SEASONAL TRENDS IN THE NUMBER OF RAIN-DAYS OVER GREAT BRITAIN

By J. GLASSPOOLE, I.S.O., Ph.D.

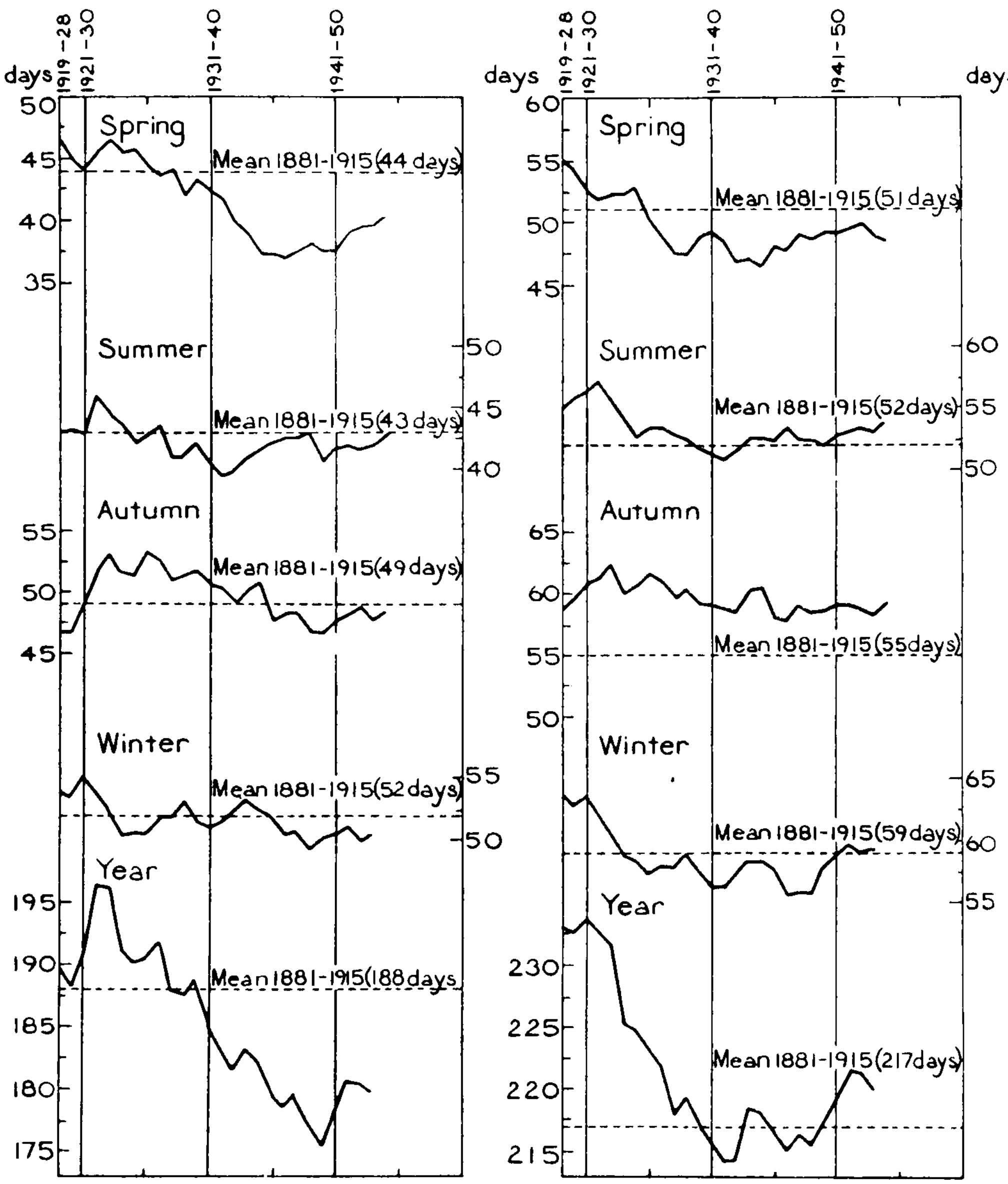
In an earlier note[1] details were given of seasonal trends of temperature, sunshine and rainfall using 10-year moving averages and this note gives similar diagrams for rain-days (days on which precipitation reaches or exceeds 0·01 in. or 0·2 mm.). Monthly and annual values of the number of rain-days for England and Wales, and for Scotland, have been published in the annual volumes of *British Rainfall*. These values are available since 1919. They are based on the means for 48 stations over England and Wales and 27 stations over Scotland, a selection of 100 stations being made to cover the British Isles. The stations are selected to give a good representation over the country, and have only been replaced as they terminated or failed to give complete returns. The object of this note is to define recent trends in the number of rain-days, and also to ascertain whether there has been any marked change in the amount of rain per rain-day, especially in view of the general increase of temperature in the spring, summer and autumn from the decade 1922–31 to the present time.

Maps of the average number (1881–1915) of rain-days for each month have been published[2] and from these maps the general monthly values for England and Wales, and for Scotland, were evaluated. The seasonal values are 44, 43, 49 and 52 for England and Wales, 51, 52, 55 and 59 for Scotland, for the spring, summer, autumn and winter respectively. These values are shown on the diagrams. Serial monthly values have not been evaluated throughout this period, but annual values for England and Wales, and for Scotland, from 1881 to 1926 are given in *British Rainfall*, 1926[3].

Number of rain-days (Fig. 1).— The curves for England and Wales and for Scotland show considerable similarity to those for rainfall. This is not surprising when it is recalled that there is a high correlation between the annual number of rain-days and amounts of rainfall—the correlation coefficient for the 45 years 1881–1925 for the British Isles is given as + 0·82 (Glasspoole 1927). Indeed the fact now shown that there is a difference in the trends of annual values of rainfall and rain-days partly explains why the correlation coefficient is not larger. The following points are of interest:

(*a*) The annual curves show a steady decrease, followed by a small rise, but the rise in the number of rain-days is much less striking than the rise in the amount of rainfall.

(*b*) The curve of the number of rain-days for the autumn for Scotland is noticeably above the mean line of 55 (for 1881–1915). The curve for rainfall was similarly above the mean line for this period, although for the previous four decades the curve was much nearer the mean line.



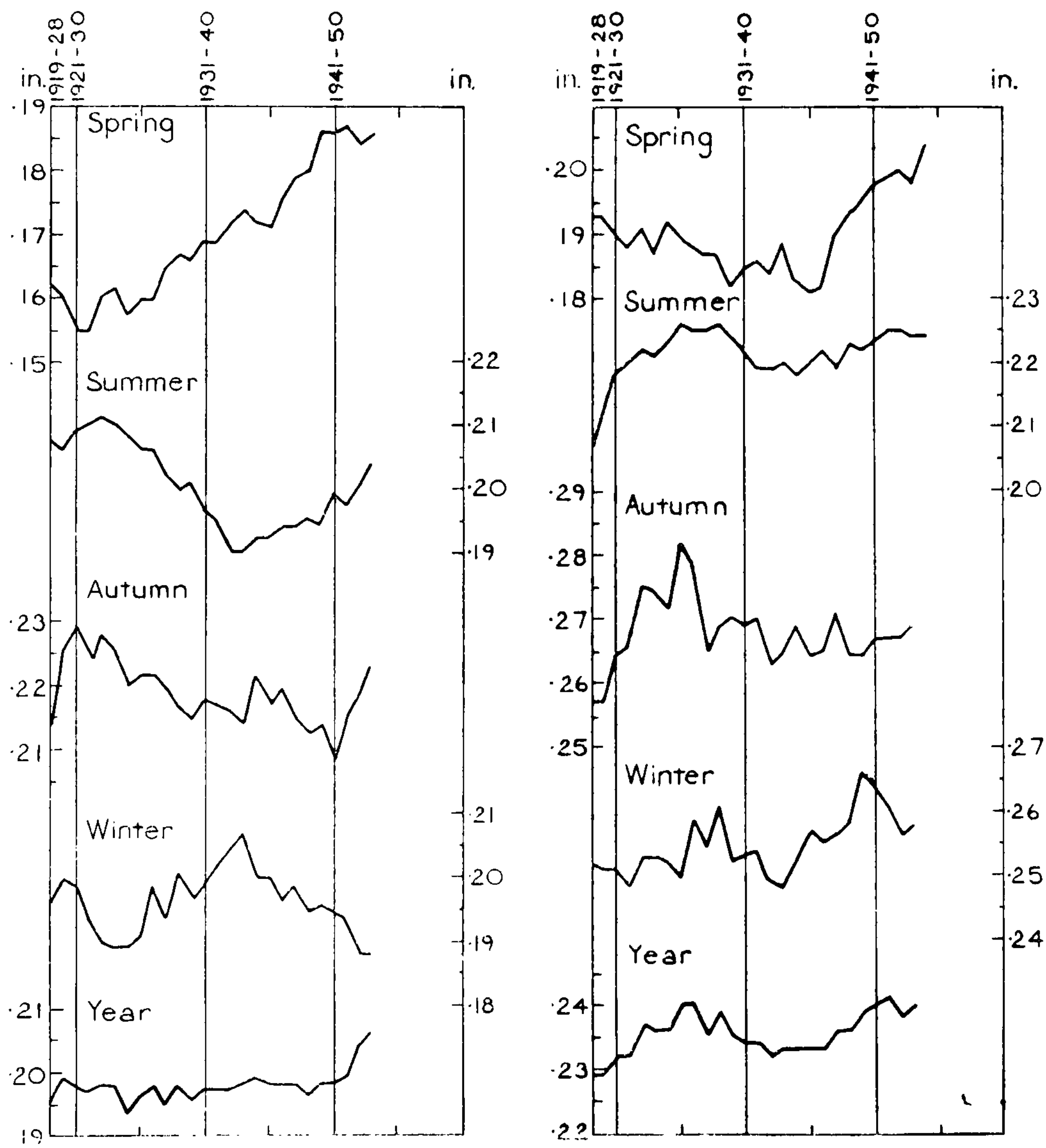
England and Wales — Scotland.

FIG. 1—10-YR. MOVING AVERAGES OF RAIN-DAYS

Mean rain per rain-day (Fig. 2).—The most striking features of the curves are:

(*a*) While the number of rain-days for the year has markedly decreased from the beginning to the end of the curves, the amount of rain per rain-day has noticeably increased, especially recently.

(*b*) There is marked similarity in the curve of mean rain per rain-day for the spring for England and Wales with the corresponding curve for temperature. Since 1922–31 the mean temperature has increased by 2°F., and the mean rain per rain-day by about 0·03 in. There is little similarity in the curves of mean rain per rain-day and temperature for the other seasons or for the year.



England and Wales. Scotland.

FIG. 2—MEAN RAIN PER RAIN-DAY

(*c*) The recent increase in the mean rain per rain-day for the year is due, over England and Wales, more especially to the increase for the summer and autumn. Over Scotland the recent increase is not so markedly due to an increase of any particular season.

(*d*) The recent increase in the mean rain per rain-day (and of the number of rain-days) both for England and Wales, and for Scotland shows some relationship to the corresponding curve for sunshine, suggesting a possible increase in instability rains.

