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THE GEOGRAPHICAL DISTRIBUTION OF CLEAR-AIR TURBULENCE

By H. S. TURNER, B.A.

Introduction.—There has long been a need for a practical investigation into the relationship between clear-air turbulence and the nature of the terrain over which the air is moving. An attempt to show that clear-air turbulence may have a real connexion with topography should take into account its frequency over areas where there are no hills, that is over the sea, and compare this with the frequency of turbulence over land.

Method of working.—An experiment to make this comparison was made from London Airport in 1956 with the kind co-operation of a number of air-line pilots. Each pilot was given a log book. This book contained:

(i) definitions of moderate and severe turbulence;
(ii) instructions on completing the short questionnaire appropriate to each flight;
(iii) questionnaires to be completed for each flight.

Sufficient questionnaires were included in each log book for twenty flights. The books were pocket-sized and designed for easy handling. They proved to be popular with the pilots, some of whom kept a continuous record from March to November.

Instructions included a request for negative reports to be included, for slight turbulence to be ignored, and for turbulence in cloud, in close proximity to cumulus and cumulonimbus and turbulence below 12,000 feet to be excluded. An important entry requested for each flight was: "Portion of the route flown at operational height and not in cloud."

The aircraft participating in this experiment were Viscounts and Strato-cruisers. Flying heights varied from 12,000 feet up to 30,000 feet with an average of about 21,000 feet.

Explanation of diagrams.—When an aircraft is flying across a coastline with the gradient wind blowing from land to sea, it is clear that for some distance over the water, the aircraft is effectively "flying over land". It was thus necessary to find the average distance to the lee of the land which should be added to the overland part of the flights. Frequency curves (Figure 1)

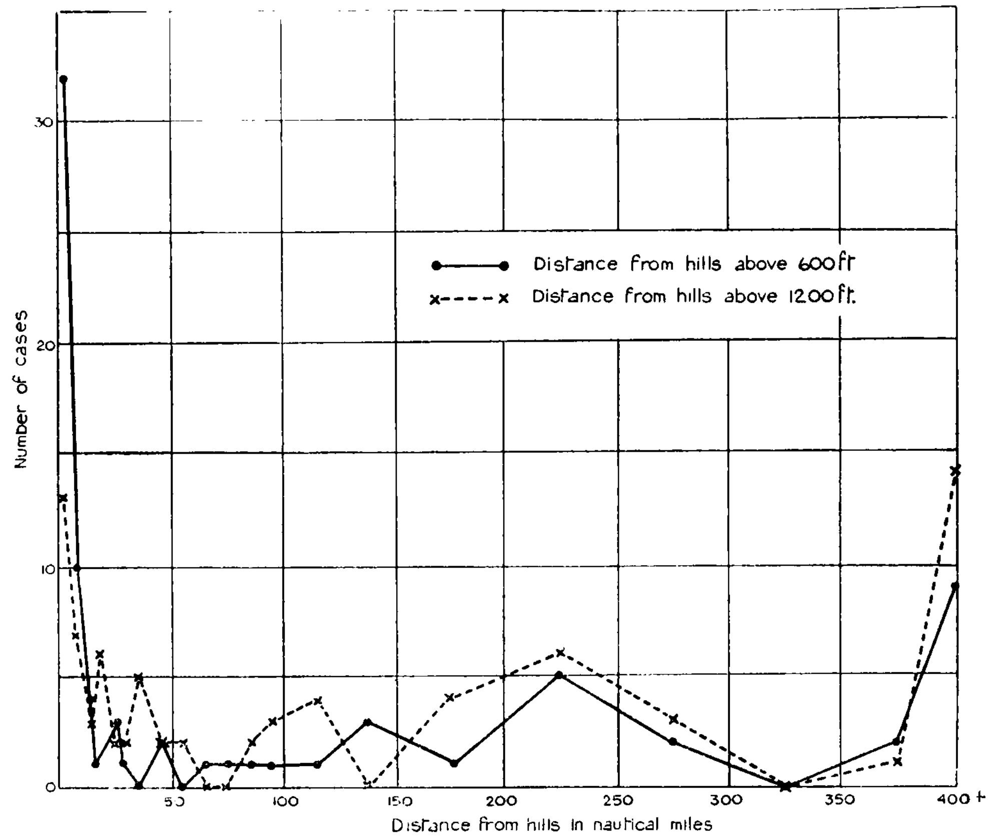

FIGURE 1—FREQUENCY CURVES COMPARING NUMBER OF CASES OF TURBULENCE WITH DISTANCE FROM HILLS

comparing the number of cases of turbulence with their distance away from hills of 600 and 1,200 feet were constructed. A brief inspection of the curves might suggest that here is a simple answer to the main problem being considered, but the curves take no account of the high frequency of flights near hills and the only conclusion drawn from them is that, if there is any reality in the relation between topography and turbulence, a reasonable amount of lee to allow for an average land mass is 10 nautical miles. ("Average" should be stressed as one pilot considered that he felt turbulence effects from the Pyrenees 70 miles away.) The routes over Holland, extreme north Germany and Denmark were counted as sea routes because of the flatness of the terrain.

Figure 2 gives the positions above which turbulence was reported over Europe and adjacent waters. The arrows show the directions of the gradient wind. The small number of reports of extensive turbulence are represented by a single dot to avoid congestion on the map. Reports over the Atlantic are not illustrated as the actual positions have no significance to the main section of this paper.

It will be seen that there are some areas where turbulence reports were concentrated. The topography near Troyes, the most striking of these areas, is shown in Figure 3. Extended turbulence is shown here by a dotted line. It will be seen that gradient winds are predominantly north-easterly.