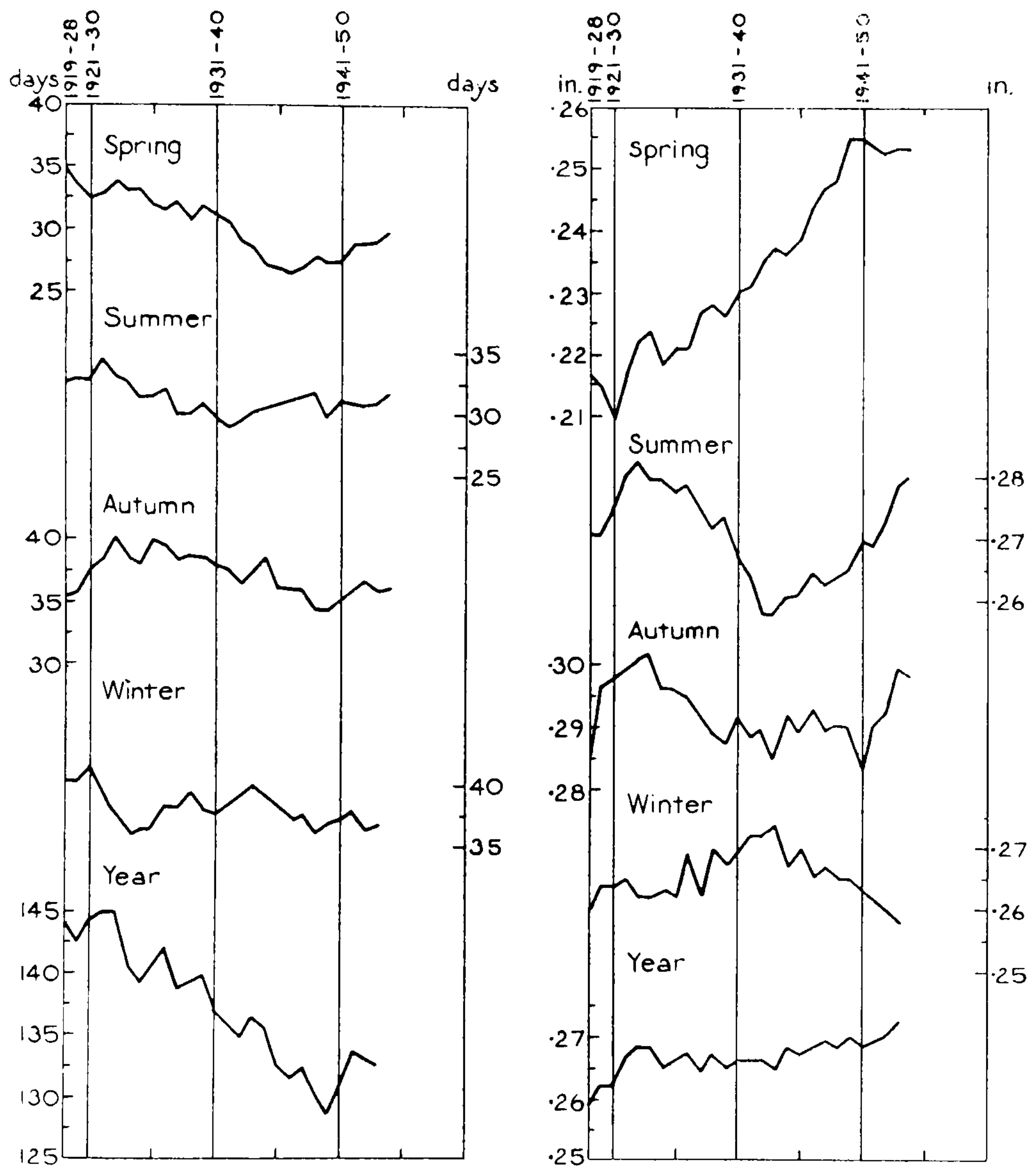


FIG. 3—10-YR. MOVING AVERAGES OF WET-DAYS AND MEAN RAIN PER WET-DAY FOR ENGLAND AND WALES

Number of wet-days and mean rain per wet-day for England and Wales. (Fig. 3).—Similar monthly and annual values are available for wet-days (i.e., rain-days with 0·04 in. or 1·0 mm. or more of rain) from 1919, but the average values have not been computed for the standard period 1881–1915. The curves of the 10-year moving averages of wet-days for England and Wales are similar to those for rain-days. The main feature is the steady decrease in the annual number of wet-days, with a small increase at the end of the period. The values of rain-days and wet-days both decreased from 1922–31 to 1940-49, the decrease in rain-days being 21 from 196 to 175 and with wet-days 16 from 145 to 129. The mean rain per wet-day shows a marked increase during the spring, similar to that for mean rain per rain-day. The two curves of Fig. 3 for the year also show a slight rise towards the end of the period. In calculating the mean rain per wet-day the general values of total rainfall have been used as given in the annual volumes of *British Rainfall.*

Conclusions.—The main trends in the number of rain-days and wet-days are similar to those for rainfall.

The differences are brought out by the curves of mean rain per rain-day and per wet-day. These show a similarity with temperature in the case of the spring and with annual sunshine for recent periods.

The variations in the mean rain per rain-day may be due to fluctuations in the predominating synoptic pattern accompanied by variations in evaporation or by variations in instability rains. These curves are reproduced as likely to provide a clue in future investigations of their inter-relationship and as part of our background knowledge.

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VARIATION OF VISIBILITY IN FOG AT EXETER AIRPORT, AND THE TIME OF FOG DISPERSAL

By W. E. SAUNDERS, B.Sc.

Summary.—An account is given of the variation in visibility at Exeter Airport during periods of fog. Main features of interest are the rapidity with which visibility falls to lower values within the fog range once fog has formed, the effectiveness of cloud cover as a fog-clearing agency, and the comparatively regular intervals between times of clearance of fog during the morning, and times of sunrise.

The site and observational programme.—The situation of the airfield is shown in Fig. 1. The airfield lies in a shallow basin formed by the high ground of Dartmoor to the south-west and west, Exmoor to the north, and the Blackdown Hills to the east. There are no intervening hills between the airfield and the English Channel to the south and the Exe estuary to the south-west. The only significant source of local smoke is the city of Exeter, some three miles west of the airfield.

The normal hourly and special observations of a synoptic station were made at Exeter throughout the period from which data have been used in this study. Additional temperature readings, which have been included in the notes on clearance of fog beneath cloud, were as follows:—

(i) Hourly readings of the grass minimum thermometer used as an ordinary thermometer at grass level, and of a bent-stem earth thermometer with the bulb at a depth of 2 in.

(ii) Twice daily readings of a bent-stem earth thermometer with the bulb at 8 in. These readings were made at 0900 and 2100 G.M.T.

Type of fog at Exeter.—The fog was predominantly water fog as defined by Corby and Saunders[1]; that is, fog that did not form until after the relative humidity reached or exceeded 95 per cent. The investigation covers 145 cases, i.e. all the occasions of radiation fog during the period September 1953–December 1955. On only ten of these occasions did visibility enter the fog range with relative humidity less than 95 per cent., the lowest being 93 per cent. The results described therefore apply only to water fog. It is considered unlikely that they will apply to smoke fog, or to water fog containing a high smoke content. They may, however, be of interest to forecasters at other rurally placed stations, or to stations which experience "clean" fog when the air stream is moving from some known direction.

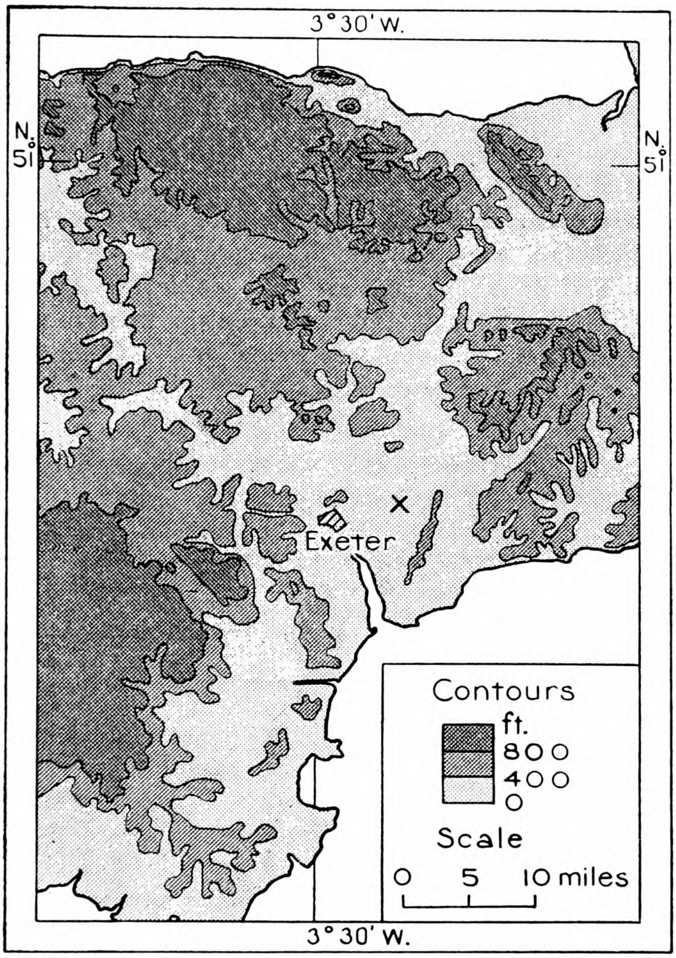

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FIG. 1—MAP SHOWING THE LOCATION OF EXETER AIRPORT

Time taken for visibility to fall below certain limits.—The variation in visibility following the initial report of fog was studied in all cases (112 out of 145) in which fog-clearing agencies were not at work. The cases omitted were those in which there was freshening wind, cloud cover, frontal passage, or those which occurred at the end of the night. Variations in visibility were examined in terms of the time taken to fall to 550 yd. or below, and to 220 yd. or below. On some occasions fog-clearing influences became apparent soon after the 550-yd. stage was reached, but there were 92 occasions suitable for examination in regard to the 220-yd. limit.

The over-all picture is given in Table I.

TABLE I—TIME TAKEN FOR VISIBILITY TO FALL BELOW 550 OR 220 YD.

Visibility	Hours from initial report of fog					Not reached
	0–1	>1–2	>2–3	>3–4	>4–5	
	Number of occasions					
550 yd. or below ...	96	11	1	0	0	4
220 yd. or below ...	47	21	6	6	1	11

Table I emphasizes the rapid fall of visibility in water fog. On 95 per cent. of occasions visibility is 550 yd. or less within 2 hr. of fog formation. The transition to dense fog is sometimes rather less rapid, but on 74 per cent. of occasions visibility is 220 yd. or less within 2 hr.

Variation with temperature.—The rate of decrease of visibility was examined in conjunction with the fog point, i.e. the temperature at which water fog formed, and the results are given in Table II. This shows that the four cases included in Table I as failing to reach the 550-yd. limit were all on occasions when the initial fog point was below 40°F. Otherwise the table is not very conclusive. Dense fog may still occur when the fog point is several degrees below freezing.

TABLE II—VARIATION OF TIME TAKEN WITH FOG-POINT TEMPERATURE FOR VISIBILITY TO REACH CERTAIN LIMITS

Fog point	Hours from 1st report of fog, for visibility to reach 550 yd. or less			Not reached	Hours from 1st report of fog, for visibility to reach 220 yd. or less					Not reached
	0–1	>1–2	>2–3		0–1	>1–2	>2–3	>3–4	>4–5	
°F.	*Number of occasions*									
60–64	3	1	0	0	2	1	1	0	0	0
55–59	5	0	1	0	3	0	0	2	0	0
50–54	21	2	0	0	11	3	1	1	0	2
45–49	27	2	0	0	9	10	2	1	0	2
40–44	19	3	0	0	11	4	1	0	0	3
35–39	11	2	0	2	6	1	1	0	1	2
30–34	7	1	0	1	4	2	0	0	0	1
25–29	3	0	0	1	1	0	0	2	0	1

Table III shows the further fall of temperature, once fog has formed, for visibility to reach 550 yd. or less, and 220 yd. or less. This shows that while, in general, only a slight fall of temperature amounting to a degree or so is required, there are a few occasions on which the fall is as much as five or six degrees. It might be expected on theoretical grounds that these would be the low-temperature occasions, but this is not borne out by the table.

Variation with visibility before fog formation.—In order to determine whether there was any connexion between the rate of fall of visibility preceding fog and in the fog, the rate of decrease of visibility was compared with the visibility three hours before fog formation, and the results are given in Table IV.

TABLE III—VARIATION OF FALL OF TEMPERATURE, WITH FOG POINT, FOR VISIBILITY TO REACH CERTAIN LIMITS

Fog point	Fall of temperature, °F., from fog point, for visibility to reach 550 yd. or less						Fall of temperature, °F., from fog point, for visibility to reach 220 yd. or less					
	0–1	>1–2	>2–3	>3–4	>4–5	>5–6	0–1	>1–2	>2–3	>3–4	>4–5	>5–6
°F.	*Number of occasions*											
60–64	2	1	1	0	0	0	1	0	1	2	0	0
55–59	3	1	0	2	0	0	1	1	0	2	1	0
50–54	16	3	1	2	1	0	8	3	1	3	1	0
45–49	24	1	1	0	1	2	11	1	4	1	1	4
40–44	16	4	1	0	1	0	6	7	3	0	0	0
35–39	8	2	2	1	0	0	5	1	1	0	2	0
30–34	7	1	0	0	0	0	4	1	1	0	0	0
25–29	2	1	0	0	0	0	2	0	0	1	0	0

TABLE IV—VARIATION OF TIME TAKEN WITH VISIBILITY THREE HOURS BEFORE FOG FORMATION FOR VISIBILITY TO REACH CERTAIN LIMITS

Visibility 3 hr. before fog formation	Hours from 1st report of fog, for visibility to reach 550 yd. or less			Not reached	Hours from 1st report of fog, for visibility to reach 220 yd. or less					Not reached
	0–1	>1–2	>2–3		0–1	>1–2	>2–3	>3–4	>4–5	
	Number of occasions									
>6¼ miles	27	2	0	1	15	7	1	0	0	3
2½–6¼ miles	36	5	0	0	15	7	3	3	1	5
2,200 yd.–2½ miles	18	3	0	3	12	6	1	0	0	3
1,100 yd.–2,200 yd.	15	1	1	0	5	1	1	3	0	0

TABLE V—VARIATION OF TIME TAKEN FOR VISIBILITY TO REACH CERTAIN LIMITS WITH WIND DIRECTION THREE HOURS BEFORE FOG FORMATION

Wind direction 3 hr. before fog formation	Hours from 1st report of fog, for visibility to reach 550 yd. or less			Not reached	Hours from 1st report of fog, for visibility to reach 220 yd. or less					Not reached
	0–1	>1–2	>2–3		0–1	>1–2	>2–3	>3–4	>4–5	
°	*Number of occasions*									
001–030	4	1	0	1	1	2	0	0	0	1
031–060	4	3	0	0	2	2	0	1	1	1
061–090	2	0	1	0	1	1	0	1	0	0
091–120	6	0	0	0	2	1	0	1	0	1
121–150	7	0	0	0	5	0	0	0	0	0
151–180	11	2	0	0	8	3	1	0	0	0
181–210	2	0	0	0	2	0	0	0	0	0
211–240	4	0	0	0	2	1	0	0	0	0
241–270	3	0	0	0	2	0	1	0	0	0
271–300	2	0	0	0	0	1	0	0	0	1
301–330	9	1	0	0	2	1	2	0	0	1
331–360	1	0	0	2	0	0	0	0	0	2
Calm	41	4	0	1	20	9	2	3	0	4

Table IV shows that there is some tendency for hazy initial conditions to be followed by a rather slower deterioration than when fog forms in clean air.

Variation with wind direction before fog formation.—The time taken for visibility to fall to the prescribed limits was compared with the wind direction three hours before the time of fog formation, as shown in Table V.

The large proportion of calms renders analysis of Table V difficult, but perhaps some tentative conclusions may be drawn. The most significant feature seems to be the rapidity of decrease of visibility with wind direction bringing moist air from the English Channel or the Exe estuary. Thus, in all cases with wind direction between SE. and W. (through S.) the visibility was 550 yd. or less within 2 hr., and 220 yd. or less within 3 hr. of fog formation.

Variation with state of ground.—The times for visibility to reach the agreed limits were compared with the reported state of ground before fog formation. The results, given in Table VI, show that in all cases of wet ground visibility fell to 550 yd. or less within two hours of fog formation, and that wet ground much reduces the chance of visibility 220 yd. or less not being reached.

TABLE VI—VARIATION OF TIME TAKEN WITH STATE OF GROUND BEFORE FOG FORMATION FOR VISIBILITY TO REACH CERTAIN LIMITS

State of ground before fog formation	Hours from 1st report of fog, for visibility to reach 550 yd. or less			Not reached	Hours from 1st report of fog, for visibility to reach 220 yd. or less					Not reached
	0–1	>1–2	>2–3		0–1	>1–2	>2–3	>3–4	>4–5	
	Number of occasions									
Dry	50	2	1	4	23	11	4	3	0	9
Wet	46	9	0	0	24	10	2	3	1	2

The effect of cloud cover on fog.—The effect of cloud spreading over existing fog was examined. The criteria adopted were that the cloud amount, excluding broken cirrus, should increase from four oktas or less to five oktas or more, or that an existing cloud sheet should lower significantly. Cases where other fog-clearing influences were at work, such as frontal passage or freshening wind, including cases where fog lifted to stratus, were omitted. Cases of sky-obscured fog were also omitted for obvious reasons. The effect of cloud cover on fog is shown in Table VII.

TABLE VII—TIME TAKEN FROM INCREASE IN CLOUD FOR VISIBILITY TO IMPROVE

Fog clearance. Hours taken from increase in cloud for visibility to increase to 1,100 yd. or more						No clearance
0–1	>1–2	>2–3	>3–4	>4–5	>5–6	
Number of occasions						
18	11	4	2	4	1	10

Table VII shows that to a marked extent water fog is dispersed by any appreciable cloud cover. This applied on 40 out of 50 occasions, and on nearly half the nights when fog cleared it did so within one hour of the cloud arriving or increasing.

The temperature distribution during the fog preceding the arrival or increase of cloud was always of the same type. The lowest temperature of those measured was at the grass level. Of the soil temperatures at −2 in. and −8 in. the latter was always the higher. The screen temperature was intermediate between the grass and −2 in. temperatures. After the arrival of cloud the most pronounced change in temperature was at the grass level.

This always increased, in some cases by as much as 10 or 12°F. At both screen level and −2 in. changes were slight, often less than ±1°F. After clearance of the fog, readings of screen and grass temperatures were usually nearly the same, though sometimes there was still an inversion between them.

The following is an example of recorded observations:—

Date	Time	Wind	Cloud	Visibility	Temperatures Screen	Grass	−2 in.	−8 in.
	G.M.T.			yd.				
18.11.53	2356	Calm	Nil	160	42·2	40·9	46·7	48·8
19.11.53	0156	Calm	8/8 1,800 ft.	1,800	44·9	44·3	47·2	...

The records of all the foggy nights affected by cloud were examined to see to what extent the result was affected by height of cloud. This showed that on all occasions when the cloud was not above 2,500 ft. the fog cleared. Most of these cases cleared within 2 hr. of the arrival of cloud, but in one instance the process required 5–6 hr. The effects of medium and high cloud and of higher stratocumulus were much less regular. The records of cases which failed to clear under cloud contained some suggestion of west or north-westerly drift at some stage in most of them; this might imply some smoke content from Exeter. The investigation leaves a strong impression that clean water fog is readily cleared by cloud, and that if the cloud is not above 2,500 ft. the process is likely to be rapid.

The time of clearance of fog.—The time of clearance of fog was studied. In the absence of other fog-clearing influences such as increasing cloud cover or freshening wind the time of clearance should be roughly determined by the amount of insolation, which varies with the date, and by the vertical thickness of the fog. In the absence of measurements of the depth of fog, some guidance is given by the appearance of the fog from the ground, whether it is reported as sky obscured or sky visible.

In Fig. 2, for which the period of the investigation was extended to 1939–1955, the intervals between the times of sunrise and of fog clearance have been plotted against the date, and separated according as the sky was or was not visible at 0600 G.M.T. This time was selected partly because it marks a stage at which, taking the year as a whole, cooling is practically completed, and partly because it is a convenient time in relation to the issue of short-term forecasts on which many day-time activities depend. Occasions when the fog formed after 0600 G.M.T. were plotted as sky visible regardless of whether it later became obscured. Occasions omitted were those in which cloud appeared to affect the result, or when there was freshening wind. Cases of fog clearing by lifting to stratus were taken to be due to freshening wind and thus omitted. Occasions included on Fig. 2 should therefore be those of straightforward fog clearance due to insolation. The number of cases was sufficient to draw the mean curves AA and BB with fair accuracy, except in midwinter. The minimum time interval between sunrise and fog dispersal occurs in spring, and this is perhaps due to a somewhat lower water content in fogs at this season as compared with summer and autumn. A small number of sky-visible cases were noted in January–March in which the original fog point was below 32°F. and the clearance time mostly before sunrise. The fog-point temperature has been inserted against these cases in Fig. 2, and they have been disregarded in drawing BB. Presumably the fog clearance in these cases was due to deposition of the moisture as frost. Fig. 2 shows that a substantial proportion of fogs cleared within one hour of the times indicated by AA and BB. It is not known how the scatter compares with accuracy at present attained by forecasters in predicting times of fog clearance, but preparation of diagrams of this type for various sites may help to prevent large errors. Perhaps the real significance of Fig. 2 is that it shows that a quite marked