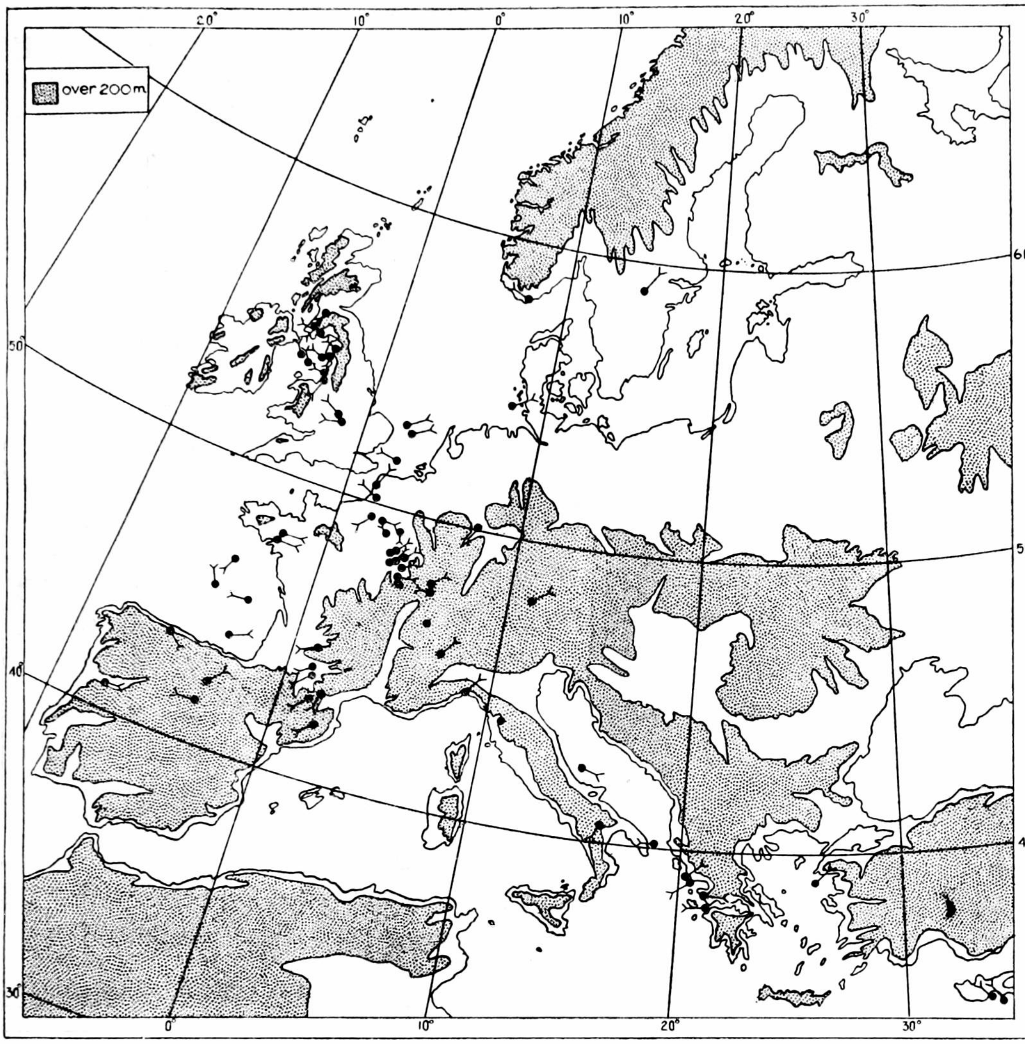

FIGURE 2—POSITIONS OF TURBULENCE REPORTS

Principal results.—The average distance between two cases of turbulence was worked out for land, sea and coastal flying, for spring, summer and autumn, and also for the three seasons taken together. The results in nautical miles are given in Table I.

TABLE I—THE AVERAGE DISTANCE (IN NAUTICAL MILES) FLOWN BETWEEN TWO CASES OF TURBULENCE

	Over land	Over sea	Over coasts
Spring	1650	4050	1100
Summer	4000	4400	1300
Autumn	1500	4450	900
Spring, summer and autumn	2000	4250	1100

These figures were obtained for each season by dividing the total distance flown in clear air over land, sea and coasts by the number of cases of turbulence occurring over each.

The total distance flown in clear air was 185,760 nautical miles. These figures indicate that clear-air turbulence was four times as frequent over the coast and

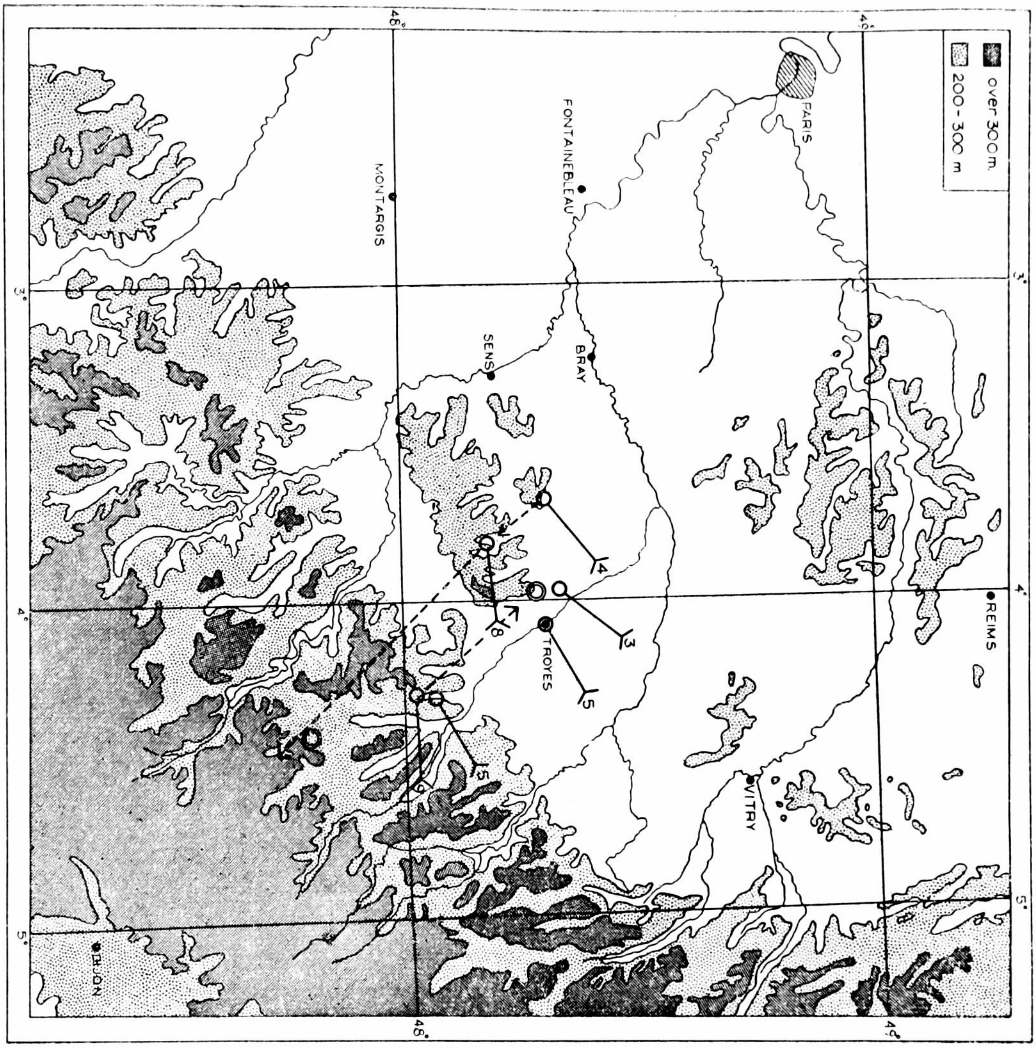

FIGURE 3—TOPOGRAPHY AROUND TROYES, FRANCE

more than twice as frequent over the land than it was over the sea; but in the summer the difference was less marked, and became negligible except over the coasts.

The position of turbulence in relation to surface fronts also seems to have a geographical variation. If a report were within 200 miles of a surface front, it was classed as near a front; and, if not, it was taken to be non-frontal. The results are given in Table II.

TABLE II—DISTRIBUTION OF TURBULENCE REPORTS

	Over land	Over sea	Over coasts
Total number of cases	56	22	18
Number of reports near cold fronts and rear of occlusions...	17	8	7
Number of reports near warm fronts and ahead of occlusions	1	8	0
Total number of reports near fronts	18	16	7
Percentage of reports near fronts	32	73	39

The reports near warm fronts were either on them or ahead of them, while they were equally divided on either side of cold fronts.

It is apparent that over land and coasts only a third of the cases of turbulence were associated with fronts. Over the sea, however, three quarters of the reports were connected with fronts and half of these were warm fronts. Over land areas the association with a warm front was very rare. This may be due to the weakening of warm fronts over Europe in the summer.

Interpretation.—The facts given above are interesting and perhaps important in their own right and are, of course, independent of the interpretation which follows.

The results show that the majority of reports of turbulence over the sea were associated with fronts, and the majority of reports over land were not. Turbulence was, moreover, much more frequent over the land than over the sea, allowance having been made for the greater distance flown over land. It is therefore not possible to explain the concentration of turbulence over land by increased frontal activity, and one is forced to relate the turbulence to the topography itself. It should be noted that turbulence due to convection was excluded from the investigation and that, in any case, clear-air turbulence is rare in unstable air. Hislop[1] found no cases, and a study of the tephigrams relating to the "upper bumps" investigation of 1952–54 showed that a vast majority (five to one) of clear-air turbulence cases occurred in stable air. Increasing instability over land could not therefore explain the increase in turbulence, but might rather account for the decrease in turbulence during the summer months.