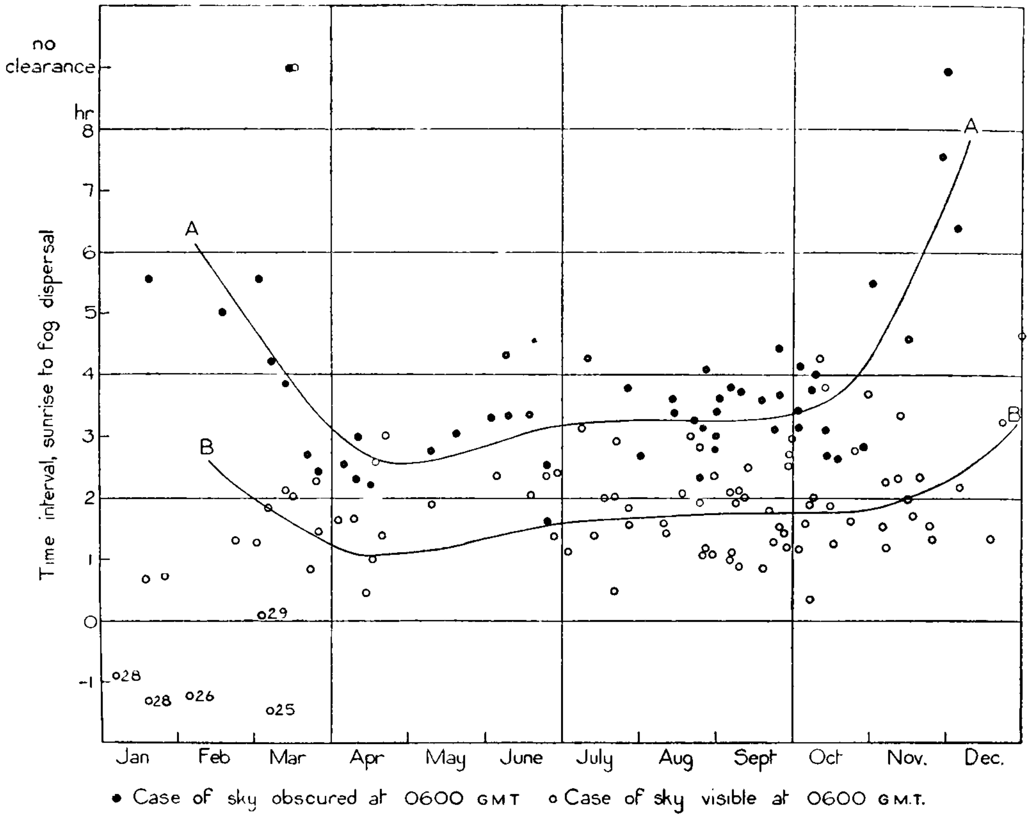

FIG. 2—VARIATION WITH TIME OF YEAR, OF TIME INTERVAL BETWEEN SUNRISE AND FOG DISPERSAL

Curve AA fits cases of sky obscured.

Curve BB fits cases of sky visible.

The temperature of fog formation has been inserted beside the symbol if below 32°F.

separation can be obtained by use of a simple parameter to represent vertical thickness of fog. This suggests that if measurements of depth of fog were available it might be possible to replace AA and BB by a series of curves representing different thicknesses of fog, and so increase the usefulness of the diagram as a forecasting tool.

It is emphasized that the cases included must be regarded as water fog, and that for many sites it will be necessary to distinguish between clean and heavily polluted fog.

REFERENCE

1. CORBY, G. A. and SAUNDERS, W. E.; Water-fog point—a further test. *Met. Mag., London,* **81**, 1952, p. 225.

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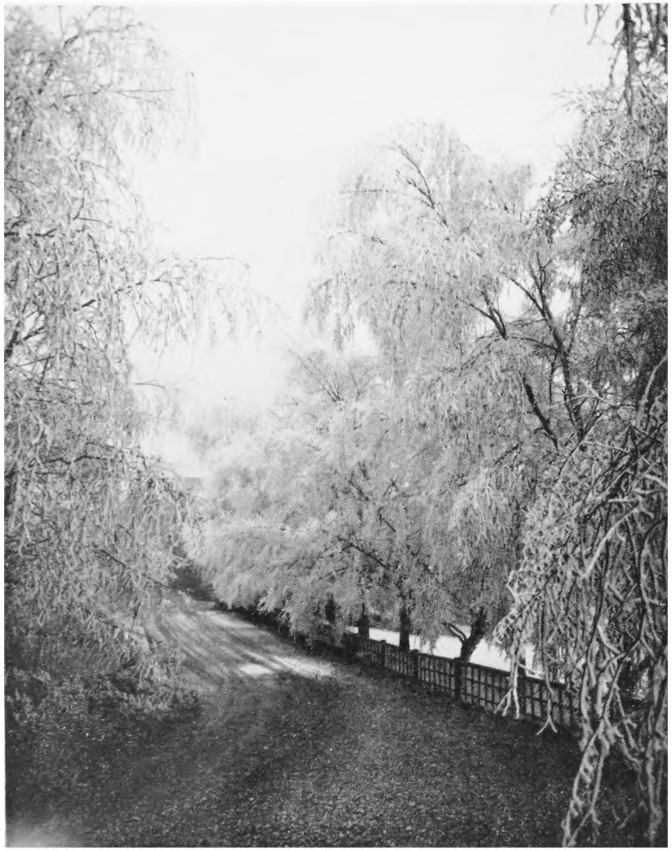
STANDARD PRESENTED TO THE METEOROLOGICAL SQUADRON OF THE ROYAL AIR FORCE

The presentation was made by Air Chief Marshal Sir Douglas C. S. Evill, G.B.E., K.C.B., D.S.C., A.F.C.

(see p. 379)

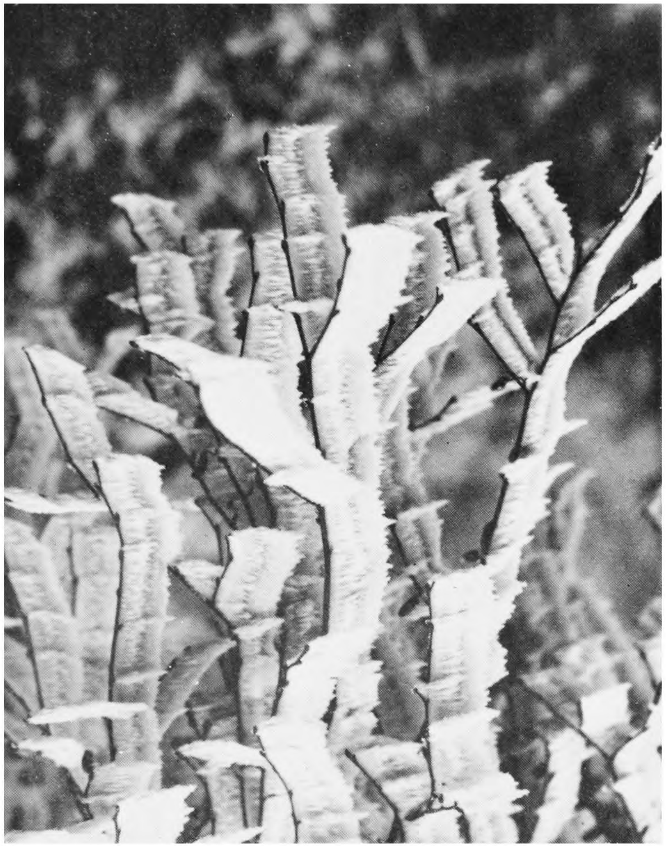


Photograph by Gayroma

Photograph by Gayroma

RIME AT LOWER PENN

We are indebted to Mr. G. R. Sankey, C.B.E., J.P. of Gay Hills, Lower Penn, Wolverhampton for the four photographs reproduced on this and the following page. Mr. Sankey took the pictures, on December 20 and 21, 1956, at his home.



Photograph by Gayroma

Photograph by Gayroma

DETAILS OF RIME FORMATION AT LOWER PENN

Photograph by Cambridge Daily News

CONDENSATION TRAILS OVER CAMBRIDGE

The trails were observed by Mr. L. L. Alexander, on September 5, 1957, in the vicinity of Waterbeach. Mr. Alexander reports that the contrails were from a fleet of Canberra aircraft flying to Farnborough and the trails were at 34,000 feet (measured); the shallow cumulus or stratocumulus was at 4,000 feet and the view is towards the south-west.

METEOROLOGICAL RESEARCH COMMITTEE

The Committee met on November 22, 1956, and reviewed in detail the progress reports from the three Subcommittees for March-August, 1956, and two reports from the Cloud Seeding Panel. The need for further investigation of slant visibility was noted, in view of the requirements for the safe landing of aircraft in conditions of bad visibility. There was general discussion on the organization and effort available for research within the Meteorological Office, with mention of several problems of weather and the atmosphere which merit study but for which provision has not yet been practicable.

Physical Subcommittee

At the meeting held on October 10, 1956, the Subcommittee, after reviewing the progress report for March-August, 1956, considered three papers dealing with aircraft condensation trails. The first paper presented observational data of trails made by the Canberra aircraft of the Meteorological Research Flight and indicated how the resulting analysis might aid the forecasting of the length of trails made by jet aircraft. The second paper included a treatment of the persistence of condensation trails as a problem of diffusion and also examined the relationship between observations on the height of persistent trails and the air temperature. The approach of the third paper was more general in that detailed account was taken of the effects of mixing, with the ambient air, of exhaust gases issuing with a given temperature and speed from a jet engine of which the fuel consumption and mass flow through the engine are known: an approach which, with the application of appropriate observational data, is likely to lead to results of assistance in forecasting the size and persistence of condensation trails. The other paper before the meeting indicated that the daily sequence of counts of freezing nuclei in the atmosphere, made during flights by the Meteorological Research Flight in January, 1956, gave no support to E. G. Bowen's hypothesis on the connection between rainfall peaks and meteoritic showers. There was discussion on the uncertainties associated with the determination of the concentration of freezing nuclei in the atmosphere.

At the meeting held on November 28, 1956, the Subcommittee noted, from comments obtained from three institutions concerned with the experimental investigations of fluid motion, that the operation of an incompressible fluid model for the study of two-dimensional air flow over a ridge (suggested by J. S. Sawyer in M.R.P. 935) would present serious difficulties. In the discussion, some suggestions were made for avoiding or reducing some of the difficulties and it was noted that laboratory experiments on the air flow over mountains are being made by the Department of Meteorology, Imperial College. A paper from Porton on the diffusion of airborne particles reported close agreement, up to 500 yards downwind, between vertical distribution of lycopodium particles emitted from a point 500 feet above ground and the distribution of the inclination of wind to the horizontal as recorded at the point of emission: and gave rise to discussion on the mechanism of atmospheric turbulence. Next, consideration was given to proposals for future research at the Meteorological Office radar station, taking into account the transfer of the station to another site within a few years and the expectation of obtaining millimetric radar in addition to centimetric radar equipment. Finally, the desirability of instituting systematic work on atmospheric nuclei was considered on the basis of the survey provided in the fourth paper, with expression of views on the relative importance of investigations of dust particles, condensation nuclei and freezing nuclei in the light of existing techniques and general resources.

ABSTRACTS

HELLIWELL, N. C. and MACKENZIE, J. K.; Further observation of condensation trails. *Met. Res. Pap., London*, No. 979, S.C. III/206, 1956. Two methods of observing tops and bases of trails formed by a Canberra are described: by a second aircraft and by a camera in the tail operated by remote control. Temperature, height, airspeed and frost point were also measured. Observations during 1955 are tabulated and frost points of trail formation plotted against temperature and pressure. Plots of airplane ascents and photos of trails are given for three special cases. Plots also show length of trail against temperature difference from Mintra and depression of frost point, effect of engine setting and effect of relative humidity on temperature at contrail base. It is concluded that temperature is the most important variable in contrail formation, relative humidity and engine setting only secondary factors. The length of the trail is a complex function of temperature and humidity. A forecasting procedure is suggested.