There is not, of course, any difficulty in relating phenomena at high levels with topography. There is visible evidence of this to be seen in stationary high-level cloud phenomena such as mother of pearl clouds and the leading edges of billow cirrus clouds which may remain stationary over the low hills in the southern half of England.[2] It should be remembered that it is a perturbation which is transmitted upwards and not a pocket of air.

If turbulence is connected with topography, it may be related to standing waves. Both are usually associated with strong upper winds and stable air; both show a decrease in frequency in the summer; both have been reported in the same airstream near hills, sometimes above places close together.[3]

There appear to be at least three ways in which standing waves may be the primary step towards turbulent conditions.

(i) The intervention of an unstable layer near the middle of the troposphere. Two such occasions have been reported.

(ii) The air might not be sufficiently stable to maintain standing waves and incipient waves might break into turbulent flow.[3]

(iii) Wave effects from different hill ranges might combine to give turbulence.

In connexion with the second method it may be significant that the average surface pressure for the reports in this investigation is 1013 millibars, whereas the average pressure for standing waves in an investigation at Northolt was 1019 millibars. The higher figure for standing waves suggests that they may require on average a greater degree of stability than does turbulence. Pressure tendencies were, in the present investigation, found to be usually steady, but in the remaining cases rising pressures greatly exceeded falling ones.

The concentration of reports near the coasts suggests that turbulence is likely where the general level of the earth's surface is changing rapidly. This was mentioned by Radok[4] as the probable cause of a case of severe turbulence over a gap in the Australian Alps. Of course the coastline also provides a different type of surface as well as a different height and this may be important in causing turbulence.

The relative rarity of turbulence over the Atlantic as compared with the mountains of Europe was mentioned by Harrower in a Meteorological Office discussion[5] and is supported by Hislop's paper.[1]

Conclusion.—It may be well to re-state the main results of the experiment: that, from the spring to the autumn of 1956 on the principal air routes out of London, clear-air turbulence was more than twice as frequent over land, and four times as frequent over the coasts, as over the sea.

Acknowledgements.—I am very grateful to the pilots who supplied the data for this experiment. They are of B.E.A.C. unless it is stated otherwise in the following list.

Captains: P. E. Bressey, A. Caesar-Gordon, A. M. Carroll B.O.A.C., M. D. Deloford B.O.A.C., T. M. MacKenzie, D. Mason, T. Oakes, D. F. Redrup B.O.A.C., F. A. Tricklebank, C. E. Twite, W. J. Wakelin, A. N. Werner.

I am very grateful also to the administrative staff of the Meteorological Office, London Airport, who made the log books, and to Miss Janet Rolls for preparing the diagrams for this article.

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THE TEMPERATURE GRADIENT IN THE AIR ABOVE AN ICE SHEET

By R. A. HAMILTON, O.B.E., M.A.

The density gradient in the atmosphere refracts the ray of light from a beacon to a surveyor's theodolite and is one of the main causes of error in measuring altitudes. The meteorologist can turn the tables on Nature and use the surveyor's bête-noir by using this refraction as a means of measuring temperature gradients.

The determination of temperature gradients in the lower atmosphere by measuring the refractive index of air was proposed by Whipple and carried out by Johnson and Roberts[1] who concluded that the method was satisfactory. Brunt[2] pointed out that in this way it was not the temperature gradient but the gradient of optical density which was measured, and the water vapour could seriously affect the results. Brocks[3] has used the method extensively in temperate regions for determining temperature gradients both on mountain tops and on lower land.

The optical method is particularly suitable for measuring temperature gradients over the Greenland ice sheet for an extensive flat area is available and, due to the low water vapour content of the air, the errors due to vapour density gradients are negligibly small. Moreover measurement of temperature gradients by conventional thermometric methods is difficult as the diffuse reflection by the snow surface of the strong solar radiation makes it difficult to provide at the same time adequate screening and ventilation of the thermometers.

Two sets of measurements by this method of the temperature gradient approximately at screen level above the Greenland ice sheet were made by members of the British North Greenland Expedition 1952–54. Measurements were made incidentally in the course of the survey by a party which travelled right across the northern part of the ice sheet during the summers of 1953 and 1954, while I made special observations on fixed targets at "Northice" (78°N. 38°W., 2341 metres) during the summer of 1953. The targets were about 2 metres above the snow surface and were approximately 1, 2, 3 and 4 kilometres from the theodolite. The results of the survey party have been reported by Paterson[4] and the results of the "Northice" observations have been published in a paper[5] describing the experimental methods. The standard error of the measurements of temperature gradient was about $1\cdot5 \times 10^{-4}$ °C. per centimetre.

The two sets of observations are complementary in that the measurements of the survey party were made at different places during the warmer part of the day and are, therefore, suitable for studying the diurnal variation of the temperature gradient in the second half of the day, while the "Northice" observations were made at a fixed station near standard times and are thus more suitable for studying the variation of temperature gradient with the meteorological conditions. It is mainly these observations which are discussed below.

When the survey party's values of temperature gradient, dT/dz, are plotted against time a marked diurnal variation is apparent. This is illustrated not only by mean curves but by curves of each individual day, all of which tend to a certain shape though one day's curve may be displaced relative to another, showing that it was a day of relatively large temperature gradients. Discontinuities occurred in the daily curves, and there are a few abnormal shapes, but these are almost always associated with abnormal weather.

Paterson, treating the survey party's measurements as a whole, showed that the time of minimum dT/dz, was about $11\frac{1}{2}$ hours L.M.T. in 1953 and 11 hours L.M.T. in 1954. I have taken the readings made by the survey party during the same period as that in which the "Northice" observations were made, namely 13–21 June and 3–11 July, 1953, and having rejected a few abnormal readings and using the 1954 figures as a guide, have deduced the probable mean curve for the diurnal variation of dT/dz during normal fair weather. This mean curve is shown in Figure I, with all the "Northice" measurements made during the same periods. It will be seen that dT/dz falls quickly from a value of about 9×10^{-4} °C. per centimetre at 05 hours to a minimum of $(-1 \text{ to } -2) \times 10^{-4}$ °C. per centimetre at $10\frac{1}{2} \pm 1$ hours and then rises to a value of about 7×10^{-4} °C. per centimetre by 18 hours. The gradient is negative, that is, there is a lapse of temperature from about 08 to 13 hours L.M.T. during this midsummer period.