BRIGGS, J.; Condensation trails formed by jet aircraft. *Met. Res. Pap., London*, No. 996, S.C. III/214, 1956. Assuming that heat and water vapour supplied by a jet aircraft mix with the air in a few yards, the critical temperature for initial trail formation in saturated air at pressures 150–500 mb. is calculated. The persistence of a trail depends on a number of factors and simple forecasting criteria are difficult to define, but a persistent trail is more likely at high humidity, low temperature and low wind speed. Theoretical critical values of pressure, temperature and wind are given for persistence over at least 10 sec. Reported heights of base or top of persistent trails are tabulated in respect of temperature.

JONES, R. F.; The exhaust trail from jet engines. *Met. Res. Pap., London*, No. 990, S.C. III/210, 1956. Knowing the rate of burning of fuel, flow of air through the engine, water vapour production (1·3 gm. for 1 gm. kerosene), temperature and pressure of ambient air and speed, formulae are calculated for temperature T_m and mixing ratio x_m of the exhaust trail and examples quoted. A table gives T_m and x_i, x_w (x_i over ice at 200 mb. x_w over water) for dry ambient air, and a diagram gives also curves for various mixing ratios of ambient air. When the trail is saturated latent heat of condensation must also be taken into account. Conditions for formation and persistence of a visible trail are then considered. By comparison with observations, it will be possible to forecast the temperature at which, for a particular aircraft, persistent trails are likely or not likely. Finally the diameter of a trail as a result of entrainment is considered.

MURGATROYD, R. J. and GARROD, M. P.; The measurements of natural freezing nuclei made by the Meteorological Research Flight during January, 1956. *Met. Res. Pap., London*, No. 998, S.C. III/215, 1956. Counts of natural freezing nuclei in a cold chamber carried by airplane are described, including instrumentation and limitations. Counts were made on 25 days in January 1956 up to 10,000 ft. over south England; numbers as observed and at $-20°$ and $-25°$C.

are tabulated, and plotted against temperature, frost point and cloud. Day-to-day variations were not significant and gave no support to Bowen's meteor hypothesis; on the other hand horizontal variations were large. Concentrations of +1/litre were not usual until temperature fell to −20°C. or below. Results of other workers are compared. Concentrations were low when vertical stability was low, suggesting that in contrast to condensation nuclei, freezing nuclei are not due to transport upwards from the ground. There was no correlation with air mass or wind direction.

SAWYER, J. S.; Dynamical similarity in an incompressible fluid model of two-dimensional air flow over a ridge. *Met. Res. Pap., London,* No. 935, S.C. III/191 and S.C. II/198, 1955. [An abstract of this paper was published in the *Meteorological Magazine,* Vol. 85, p.150.]

HAY, J. S. and PASQUILL, F.; Measurements of the short range diffusion of airborne particles at a height of a few hundred feet in the atmosphere. *Met. Res. Pap., London,* No. 1006, S.C. III/218, 1956. Experiments are described in which lycopodium spores were released at a height of (usually) 500 ft. and the vertical distribution at 100, 300 and 500 m. downwind was examined. Measurements of wind inclination were also made. The medium values of spore elevation and wind inclination agreed to 0·2°. Distributions of wind inclination and spore elevation were approximately Gaussian, and of similar dimensions. Results show that the Lagrangian correlation (related to time in the sense of following the motion) equals unity for at least 1 min., but Eulerian correlation (at a fixed point) falls to 0·2 in 10 sec. This is explained by motion in straight lines of individual elements (puffs) of the plume. Appendices discuss sampling technique and Eulerian autocorrelation coefficient of vertical component of eddy velocity.

HARPER, W. G.; A survey of facilities and research programme of the Radar Research Station. *Met. Res. Pap., London,* No. 1009, S.C. III/220, 1956. Radar research at East Hill, near Dunstable, began when the Meteorological Office took over the station in 1947. Equipment for cloud and precipitation echoes, upper winds and sferics is described. Past work is summarized and 21 papers originating from East Hill are listed. Future plans are outlined, including use of 8 mm. radar. An alternative site is being sought.

ODDIE, B. C. V.; Atmospheric nuclei. An estimate of the value and practicability of routine measurements. *Met. Res. Pap., London,* No. 1012, S.C. III/221, 1956. Counting of dust particles by Owens dust counter or of Aitken condensation nuclei seems unlikely to contribute much to other branches of meteorology, though counting Aitken nuclei at a few places might be useful. Counts of freezing nuclei under natural conditions would be valuable but difficult. Objectives are set out; none of the methods yet tried satisfy them but Cwilong's threshold temperature method and E. K. Bigg's new type of cloud chamber deserve further study.

Synoptic and Dynamical Subcommittee

At the meeting held on November 1, 1956, consideration was given to the progress report for March-August, 1956 and to papers on the synoptic study of anomalies of surface air temperature, atmospheric models for numerical integration of the equations of motion and a survey of heat sources and sinks at the earth's surface.

The evidence in the first paper, on the large area, slow motion and high degree of persistence of the main anomaly patterns of 5-day mean surface air temperature, and indications of associations between anomalies and the general circulation pattern, was regarded as an important contribution to the study of methods of approach to forecasting for periods beyond one or two days, though the need to search for dependable relationships was stressed. The papers on atmospheric models represent further stages and refinements in the preparations being made for the construction of forecast pressure-contour charts by numerical integration when an electronic computer is available in the Meteorological Office. There was discussion on fundamental details of the two papers. The survey of the effects of differences or changes in the state of the earth's surface on the energy available to the atmosphere suggested certain factors (e.g., an anomaly in sea surface temperature and some changes in the nature of the earth's surface) might be expected to influence atmospheric systems on a synoptic scale. In the discussion, it was stated that it is proposed that further study on these lines shall be linked to the study of anomalies of surface air temperature as reported in the first paper presented.

ABSTRACTS

CRADDOCK, J. M. and LOWNDES, C. A. S.; A synoptic study of anomalies of surface air temperature over the Atlantic half of the Northern Hemisphere. *Met. Res. Pap., London*, No. 994, S.C. II/214, 1956. Differences of 5-day temperature means from normal (1921–40) were charted for 240 stations in U.S.A., North Atlantic and Europe for May 1955–April 1956. Some of the charts showed very large anomalies. Ten salient periods are selected for discussion and illustrated by representative 5-day charts. The patterns of temperature anomaly are large, slow moving and long-lived. They may be of use for long range forecasting either through their persistence or as indicators of the general atmospheric circulation.

KNIGHTING, E.; An atmospheric model for numerical integration including the tropopause effects. *Met. Res. Pap., London*, No. 1002, S.C. II/216, 1956. The usual atmospheric models for numerical integration of the equations of motion ignore the transition from troposphere to stratosphere. This is illogical and a simple model is developed which includes a variable pressure surface corresponding with the tropopause. Prognostic equations include one for tropopause pressure.

KNIGHTING, E.; A non-geostrophic extension of the Sawyer–Bushby model of the atmosphere suitable for numerical integration. *Met. Res. Pap., London*, No. 1003, S.C. II/217, 1956. A two-level model is used in which divergence is not zero at the surface but is zero at 500 mb. Vertical velocity becomes the key to development. Prognostic equations are set out and stream and potential functions introduced. The equations are difficult to solve and some simplifications are suggested.

HOUGHTON, D. M.; Heat sources and sinks at the earth's surface. *Met. Res. Pap., London*, No. 1005, S.C. II/218, 1956. The factors in the heat balance of the earth's surface are discussed from the point of view of variations which may affect the circulation of the atmosphere over a wide area. Heat storage in the oceans is first considered and it is estimated that an anomaly of $+1$ °C. in sea temperature would supply about 50 cal./cm.^{2}/day to the air, rising to 1200 in strong convection. Freezing of the sea causes a loss of 380 cal. by long-wave radiation. On the continents the factors are all highly variable; the maximum effects are (cal./cm.^{2}/day): conduction ± 30, thawing ground in sun -150, thawing snow -40, albedo of snow -180, of dry ground -50, evaporation and evapotranspiration (change from moist ground to desert or vice versa) ± 200. An excellent bibliography is appended.

OBITUARY

Professor Carl-Gustaf Rossby

The news of the sudden death of Professor Carl-Gustaf Rossby in Stockholm on August 19, 1957 was received with grief and shock by meteorologists all over the world. In any science there are at any one time a few outstanding figures and in meteorology Rossby was one of these, but we shall never know what Rossby might have become had his physique measured up to the tremendous pace he set himself; he died a victim of overstrain at the height of his powers.

Born in Stockholm in 1898, Rossby graduated at the university of that city, spent some time at the Swedish Meteorological and Hydrological Institute (the State Meteorological Office), and in 1926 moved to America where, as it turned out, he was to remain for many years to become an American citizen, to marry an American wife, and to attain acknowledged leadership among American meteorologists. Before the war his associations were mainly with the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution, during and after the war with the Department of Meteorology of the University of Chicago although some two important years were spent with the Weather Bureau.

It was to the surprise of many people that Rossby, with his reputation steadily growing and with all the opportunities which the United States could provide, should in 1947 return to Sweden to take a chair at the University of Stockholm. But this was no example of the successful man retiring from the turmoil of American life to the quiet academic atmosphere of his small native country. He created a new institute, the International Meteorological Institute, a unique organization linked with the University of Stockholm but financed not only from Sweden but also from various other sources including the United States and both the United Nations Educational, Scientific and Cultural Organization and the International Union of Geodesy and Geophysics. In ten years a great deal had been done to justify the title and no one could attend the Institute either for extended study or as a member of one of the frequent seminars without feeling that meteorology was a vital world science, moving ahead, with a man of vision there to guide. Had Rossby been content to realize his vision of an International Institute he might, who knows, have lived to lead it for many years but his interests remained world-wide and during his last year he had visited the United States and Central America as well as Britain and other countries of Europe on meteorological business of many kinds. In happier circumstances he would have presided at the General Assembly of the International Association of Meteorology in Toronto, which opened but a few days after his death.

Rossby's position, secured as it was in recent years by his leadership, enthusiasm and warm personality, was of course built on a firm foundation of personal achievement in the advancement of scientific knowledge. He will be remembered for his early work on the dynamics of ocean currents and on the drag between atmosphere and ocean as well as for his later meteorological work, mainly of the last two decades, on the large-scale motions of the atmosphere. The "Rossby diagram" of thermodynamics, "Rossby waves", the near-barotropic waves of the westerlies, and the "Rossby number", a ratio of central significance in planetary fluid motions, are sufficient to perpetuate his name in our science; there is no name in modern meteorology more deserving of remembrance.

R. C. SUTCLIFFE

LETTERS TO THE EDITOR

Poliomyelitis and water temperature

In his article on Poliomyelitis and weather[1] Mr. Lawrence makes the point that outbreaks of the disease follow periods of hot weather and also mentions the well-known fact that it reaches its maximum in the late summer and autumn. It seems, therefore, that bathing may play an important part in spreading the disease. This view has some official support as the B.B.C., during an outbreak, advises bathers to use chlorinated baths and not rivers.