It can be seen that there is a considerable variation of dT/dz from the mean curve. The difference $\Delta\ dT/dz$ of each point from the mean curve has been taken, and the values of this, together with other meteorological data is given in

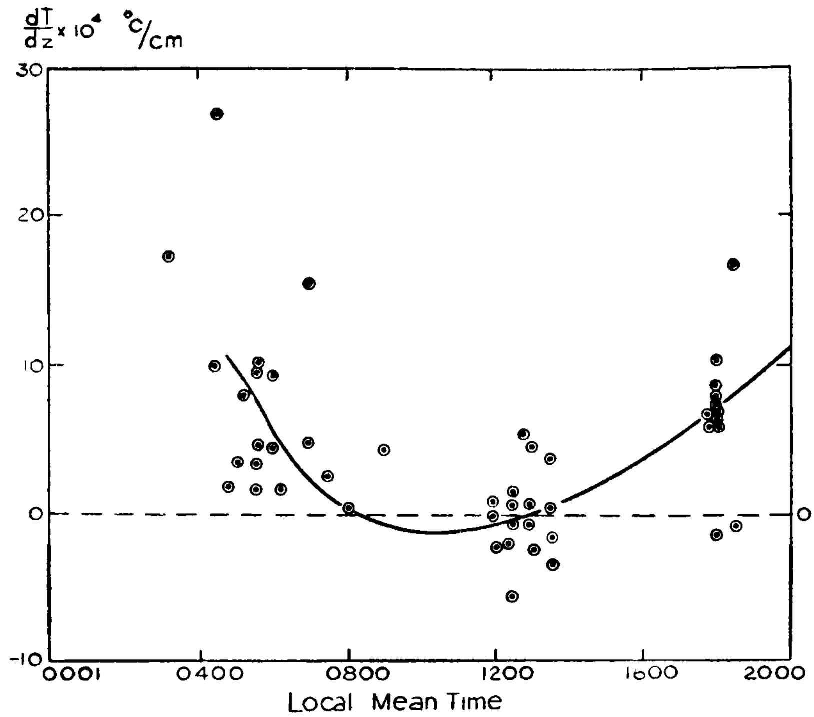

FIGURE 1—DIURNAL VARIATION OF TEMPERATURE GRADIENT ABOVE THE GREENLAND ICE SHEET 13–21 JUNE AND 3–11 JULY 1953

Table I. Values of $\Delta\, dT/dz$ before 05 hours are omitted owing to the uncertainty of the shape of the curve.

The temperature gradient may be expected to vary with the wind speed, but the correlation between $\Delta\, dT/dz$ and wind speed (which shows little diurnal variation) is only 0·1. The correlation coefficient between $\Delta\, dT/dz$ and T, the screen temperature, is −0·52 (significant at one per cent level, 23 pairs) for the evening observations around 18 hours, but only −0·23 for the midday observations, and + 0·20 for the morning observations.

Light snow was falling on seven occasions; on these occasions the mean value of $\Delta\, dT/dz$ was −4, indicating a temperature gradient below normal. There were not enough occasions of cloudy conditions without snowfall to determine the correlation between cloudiness and temperature gradient.

It will be seen from Column 4 of the Table I that there is a marked tendency for $\Delta\, dT/dz$ to adopt values which fluctuate round a mean which changes little over a period of days, for example, 8–11 June was a period of positive $\Delta\, dT/dz$, with a mean of about + 5. This was followed by a period 12–14 June when the mean value was 0, and, after a period of snowfall, fell to a mean value of about − 2 for the period 16–19 June. The 700-millibar charts show that during the period 8–10 June there was a south-westerly flow. A weak occlusion passed "Northice" during the night of the 10th–11th and by the 12th a southerly flow was established: an occlusion from the south passed on the 13th giving snow at "Northice". Thereafter the southerly type continued until the 18th.

A "wave" passed east of "Northice" during the morning of the 20th and with an easterly circulation at 700 millibars the surface wind fell to calm: a high value, + 13, of $\Delta dT/dz$ was measured during the calm period when the sky had

TABLE I—DATA FROM THE BRITISH NORTH GREENLAND EXPEDITION FOR JUNE AND JULY 1953

Ref. No.	L.M.T./ Date	$\frac{dT}{dz}$ 10^{-4} °C./cm.	⅃ $\frac{dT}{dz}$	T °A.	Weather	Wind deg./kt.	Shimmer code figure	700-mb. wind deg./kt.	Type of airflow, fronts
1	1200/8	3·5	4	264	bc	320/16	0	290/10	
2	0730/9	4·0	3	260	bc	270/18	0		
3	1330/9	9·9	9	261	b	240/15	0	260/28	
4	1330/10	15·1	8	261	bc	240/12			W.S.W.
5	0630/10	9·9	5	258	b	240/18	0		
6	1330/10	3·3	3	262	b	240/18	0	250/27	
7	1730/10	9·6	4	262	c	240/16	3		
8	0600/11	11·4	4	260	bc	240/12	5		Occlusion
9	1300/11	4·2	4	263	b	240/15	0	230/23	
10	1800/11	14·6	7	255	b	240/07	4		
11	0530/12	7·9	0	255	b	240/07	4		
12	1300/12	−1·6	−2	262	b	200/10	4	170/17	S. to S.E.
13	1800/12	10·4	3	262	b	200/04	2		
14	0600/13	9·2	2	257	bc	230/04			
15	1200/13	−0·3	1	264	os_0s_0	150/08		140/19	
16	1800/13	5·4	−2	264	os_0s_0	100/05			Occlusion
17	1230/14	0·2	1	262	os_0s_0	Calm	4		
18	0430/15	26·8		250	b	240/05	6		
19	1200/15	0·6	1	260	b	180/12	0	180/28	
20	1800/15	7·2	0	260	bks_0	210/20	0		S.
21	0600/16	4·4	−3	255	b	220/12	0		
22	1330/16	−1·8	−2	262	b	180/11	0	210/17	
23	0530/17	3·3	−5	253	bc	270/09			
24	0515/18	4·5	−5	252	b	260/15			
25	1245/18	−2·3	−2	259	bc	180/14	2	180/31	Warm front
26	1800/18	6·9	0	261	b	210/13	4		
27	0530/19	9·7	−1	250	b	240/15	2		
28	1330/19	3·5	3	266	b	220/08	0	210/15	S. to S.E.
29	1800/19	6·2	−1	265	bc	160/08	4		
30	0700/20	15·4	13	265	bc	Calm	4		Frontal activity
31	1330/20	−3·8	−4	267	b	210/07	0	200/10	
32	1800/20	8·3	1	265	b	220/10	5		
33	0730/21	2·4	1	262	b	230/17	2		
34	1300/21	4·3	4	266	bks_0	230/18	2	230/29	S.S.W.
35	1745/21	5·4	−1	265	b	220/13	5		
36	0445/22	1·9		264	cs_0s_0	190/05	0		
37	1230/22	−5·9	−6	267	os_0s_0	130/15		160/27	Warm front
38	1800/22	−1·7	−9	268	os_0s_0	150/13			
39	1530/29	−2·4	−5	268	b	Calm	0		
40	0500/30	2·2	−7	260	b	290/13	2		
41	1200/30	−0·9	−1	266	b	230/15	0	200/04	
42	0500/1	15·5	+6	260	b	260/15	6		
43	1330/1	−1·6	−2	265	b	270/15	2	230/10	
44	0500/2	3·6	−6	258	b	270/13	0		
45	1330/2	−4·2	−4	265	b	310/15	0	280/04	
46	1830/2	7·4	−1	265	b	290/11	4		
47	0430/3	9·9	0	259	b	300/13	3		
48	1330/3	−0·1		265	b	300/14	0	340/05	
49	1830/3	16·5	9	265	b	290/12	5		Anticyclonic period
50	0315/4	17·4		259	b	300/13	6		
51	0615/4	1·3	−5	260	b	300/13	4		
52	0930/4	4·1	−5	263	b	330/12	0		
53	1830/4	−1·2	−9	267	cis	Calm	4		
54	0800/5	0·3	0	266	c	300/10	0		
55	1230/5	−1·0	−1	268	bc	290/10	0	300/05	
56	1800/5	7·6	1	266	b	280/11	4		
57	0530/6	9·9	1	260	b	280/16	4		
58	1315/6	5·1	5	265	b	300/13	3	300/12	
59	1800/6	10·1	3	265	b	290/14	4		
60	1200/7	−2·8	−3	265	b	280/16	3	280/06	

TABLE I—(Continued)

Ref. No.	L.M.T./ Date	$\frac{dT}{dz}$ 10^{-4} °C./cm.	$\Delta \frac{dT}{dz}$	T °A.	Weather	Wind deg./kt.	Shimmer code figure	700-mb. wind deg./kt.	Type of airflow, fronts
61	1800/7	5·6	−1	265	b	280/13	3		Anticyclonic period
62	0515/8	7·9	−1	260	b	280/16	2		
63	1230/8	1·2	2	265	b	280/13	0	230/09	
64	1800/8	6·5	−1	265	b	270/10	4		
65	0700/9	4·8	3	260	b	270/02	0		
66	1300/9	0·2	0	265	b	250/11	2	220/12	
67	1730/9	6·2	0	265	b	260/12	4		
68	0500/10	3·3	−6	259	b	270/16	4		
69	0530/11	1·5	−7	261	c	290/12	2		S.W.
70	1200/11	−2·6	−2	265	bc	290/13	2	290/16	
71	0500/12	10·5	1	259	b	240/13	2		
72	1230/12	−1·4	−2	266	b	240/13	0	250/23	
73	1830/12	9·0	1	266	bc	260/11	3		
74	0600/13	−1·7	−9	264	c	220/12	2		Occlusion
75	1330/13	−1·6	−2	263	os_0s_0	300/20	3	280/12	
76	1830/13	4·3	−4	260	b	300/11	3		
77	0515/14	8·2	−1	255	bc	260/15	2		W.S.W.
78	1215/14	3·9	3	264	bc	230/15	2	260/22	
79	1830/14	10·1	2	264	bc	220/12	5		
80	0530/15	3·9	−5	258	bc	270/20	2		Polar low
81	1330/15	−1·0	−1	261	bc	280/14	3	280/28	

broken after the snowfall had ceased. On the 20th and 21st the airflow was south-westerly and $\Delta\ dT/dz$ fluctuated around zero: low values were measured during snowfall on the 22nd due to a warm front from the south-south-east.

During the anticyclonic period, 30 June to 11 July, the airflow at 700 millibars was light and variable and the values of $\Delta\ dT/dz$ fluctuated considerably about a zero mean. From midday 11 July a south-westerly flow was re-established with fine weather and steady zero values of $\Delta\ dT/dz$ were measured during the fine weather on the 11th, 12th and 14th, but from the 13th to 15th there was frontal activity with abnormally large amounts of cloud with some snowfall and values of $\Delta\ dT/dz$ were generally negative.

It is not possible to obtain a quantitative relation between the temperature gradient and the air mass, but the correlation between the westerly component of the 700-millibar wind measured near local noon and $\Delta\ dT/dz$ is 0·51 for 27 pairs, which is significant at the one per cent level. When the westerly component of the surface wind is considered the correlation coefficient is only 0·24.

These results indicate that the value of the departure of the temperature gradient from the mean value for the time of day depends mainly on the origin of the air mass and not appreciably on the screen temperature or wind speed. During snowfall and perhaps in cloudy conditions, the value of the temperature gradient tends to be below normal. The significant correlation between temperature gradient and screen temperature in the evening is probably due to a high correlation between this temperature (mean value 0·5 °C. less than the maximum temperature two hours earlier) and the origin of the air mass, though one would, in this case, have expected a higher correlation with the screen temperature at local noon (mean value 1·5 °C. less than the maximum temperature four hours later).

A note was made at the time of observation of the degree of shimmer of the image. To enable the shimmer conditions to be correlated with the temperature gradient, the degree of shimmer has been entered in Table I as a code figure varying from 0 = no shimmer to 6 = severe shimmer. The correlation coefficient between the shimmer code and the temperature gradient, for the 73 occasions on which the degree of shimmer was noted, is 0·56 which is highly significant. It appears that shimmering, which is presumably due to uneven temperature stratification of the air is the greater the more intense the inversion and is normally least for a temperature lapse or small temperature gradient.

It will be of interest, perhaps, to give an idea of the amount of refraction that a nearly horizontal ray can undergo. Using normal values of pressure and temperature the total refraction (which is proportional to the distance of the object viewed) is given by

$$\alpha = 0{\cdot}9\left(\frac{dT}{dz} + 3{\cdot}4\right) \text{ seconds per kilometre}$$

where dT/dz is measured in °C. per 100 metres, so the dry adiabatic lapse rate $\Gamma = -1$ and a positive value of α denotes a curvature concave towards the centre of the earth.

The equation shows that convex curvature of the ray occurs only for lapse rates exceeding $3{\cdot}4\Gamma$, and can be expected therefore to occur only near the surface under strong radiation conditions (for example, desert mirages). When dT/dz exceeds about 15 the curvature exceeds that of the earth (16·2 seconds per kilometre), and the further the object the higher does it appear in the sky. Inversions greater than this critical value seem to occur frequently on the inland ice for the horizon appears to rise in the sky and the poor traveller seems to live in the middle of a saucer with always an uphill climb ahead of him.

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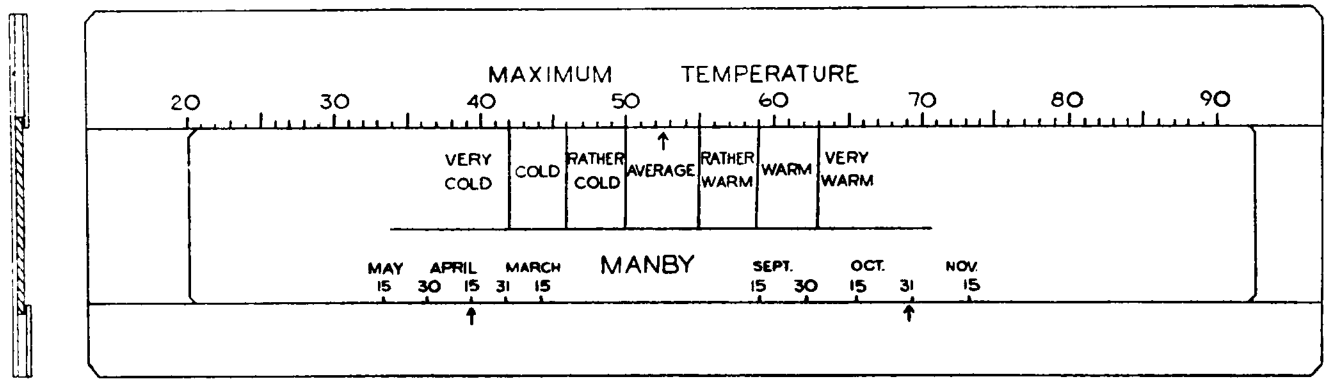
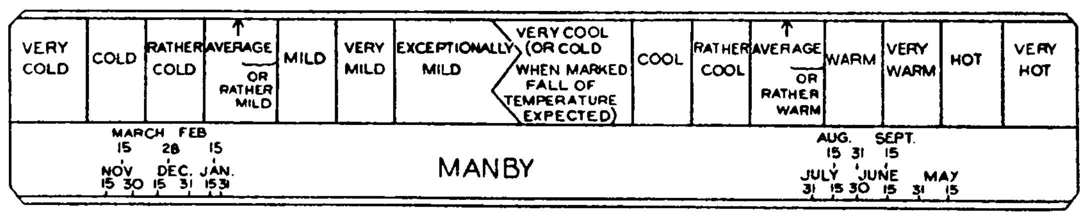
A DEVICE FOR RELATING DESCRIPTIVE TERMS TO AIR TEMPERATURES

By S. A. CASSWELL

Forecasts to the Press, etc., require descriptive terms to indicate the temperatures expected, for example, "rather cool" and "very warm".

For reasonable accuracy in finding the term equivalent to a particular temperature range, this entails reference to tables of average temperatures, interpolation for the date, and a reference to a further table of the terms used for the particular season. A "slide rule" type of device, as shown in the diagram, has been made to simplify this. It is displayed near the forecast bench with the date in line with the arrow. A glance at it will give the description for any desired temperature.