There is an obvious correlation between maxima of the disease and anything else which occurs in the late summer and autumn but the probable relation between the disease and bathing suggests that water temperatures may be important in this respect. It is obvious that increase in water temperature would correlate quite well with increase in the disease but this may be important or merely fortuitous.

It might be possible to resolve the problem by comparing frequencies among riverside communities. The temperature of most rivers increases downstream and the disease should be more common in the lower reaches; but some rivers, probably flowing north, may fall in temperature downstream, at least over a section of their courses, and the distribution of the disease may be interesting.

As Mr. Lawrence says, there are many complicating factors one of which is the apparent natural immunity possessed by more primitive peoples. It may be that research on the lines suggested has already been carried out, but Mr. Lawrence's article gave the impression that it probably has not. It might be advantageous if it were.

H. S. TURNER

London Airport, July 23, 1956

[The relation between the incidence of poliomyelitis and water temperature may well be very important, but I believe that medical rather than meteorological research is more likely to throw light on this factor. During bathing, people's proximity may possibly help to spread the disease and the water in itself may possibly be a medium for its transmission, but any correlation between water temperature and the incidence of poliomyelitis may be merely fortuitous, as Mr. Turner suggests, because bathing tends to increase with increase of water temperature.

A positive correlation between the incidence of poliomyelitis and air temperature does not imply an "obvious correlation between poliomyelitis and anything else which occurs in late summer". In fact, though the incidence of poliomyelitis does show a positive correlation with certain functions of temperature which in turn could indeed correlate positively with vapour pressure, Dr. W. H. Bradley and Brig. A. E. Richmond[2] found no obvious connection between poliomyelitis and vapour pressure.

In an investigation into the incidence of poliomyelitis among riverside communities, a positive result could be merely a reflection of the fact that where river temperatures increase, air temperatures would tend to increase also, and vice versa. Furthermore, water near riverside settlements may have artificially caused local differences of temperature within the same community (for example, local sewerage) and these local, though not typical temperatures may be biologically crucial.

Recent papers[3,4,5] on poliomyelitis and the environment state a relationship between poliomyelitis and factors which cause salt depletion of the body. The accentuation of salt depletion by frequent bathing is connected with the predisposition to paralytic poliomyelitis of countries with high standards of hygiene. —E. N. LAWRENCE.]

REFERENCES

1. LAWRENCE, E. N.; Poliomyelitis and weather. *Met. Mag., London,* **85,** 1956, p. 164.
2. BRADLEY, W. H. and RICHMOND, A. E.; Meteorological conditions in relation to poliomyelitis in England and Wales 1947–1952. *Mon. Bull. Minist. Hlth. Lab. Serv., London,* **12,** 1953, p. 2.
3. IRVING, F. A.; An investigation into the relationship between the incidence of poliomyelitis and the environment. Annual Report of the County Medical Officer of Health of Essex, 1954. Chelmsford, 1955, p. 113.
4. IRVING, F. A.; The environmental approach to the prevention of poliomyelitis, Maldon, 1956. (Communicated privately).
5. International Society of Bioclimatology and Biometeorology, Report of First Bioclimatological Congress, Vienna, 1957. (Communicated privately).

Ball lightning

You may like to have a note of a fire-ball—or what appeared to be one—seen by my wife and myself on Sunday, June 30.

We were motoring south-east along B.3135 across the Mendips in very heavy rain and poor visibility at the time—2.30 p.m. About half a mile before crossing the Radstock–Shepton Mallet railway, at map reference ST 6048 on the National Grid, there was, without any previous warning of thunder, a tremendous flash of lightning and instantaneous crash of thunder. One fork of lightning struck about 100 yd. to our left and, at the same time, about 200 yd. ahead and slightly to the right, a bright globe of light, perfectly round, appeared. It seemed to be raised a few feet above the ground, possibly poised on a tree or farm building—it was impossible to see clearly in the bad light—and to sink slowly to the ground. It lasted only a few seconds and had disappeared when we passed the spot.

Dazzle produced by the lightning seems to be excluded by the fact that my wife, who had been dozing, did not see the lightning but, roused by the thunder, did see the fire-ball.

There was no further thunder at that point, although we did drive through a thunderstorm and heavy rain between Warminster and Amesbury later.

G. H. BROWN

Red Cottage, Colley Way, Reigate, July 29, 1957.

Abnormal temperature and visibility variations at Little Rissington on December 19–20, 1956.

A ridge of high pressure over England on December 19–20, 1956 gave widespread dense fog over most of England and Wales.

Rapid fluctuations of temperature by day and night with sharp changes in visibility occurred at Little Rissington during this period. The thermograph trace (Fig. 1) shows rises and falls of temperature of up to 6°F., in short periods of 30 min. to 1 hr., and the visibility varied between 75 yd. and 1,600 yd. with the fog clearing the airfield completely at times, although the tops of the fog layer could be seen on these occasions just beyond the airfield perimeter. Visibility between the screen and the fog bank during these clearances could be described as excellent.

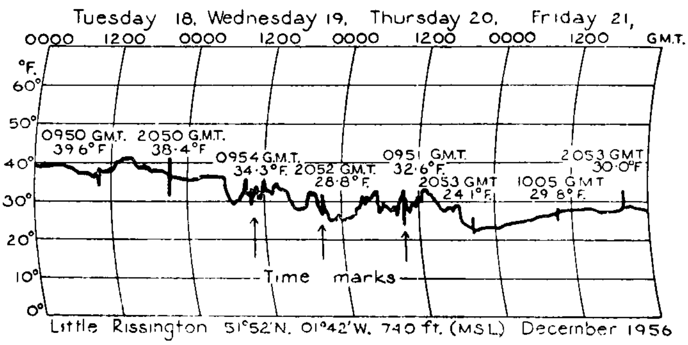


FIG. 1—THERMOGRAM SHOWING TEMPERATURE AT LITTLE RISSINGTON DECEMBER 18–21, 1956

The base of the inversion on the Crawley ascent for these two days (Figs. 2 and 3) varied between 988 mb. and 1010 mb. The recorded airfield pressure at Little Rissington during this period was between 1000–1003 mb. As the airfield at Little Rissington is situated on a high point in the Cotswolds at 750 ft. above mean sea level, it seems probable that the observed variations in temperature and visibility resulted from variations in the level of the inversion, drier and warmer air from above affecting the station from time to time. From observations of the thickness of the fog layer above and around the station it was estimated that the top of the fog layer was varying by about 50–150 ft. It would seem that Little Rissington was in or just below the inversion layer and this would account for the rapid rise and fall of the temperature and visibility.

Apart from small amounts of Ac. and Ci. at times, the sky was observed to be clear through the thin layer of fog or during temporary breaks. It will be seen from the thermograph trace that the sudden variations of temperature referred to continued during the night and cannot therefore be explained solely in terms of solar heating.

Calm conditions prevailed most of the time, although a few observations up to 3–6 kt. were recorded. The recorded sunshine during this period was 1·9 hr. on the 19th with visibility between 100–250 yd. and 2·8 hr. on the 20th

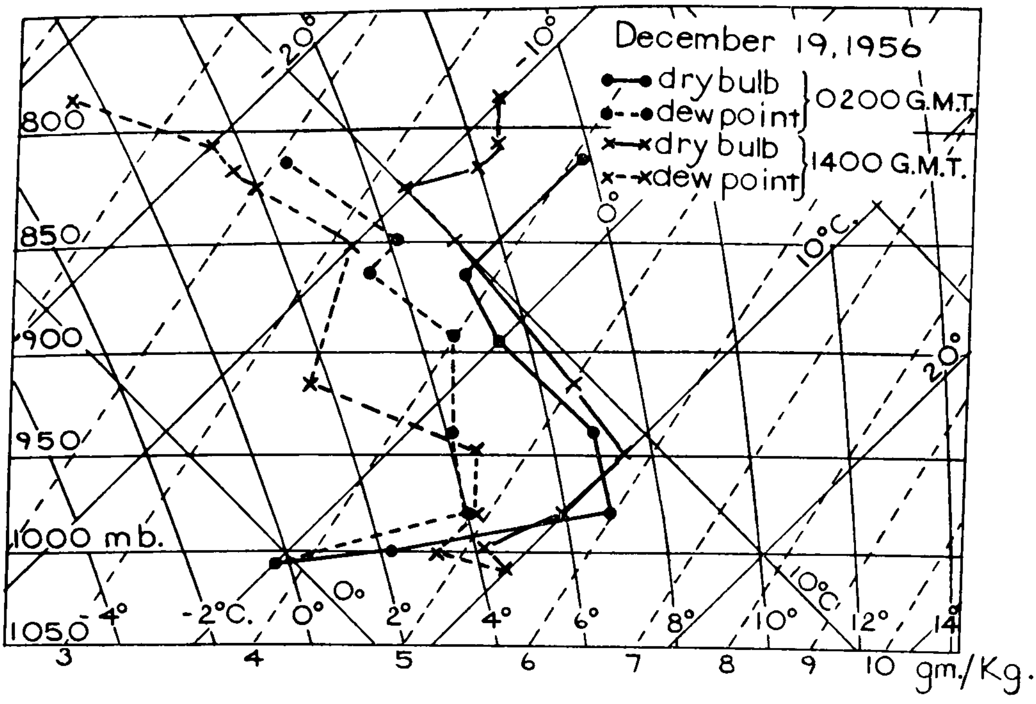


FIG. 2—TEPHIGRAM FOR CRAWLEY, DECEMBER 19, 1956

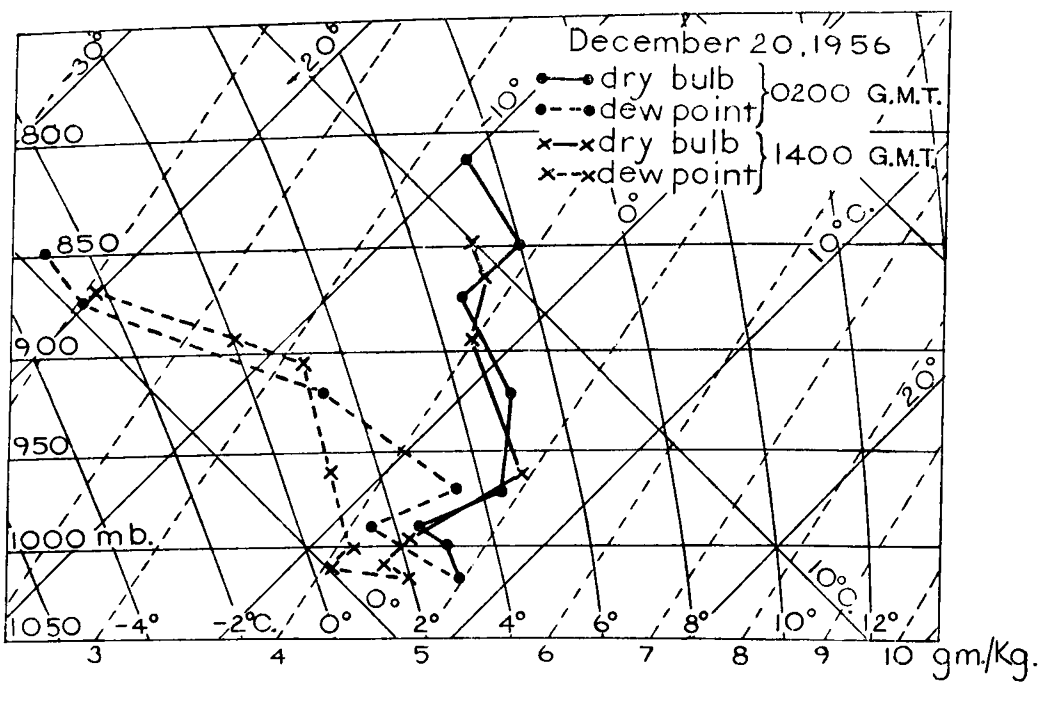


FIG. 3—TEPHIGRAM FOR CRAWLEY DECEMBER 20, 1956

with visibility between 150–700 yd. This was due to the fact that the fog bank was never further away than 700 yd. from the enclosure.

Hourly relative humidities for the period were between 99 per cent and 94 per cent on 32 out of 48 occasions, and even as low as 87 per cent and 83 per cent on the 20th at 1200 hr. and 1300 hr. respectively, when the fog bank was between 500–700 yd. from the screen. This again indicates the presence of drier air from above the inversion. The downwards movement of the inversion resulting in the replacement of moist cold air by drier warmer air and *vice versa.*

Little Rissington, Gloucester, January 18, 1957. J. KONIECZNY

NOTES AND NEWS

Snow Survey of Great Britain

For the last three years the annual report of the Snow Survey has appeared in the December issue of the *Meteorological Magazine.* The report for the season 1956–57 and subsequent years will be published in *British Rainfall,* commencing with the 1957 volume. Advance copies of the 1956–57 report have been duplicated and distributed to co-operating observers. A limited number of copies are available to others interested in the Snow Survey and may be obtained on application to the Director-General, Meteorological Office, M.O.3.b., Headstone Drive, Harrow, Middlesex.

Meteorological Magazine: increase in price

We regret, as announced in our November number, that owing to further increases in the cost of printing and publication it has become necessary to again raise the price of the *Meteorological Magazine.* The price will be 2*s.* 6*d.* an issue with effect from the January 1958 number. The net annual subscription will become 32*s.* including postage. Present subscribers will remain on the existing rate until renewal of their subscriptions is due.

Microcards of International Geophysical Year meteorological data

Report No. 7 of the Meteorological Data Centre of the World Meteorological Organization contains full particulars of the microcards of I.G.Y. meteorological observations which the Centre is to produce.

The types of cards will be as follows:

1. Synoptic surface observations—land stations.
2. and 2b. Synoptic surface observations—sea stations.
3. Radio-sonde and rawin-sonde observations.
4. Upper-wind observations.

The observations will be grouped regionally. About 25 cards of Type 1 will comprise the world-wide data for 5 days and the complete set of Type 1 cards should not exceed 2,750. The number of the others will be larger, for Type 3 it is about 5,000. Full details and prices can be obtained from World Meteorological Organization, I.G.Y. Meteorological Data Centre, 1 Avenue de la Paix, Geneva, Switzerland.

Presentation of standard to 202 (Meteorological) Squadron, R.A.F. On September 6, 1957 the ceremony took place at Aldergrove of the consecration and presentation of a standard to 202 Squadron, Royal Air Force, the squadron which carries out the "Bismuth" meteorological reconnaissance flights. The presentation was made by Air Chief Marshal Sir Douglas C. S. Evill, G.B.E., K.C.B., D.S.C., A.F.C., who commanded the squadron in 1916.

The Meteorological Office was represented at the ceremony and at the lunch which followed by Mr. S. P. Peters, D.D.M.O. (C), Mr. F. H. Dight, Chief Meteorological Officer, Headquarters Coastal Command, Mr. R. A. Buchanan, Senior Meteorological Officer, Northern Ireland and members of the staff at Aldergrove.

No. 202 Squadron was first formed at Eastchurch in 1914 as part of the Royal Naval Air Service. During the First World War its activities included the shooting down of a Zeppelin and reconnaissance work in preparation for the blocking of the harbours at Zeebrugge and Ostend.

After a period of disbandment the squadron was re-formed in 1929 as a flying-boat squadron and was stationed for some years in the Mediterranean.

During most of the Second World War 202 Squadron was stationed at Gibraltar and, flying in Catalina and Sunderland aircraft, helped to guard the approaches to the Mediterranean. Its record includes the sinking of three enemy submarines, a share in the sinking of three others and, in decorations, one Distinguished Service Order, two bars to the Distinguished Flying Cross, 12 Distinguished Flying Crosses, seven Distinguished Flying Medals and one George Medal.

Late in 1946 the squadron moved to Aldergrove and took over the meteorological reconnaissance work previously carried out by 518 Squadron. At first Halifax aircraft were used but in 1950 these were replaced by Hastings aircraft.

Five times a week a meteorological reconnaissance flight takes place along a track nominated by the Central Forecasting Office, and it is the firm belief of the aircrew that the Senior Forecaster there chooses the area of worst weather within range. During the recent North Atlantic Treaty Organization exercises the flights were temporarily increased to twice daily and on many occasions were designed to take the aircraft through the centre of the intense depression, previously known as Hurricane Carrie, which caused the loss of the sailing ship Pamir and threatened severe gales over the British Isles. The information gained on these flights was of outstanding value in the placing of the centre of the depression and the measurement of its depth.

REVIEW

Hailstorms of the United States. By S. D. Flora. $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. xv + 368, *Illus.* University of Oklahoma Press, Norman, Oklahoma, 1956. Price: $3.50. This book of facts, figures and pictures produced in sufficiently popular style for all classes of American laymen who require an informed attitude to the hail risk, should not be overlooked by farmers, insurance businesses or professional meteorologists in other countries. More than half the book, pp. 71–176, is given up to a description of the incidence of the hail hazard State by State within the United States of America in some geographical detail, and a few pages at the end survey the rest of the world rather in the haphazard manner of newspaper reportage of weather phenomena abroad; but the first 70 pages contain information of wider interest which should command attention.

At Wichita in Kansas, the worst affected State in the Union, two hailstorms accompanied by tornadoes did $9 million and $14 million worth of damage within a two-year period. In the western plains between 100°W. and the Rocky Mountains one-tenth to one-twelfth of all the crops are destroyed annually by hail. In this region the risks are so serious that crop-hail insurance has become an important business, the rates being 15–20 per cent in the areas of greatest risk, and the 1950's have seen the development of a Severe Weather Warning Centre which attempts to forecast the size of hailstones.

Investigations so far conducted have suggested relationships between hail sizes and identifiable characteristics of the tephigram. Large hailstones with diameters 5 to 10 cm. or more are found almost exclusively when the "wet bulb freezing level" is 7,000 to 9,000 ft. above the ground. The standard severe-hail situation, which is plainly also a situation of maximum risk for thunderstorms and tornadoes, is related to the abrupt air-mass contrast between moist maritime tropical air streaming north from the Gulf of Mexico and föhn-dried cool air of Pacific origin descending from the Rockies. This makes the western plains particularly liable to violent phenomena.

Slightly heavier total losses have been assessed due to hail than to tornadoes: over the period 1944–53 the country-wide totals for the United States are given as $53 million yearly due to hail and $45 million yearly due to tornadoes. The two phenomena are however in some degree associated. These figures should serve as a sufficient warning against complacency anywhere where hail falls. The reviewer has pointed out that parts of southern and eastern England have a relatively high incidence of tornadoes; and newspaper photographs of hail lying in the streets of Tonbridge, Kent on August 6, 1956 match well with the scenes in towns in Kansas and Colorado illustrated in this book.

Maps show the incidence of hail damage over the United States, the average number of days a year with hail and the percentage of thunderstorm days on which hail is recorded. The latter percentage is highest in the maritime winter thunderstorms of the west coast, but the more serious hail is the late spring and summer hail of the Rocky Mountains and Great Plains. In this region aircraft need the provision of radar screens capable of detecting hail and farmers need insurance. The "man in the street" or on the farm in western Kansas who reads Mr. Flora's figures may also decide to change his haunts between 4 and 7 p.m.

H. H. LAMB

LETTER TO THE EDITOR

Computed forecast charts

In a paper entitled "Series of computed forecast charts and the movement of a depression, August 19–21, 1954" Pothecary and Bushby[1] study the abnormal movement of a depression. It is claimed that conventional forecasting methods proved inadequate at the stage when the depression became stationary and later moved south-east. Referring to Fig. 1 of this paper it will be observed that a large diffluent ridge-confluent trough pattern on the thickness chart is in evidence over the central and eastern Atlantic. This is the type of thickness pattern studied by J. Houseman and myself[2]. In our paper we state that "any new depression developing on the confluent trough will move slowly south-east and fill". Figs. 10 and 11 of our paper illustrate this and are very comparable with the situation of Pothecary and Bushby's work.

It is significant that the depression which they study does fill, whereas computation shows deepening at first and filling (but not sufficiently quickly) later. With the aid of our paper we can claim that conventional methods would have proved adequate and perhaps a little better than computation in this instance. It is also noteworthy that the anticyclone involved in the development behaved according to our hypothesis.

C. HAWORTH

REFERENCES

1. POTHECARY, I. J. W. and BUSHBY, F. H.; Series of computed forecast charts and the movement of a depression, August 19–21, 1954. *Met. Mag., London*, **85**, 1956, p. 133.
2. HOUSEMAN, J. and HAWORTH, C.; Anticyclogenesis in relation to a particular thickness pattern. *Met. Mag., London*, **86**, 1957, p. 321.

[I would like to add the following brief comments to Mr. Haworth's letter concerning the paper by Pothecary and myself. In this particular situation I think the movement of the depression was of prime importance, and the variation in the central pressure of only secondary importance. Certainly, the differences between the computed and actual central pressures should not have led to any serious forecasting error.

Secondly, it is very difficult to estimate, after an event, the results of applying a subjective rule before the event. Mr. Haworth's rule that "any new depression developing on the confluent trough will move slowly south-east and fill" would not seem to describe the movement of this depression which moved due east, stagnated and then drifted slowly south-west.

F. H. BUSHBY]

OFFICIAL PUBLICATION

Climatological and sea-surface current charts of the North Atlantic.

This new publication, which has been prepared in the Marine Division of the Meteorological Office, consists of monthly charts of meteorological and ocean-current data covering the North Atlantic. These charts are being produced primarily for the benefit of the masters and officers of merchant ships, as a result of a suggestion made by the master of a voluntary observing ship. The contents are based on the data contained in *Monthly meteorological charts of the Atlantic* and *Quarterly surface current charts of the Atlantic*, which were compiled from observations made aboard British voluntary observing ships between 1855 and 1939. Printed on a single sheet, 23 in. × 39 in., the new charts show wind roses, ocean currents, ice limits, main shipping tracks, and, on small insets, mean air and sea temperatures, barometric pressure, visibility, and frequencies of gales and hurricanes.

The charts for May, June and July have already been published, and the remaining charts will be published at approximately monthly intervals by H.M.S.O. at the very reasonable price of 3*s*. each. Similar monthly charts for the South Atlantic are in the course of preparation, and those for the Indian Ocean and the North and South Pacific Oceans will also be prepared and published as soon as possible.