Reverse of slide

A SLIDE RULE RELATING DESCRIPTIVE TERMS TO PARTICULAR RANGES OF AIR TEMPERATURE.

Construction.—The slide is a single piece of thin card. The base is made of three layers of card glued together, the pieces of the middle layer being slightly thicker to allow the slide to move easily. Thin white plastic would be a better material.

The temperature scale is an arbitrary one, ten degrees Fahrenheit to one inch. The descriptions on the slide are in the ranges given in the *Meteorological Magazine*[1], measured from an arrow in the centre of the scale. Since the terms used have seasonal variations, three scales are required. The winter and summer scales can conveniently be on one side of the slide, and the scale for spring and autumn on the other.

The dates are entered by sliding the arrow onto the mean temperatures for the middle and end of each month, the dates being marked against an arrow suitably placed below the slide. The date scale is the only one that would differ between one station and another.

REFERENCE

1. London, Meteorological Office; Notes and news—terminology in temperature forecasts for the British Isles. *Met. Mag., London*, **86**, 1957, p. 311.

DIURNAL VARIATION OF STRATUS CLOUD AT PEMBROKE DOCK

By A. D. KRILL

The question of whether or not a sheet of stratus cloud in a moist airstream of maritime origin will break up during the day at a near-coastal station such as Pembroke Dock is a difficult one owing to the number of factors involved, and, usually, accurate information on the thickness of the cloud is lacking. In this note the diurnal variation of this type of cloud is examined and a suggestion made of a stability parameter to aid in deciding whether or not appreciable breaks may be expected during the day.

Days when the following conditions were satisfied between 0600 and 1800 G.M.T. were used in the investigation:

(i) Cloud at 1000 feet or below was reported in the early forenoon.
(ii) The surface wind direction remained between 180 and 270 degrees.
(iii) There was no fall of dew-point.
(iv) There was no rain (but cases of drizzle were admitted).

84 days fulfilling these conditions occurred between July 1952 (when local sea-surface temperature observations began) and December 1956; they have been classified as follows:

Class 1:	mainly overcast, 7 to 8 eighths	18
Class 2:	short-lived breaks not included in Class 3	20
Class 3:	breaking to 5 eighths or less for at least three hours, or remaining broken—5 eighths or less	46

The diurnal variation of amount and height of the stratus on these occasions is shown in Table I, which gives an indication of the significance of the differentiation. In Class 3 the occasions of 7 eighths or more decrease from 23 at 0600 G.M.T. to 6 at 1800 G.M.T. and occasions of 600 feet or less decrease from 21 to 5; 'nil' occasions increase from 4 to 20. In Classes 1 and 2 combined there is little tendency for change in amount or height during the day.

TABLE I—DIURNAL VARIATION OF AMOUNT AND HEIGHT OF STRATUS AT PEMBROKE DOCK ON 84 SELECTED OCCASIONS BETWEEN JULY 1952 AND DECEMBER 1956

Time G.M.T.	Cloud amount (eighths) 8	7	4 to 6	1 to 3	Nil	Cloud height (feet) Surface to 200	300 to 600	700 or higher
	number of occasions							
Classes 1 and 2 (38 occasions)								
0600	33	0	2	1	2	13	13	10
0900	31	4	2	0	1	19	13	5
1200	34	2	0	2	0	17	12	9
1500	27	5	6	0	0	7	23	8
1800	29	3	6	0	0	13	15	10
Class 3 (46 occasions)								
0600	21	2	12	7	4	9	12	21
0900	11	5	16	11	3	3	9	31
1200	5	6	8	18	9	1	6	30
1500	4	4	9	12	17	1	8	20
1800	4	2	14	6	20	0	5	21

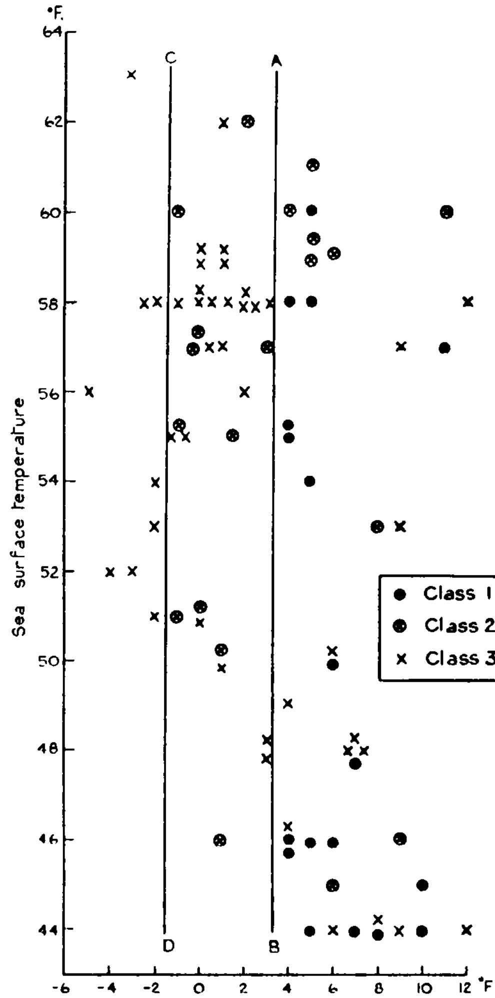


FIGURE 1—RELATION BETWEEN THE SEA-SURFACE TEMPERATURE AND THE DEPARTURE OF THE 900-MB. TEMPERATURE FROM THE VALUE AT 900 MB. OF THE SATURATED ADIABAT THROUGH THE SEA TEMPERATURE

The abcissa is the departure of the 900-millibar temperature from the value at 900 millibars of the saturated adiabat through the sea-surface temperature.

Class 1: mainly overcast 7 to 8 eighths; Class 2: short-lived breaks; Class 3: breaking to 5 eighths or less for at least three hours or remaining broken, 5 eighths or less.

A cross, Class 3, should be included at (60°F., −6°F.)

In an effort to find a critical environment curve separating the classes use has been made of the local sea-surface temperature reported by the St. Govan lightship and the 900-millibar temperature from the most representative upper air ascent—900 millibars being regarded as an average limit to the top of the stratus. In Figure 1 a symbol for each occasion has been plotted against the sea-surface temperature as ordinate, and as abscissa the departure of the 900-millibar temperature from the value at 900 millibars of the saturated adiabat through the sea-surface temperature.

In Figure 1 the lines AB and CD divide the entries as follows:

	Left of CD	Between CD and AB	Right of AB
Class 1	0	0	18
Class 2	0	11	9
Class 3	10	23	13

It seems probable that at least some of the Class 3 cases to the right of AB were occasions when the stratus top was below 900 millibars and the separation would be improved if the actual levels of cloud top could be used instead of the arbitrary 900 millibars. Nevertheless Figure 1 shows the significance of the stability parameter used. A similar diagram for other coastal stations should indicate a critical curve useful for short-term forecasting. It may be worth noting that attempts to relate the behaviour of the stratus to the wind speed and to maximum temperatures were fruitless.

The writer wishes to thank Mr. W. E. Saunders for advice and criticism.

WATERSPOUT AT NASSAU, BAHAMAS, 12 APRIL 1957

By A. BEYNON, B.Sc.

Although waterspouts occur with reasonable frequency from April to August in the Bahamas, the phenomenon which occurred on 12 April 1957 caused considerable local interest since it was the first waterspout within living memory to strike the City of Nassau itself.

It was fortunate that, although there were no Meteorological Office staff on the spot, the formation of the spout was seen from the Meteorological Office at

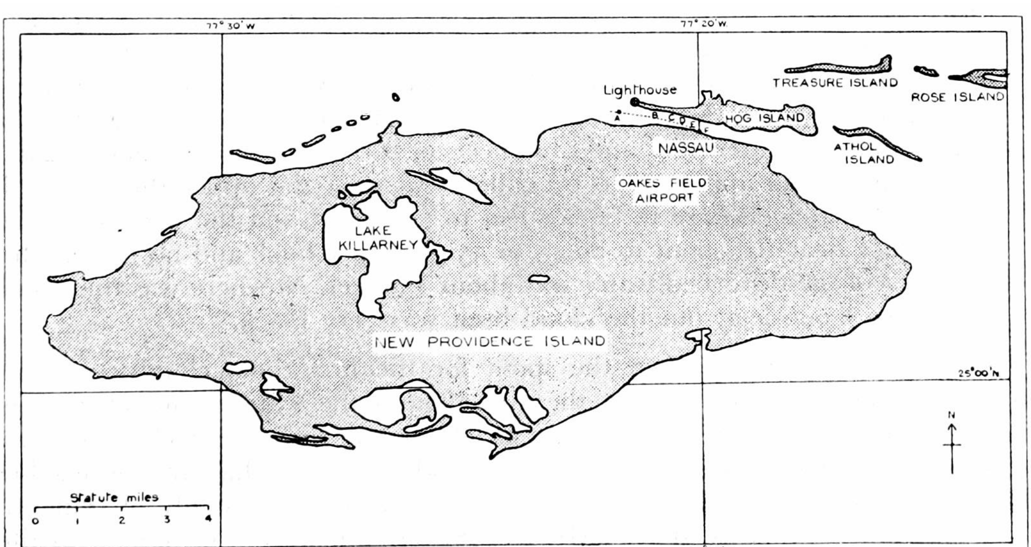


FIGURE 1—NEW PROVIDENCE ISLAND

The broken line represents the track of the waterspout on 12 April 1957.

Oakes Field about 2 miles away and a series of photographs obtained by a photographer of the *Nassau Daily Tribune.* The photographs have been kindly supplied by this Newspaper for publication (see Plates I-III). Figure 1 shows a sketch map of New Providence Island and adjacent cays and the track of the waterspout from the time of formation to its dissipation over land. Figure 2 gives its track in greater detail.

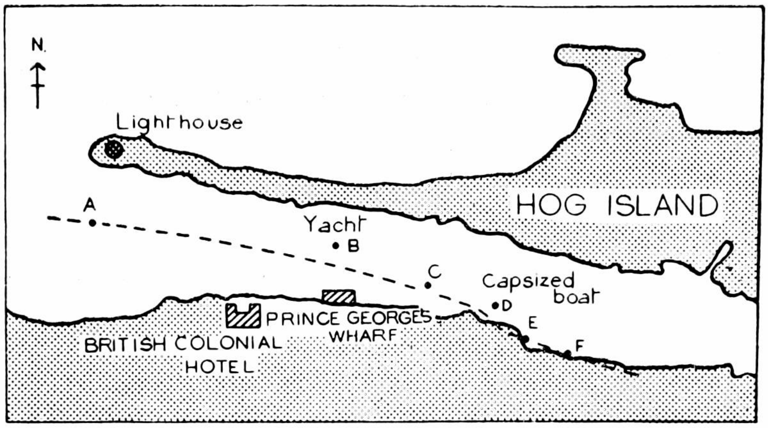


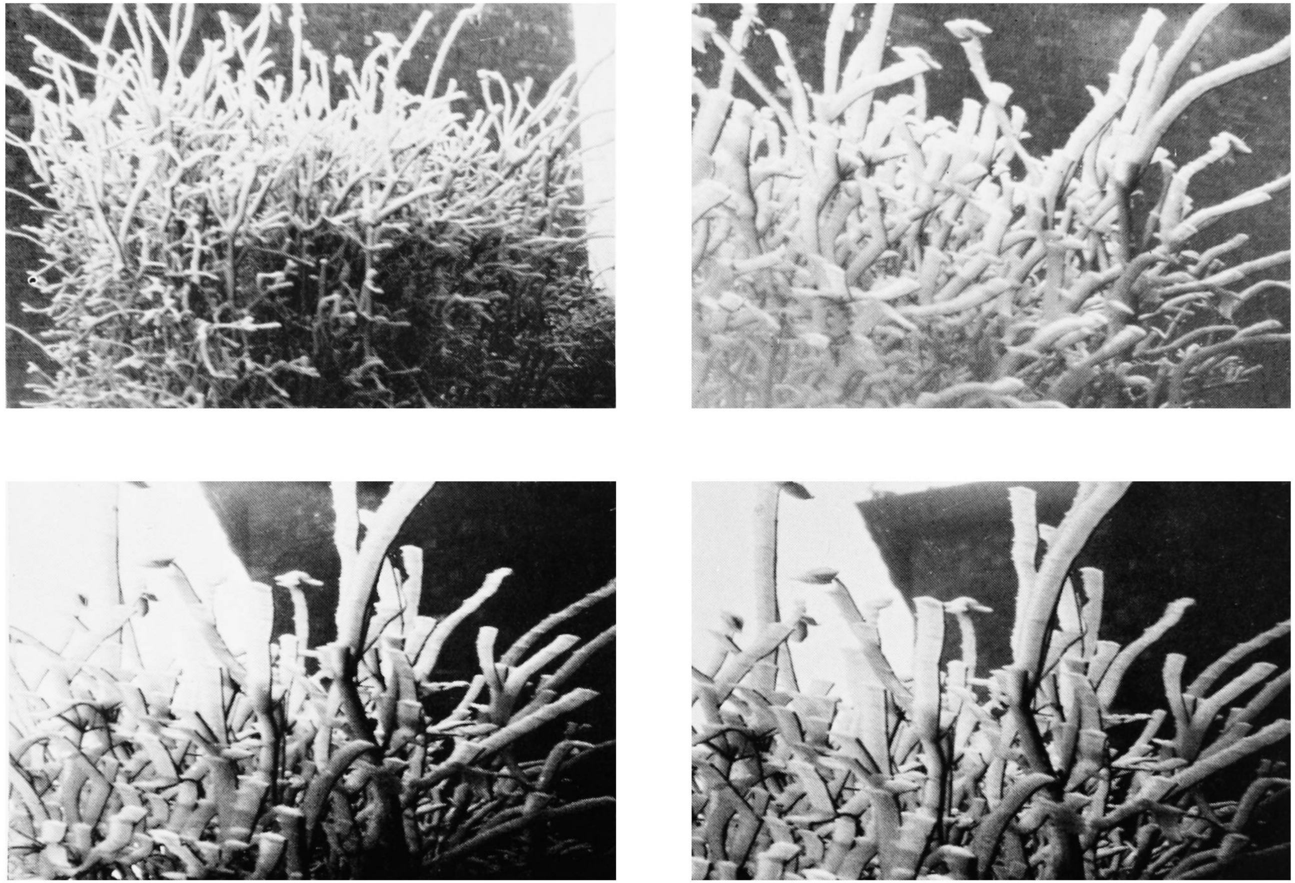
FIGURE 2—TRACK OF THE WATERSPOUT AT NASSAU, BAHAMAS, ON 12 APRIL 1957

The spout first formed at 1800 G.M.T. on 12 April, at A in Figure 2. It was observed by Captain Farrington of Bahamas Airways who was approaching the spout from the east in a Heron aircraft. He circled the spout until it dissipated and on interrogation commented as follows:

"The waterspout first appeared near the harbour's entrance at A in Figure 2 and the water beneath the spout began churning and frothing. The spout then moved up the harbour passing between Prince George's Wharf and a yacht anchored at B. It then moved towards the city and passed near Murphy's Wharf where it tore a mailboat from its moorings (C). It then moved towards Deveaux Street and capsized a fishing boat (D) before striking Mr. Don Seiler's house (E). It then moved toward Symonette's Shipyard (F) where the spout section dispersed. I flew at about 600 to 800 feet around the waterspout and saw sheets of corrugated iron at that height. The funnel cloud appeared to be hollow—at least the upper third of it. I estimated the cloud base to be 800 feet to 1,200 feet and the wind speed at the surface near the spout to be 45 to 55 miles per hour and no more. The diameter of the disturbed water was about 150 feet. Nowhere was the cloud top above 8,000 feet, but the cloud itself was very black."