METEOROLOGICAL OFFICE NEWS

Halley Bay.—We note with pleasure that Mr. J. MacDowall is to become leader of the Royal Society International Geophysical Year Expedition, Halley Bay, in January 1958 in succession to Colonel R. A. Smart, R.A.M.C. who will return then to the United Kingdom as arranged in 1956. During 1957, Mr. MacDowall has been leader of the group—all members of the Meteorological Office—responsible for the Expedition's work in meteorology, geomagnetism, glaciology and seismology[1]. Mr. B. G. Ellis and Mr. J. A. Smith, of the Meteorological Office, left England in M.V. *Tottan* on November 18, 1957 to join the party at Halley Bay for the remainder of the International Geophysical Year. Mr. P. H. Jeffries, after spending 1956 with the Trans-Antarctic Expedition advance party at Shackleton and then 1957 with the Royal Society Expedition, is to leave Halley Bay for England in January 1958.

We wish success to all at Halley Bay.

REFERENCE

1. Royal Society International Geophysical Year Expedition to Antarctica. *Met. Mag., London,* **86,** 1957, p. 25.

Academic successes.—In addition to the list published in the November magazine (p. 349) the following members of the staff have also been successful in their examinations:

B.Sc. (General): I. Jenkins.

General Certificate of Education (Advanced level) : O. W. Brittain, N. Holdsworth, J. F. Holter, J. B. Lawson, Miss M. J. Moore, D. J. Smith, D. W. Sutton, C. F. Townsend, Miss J. B. Weldon and R. A. White.

Ordinary National Certificate: M. T. Tomlinson.

WEATHER OF OCTOBER, 1957

Great Britain and Northern Ireland

Over the greater part of the British Isles the weather in the first half of the month was anticyclonic and dry, without measurable rainfall in many midland and southern districts of England, but the second half was generally changeable.

An anticyclone, which was situated to the south-west of Ireland during the first three or four days of the month, gave mainly fine quiet weather over most of England and Wales, but over Scotland and Northern Ireland, there was some light rain and drizzle. Ground frosts were fairly widespread during the early hours of both the 1st and 2nd and by day the weather was bright especially in the south of England where in many places it was brilliantly sunny. Gales occured in north Scotland on the 3rd and winds reached 70 kt. in the Orkneys as a vigorous depression off the north coast moved rapidly eastwards towards southern Scandinavia. On the 5th the anticyclone off south-west Ireland began to move eastwards to the continent, the highest pressure becoming situated over the central English Channel on the 6th and over the Balkans the following day. Most of the British Isles remained in a weak pressure gradient for another week, but with the movement of the anticyclone winds over the country backed from a northerly to a southerly direction and warmer air spread to many districts. Early morning fog developed over eastern and southern counties on the 7th and, during this second week, fog became progressively more extensive each morning over England and Wales. Afternoon temperatures were mainly in the sixties and reached 70°F. locally in Devon on the 10th, while on the 13th, 14th and 15th, which were generally the warmer days of the month in southern England, temperatures were about 10°F. above the seasonal average.

The spell of settled weather was brought abruptly to an end early on the 16th by a burst of cold air which swept eastward across the country accompanied by a broad belt of rain which was heavy at times, and associated with strong westerly winds at high levels. Many places reported nearly an inch of rain on that day. With the westerly régime well established a vigorous depression moved eastward across Ireland and northern England on the 17th giving a wet almost sunless day with some unusually heavy rain in Scotland. The following day was somewhat similar, but on the 19th weather was generally brighter though there were showers with thunderstorms in places and it remained generally cold. Ground frost was widespread early on the 20th, and, though it was sunny at many places at first, another rain belt moved across the country during the day from the north-west, followed later by cooler bright and showery weather which persisted for the next two days. Further rain belts moved into the country on the 23rd, but on this occasion they became slow moving, and dull rainy weather persisted until the morning of the 26th. After a brief finer spell the sequence of events was repeated. Rainfall was particularly heavy in western districts and during the period 26th–29th a total of 12·71 in. was recorded at Blaenau Festiniog in Merionethshire. Widespread gales developed on the last day of the month as a deep depression moved from Denmark Strait to north Scotland; a gust of 70 kt. was reported from the Hebrides.

Temperature was above the average over the month as a whole and sunshine was mainly below average. Rainfall was 74 per cent of the average over England and Wales, 113 per cent over Scotland and 188 over Northern Ireland. It was less than half the average over much of Kent, Surrey and Sussex, over an area extending from Monmouthshire to Lincolnshire and over the eastern counties of Scotland. It was above average over North Wales, north-west England and the western half of Scotland. The dry weather during the first half of the month gave growers a chance to catch up with their cultivations and field work, even on the heaviest soils, became well advanced. Rain later in the month helped planting out and the bright sunshine completed the ripening to a good deal of fruit, including the outdoor tomato crop. Heavy rain at the end of the month caused local flooding in Wales and the Midlands.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	70	27	+1·4	74	−4	86
Scotland	65	20	+1·2	108	+1	79
Northern Ireland ...	64	33	+0·6	118	0	71

RAINFALL OF OCTOBER 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·99	76	*Glam.*	Cardiff, Penylan ...	4·21	89
Kent	Dover	1·23	32	*Pemb.*	Haverfordwest	4·38	81
,,	Edenbridge, Falconhurst	1·54	43	*Radnor*	Tyrmynydd	5·09	77
Sussex	Compton, Compton Ho.	2·60	57	*Mont.*	Lake Vyrnwy	6·43	110
,,	Worthing, Beach Ho. Pk.	1·51	42	*Mer.*	Blaenau Festiniog ...	16·57	162
Hants.	St. Catherine's L'thouse	2·00	53	,,	Aberdovey	6·96	146
,,	Southampton (East Pk.)	2·39	61	*Carn.*	Llandudno	2·72	81
,,	South Farnborough ...	1·59	50	*Angl.*	Llanerchymedd ...	4·90	109
Herts.	Harpenden, Rothamsted	2·38	75	*I. Man*	Douglas, Borough Cem.	5·82	128
Bucks.	Slough, Upton	2·02	72	*Wigtown*	Newton Stewart ...	4·99	110
Oxford	Oxford, Radcliffe ...	2·06	71	*Dumf.*	Dumfries, Crichton R.I.	4·79	121
N'hants.	Wellingboro' Swanspool	1·74	69	,,	Eskdalemuir Obsy. ...	7·74	143
Essex	Southend, W. W. ...	1·43	57	*Roxb.*	Crailing...	2·58	90
Suffolk	Felixstowe	1·28	56	*Peebles*	Stobo Castle	3·31	96
,,	Lowestoft Sec. School...	1·33	48	*Berwick*	Marchmont House ...	2·02	53
,,	Bury St. Ed., Westley H.	1·54	57	*E. Loth.*	North Berwick Gas Wks.	1·21	41
Norfolk	Sandringham Ho. Gdns.	1·80	59	*Midl'n.*	Edinburgh, Blackf'd. H.	1·90	69
Wilts.	Aldbourne	2·40	67	*Lanark*	Hamilton W. W., T'nhill	3·87	119
Dorset	Creech Grange... ...	3·16	62	*Ayr*	Prestwick	3·74	130
,,	Beaminster, East St. ...	2·82	63	,,	Glen Afton, Ayr San. ...	5·88	115
Devon	Teignmouth, Den Gdns.	2·00	52	*Renfrew*	Greenock, Prospect Hill	6·60	130
,,	Ilfracombe	5·08	111	*Bute*	Rothesay, Ardencraig ...	5·74	130
,,	Princetown	7·67	91	*Argyll*	Morven, Drimnin ...	8·11	136
Cornwall	Bude	4·22	104	,,	Poltalloch	8·21	167
,,	Penzance	3·32	71	,,	Inveraray Castle ...	11·70	166
,,	St. Austell	3·43	65	,,	Islay, Eallabus... ...	5·76	121
,,	Scilly, Tresco Abbey ...	2·01	53	,,	Tiree	4·93	108
Somerset	Taunton	1·93	60	*Kinross*	Loch Leven Sluice ...	3·05	89
Glos.	Cirencester	2·10	61	*Fife*	Leuchars Airfield ...	1·42	55
Salop	Church Stretton ...	1·91	52	*Perth*	Loch Dhu	8·63	121
,,	Shrewsbury, Monkmore	1·79	64	,,	Crieff, Strathearn Hyd.	2·59	66
Worcs.	Malvern, Free Library...	1·10	37	,,	Pitlochry, Fincastle ...	1·96	60
Warwick	Birmingham, Edgbaston	1·49	49	*Angus*	Montrose Hospital ...	1·27	46
Leics.	Thornton Reservoir ...	1·23	44	*Aberd.*	Braemar	1·95	52
Lincs.	Boston, Skirbeck ...	1·55	57	,,	Dyce, Craibstone ...	1·39	41
,,	Skegness, Marine Gdns.	1·47	54	,,	New Deer School House	2·39	63
Notts.	Mansfield, Carr Bank ...	1·20	39	*Moray*	Gordon Castle	1·48	47
Derby	Buxton, Terrace Slopes	4·72	96	*Nairn*	Nairn Achareidh ...	1·53	67
Ches.	Bidston Observatory ...	2·63	80	*Inverness*	Loch Ness, Garthbeg ...	4·72	132
,,	Manchester, Ringway...	2·91	94	,,	Loch Hourn, Kinl'hourn	17·54	178
Lancs.	Stonyhurst College ...	8·13	181	,,	Fort William, Teviot ...	10·77	152
,,	Squires Gate	4·29	121	,,	Skye, Glenbrittle ...	11·13	135
Yorks.	Wakefield, Clarence Pk.	1·04	36	,,	Skye, Duntulm... ...	7·97	146
,,	Hull, Pearson Park ...	1·54	52	*R. & C.*	Tain, Mayfield... ...	1·59	58
,,	Felixkirk, Mt. St. John...	2·03	70	,,	Inverbroom, Glackour...	8·30	147
,,	York Museum	2·03	75	,,	Achnashellach	12·49	164
,,	Scarborough	3·09	99	*Suth.*	Lochinver, Bank Ho. ...	7·92	172
,,	Middlesbrough... ...	1·69	56	*Caith.*	Wick Airfield	2·02	68
,,	Baldersdale, Hury Res.	3·75	101	*Shtland*	Lerwick Observatory ...	6·28	159
Norl'd.	Newcastle, Leazes Pk....	1·75	57	*Ferm.*	Crom Castle	4·90	151
,,	Bellingham, High Green	2·66	68	*Armagh*	Armagh Observatory ...	3·49	128
,,	Lilburn Tower Gdns. ...	1·90	51	*Down*	Seaforde	4·06	114
Cumb.	Geltsdale	4·67	126	*Antrim*	Aldergrove Airfield ...	3·23	108
,,	Keswick, High Hill ...	6·29	112	,,	Ballymena, Harryville...	4·12	11[illegible]
,,	Ravenglass, The Grove	4·76	110	*L'derry*	Garvagh, Moneydig ...	3·99	11[illegible]
Mon.	A'gavenny, Plâs Derwen	2·10	45	,,	Londonderry, Creggan	4·18	11[illegible]
Glam.	Ystalyfera, Wern House	7·89	115	*Tyrone*	Omagh, Edenfel ...	3·70	10[illegible]

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