As the aircraft approached the spout for the first time, cloud-to-ground lightning was observed between the aircraft and the waterspout. There was very little rain although very large drops fell for a few minutes well to the east of the funnel cloud. Observers on the ground all report that an appreciable amount of debris was carried up in the storm consisting mainly of shingles, boarding and corrugated sheets. Mr. Don Seiler, who was in his lounge at the time of the incident reported that the veranda of his house facing the waterfront appeared to have been sucked outwards into the harbour.

[To face p. 48



Photographs by D. W. Leeson

RIME ICE AT LITTLE HALE, NEAR SLEAFORD

(see p. 57)

Photograph reproduced by kind permission of The Nassau Daily Tribune

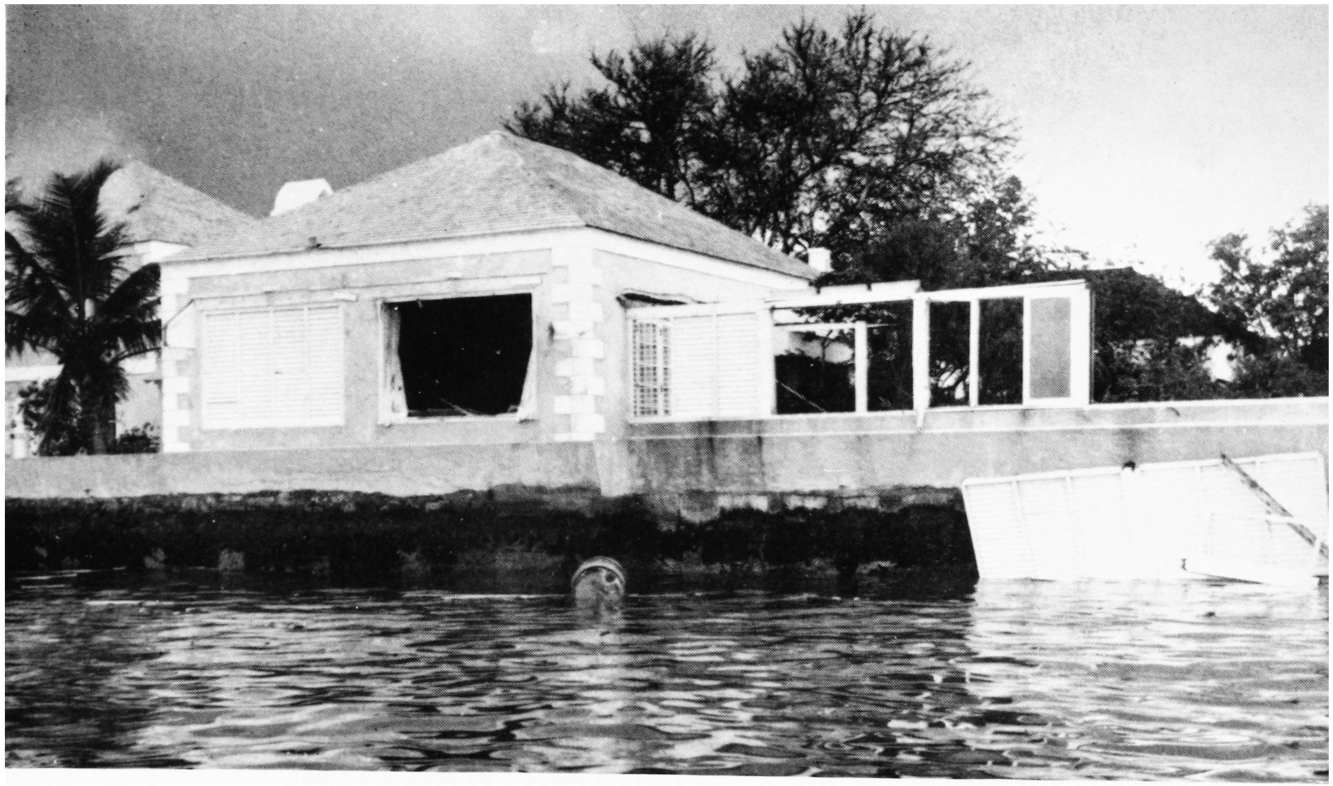
PLATE I—WATERSPOUT AT NASSAU, BAHAMAS, 12 APRIL 1957

(see p. 47)

Photograph reproduced by kind permission of The Nassau Daily Tribune

PLATE II—BASE OF WATERSPOUT AT NASSAU, BAHAMAS, 12 APRIL 1957

(see p. 47)



Photograph reproduced by kind permission of The Nassau Daily Tribune

PLATE III—DAMAGE CAUSED BY WATERSPOUT TO MR. D. SEILER'S HOUSE IN NASSAU, BAHAMAS, 12 APRIL 1957

(see p. 47)

The only raob ascents available were for Coffin Hill, Eleuthera (25° 16'N., 76° 18'W.), some 75 miles to the east of Nassau, at 0300 G.M.T. and 1500 G.M.T. on 12 and 13 April. Pilot-balloon ascents for Coffin Hill at 0300 G.M.T. and 1500 G.M.T. on the 12th and at 1500 G.M.T. on the 12th for Oakes Field, Nassau, are given in Table I.

TABLE I—UPPER WINDS FOR ELEUTHERA AND OAKES FIELD AIRPORT ON 12 APRIL 1957

	Coffin Hill, Eleuthera				Oakes Field Airport, Nassau	
Height	0300 G.M.T.		1500 G.M.T.		1500 G.M.T.	
feet	degrees	knots	degrees	knots	degrees	knots
1,000	140	19	160	13	200	13
2,000	150	23	190	15	200	19
3,000	150	23	210	19	230	22
4,000	150	20	240	14	250	16
5,000	170	17	260	14	280	19
6,000	170	17	250	20	260	20
7,000	170	19	240	23	260	18
8,000	180	17	240	20	270	22
9,000	190	17	240	32	270	26
10,000	190	15	250	35	270	26
12,000	240	17	250	41	250	22

The cloud on the forenoon of the 12th was mixed cumulus and stratocumulus. There appeared to be some stratification at the 800-millibar level and in this connexion it is interesting to note that the 0300 G.M.T. ascent at Eleuthera for the 12th shows a marked hydrolapse between 850 and 800 millibars. A large towering cumulus top about 8,000 feet was noticed over the western part of the island at 1730 G.M.T. This appeared to move over to Hog Island during the following hour. Surface winds were southerly about 10 knots during the morning but between 1800 and 1900 G.M.T. swung to north-westerly at about 6 to 8 knots. It is suggested that this was probably the "sea-breeze" effect which might well have had some bearing on the subsequent development of the cloud. The waterspout itself occurred on the western extremity of what was now a line of cumulus with tops 6,000–8,000 feet and base of about 1,000 feet. While the funnel cloud developed downwards, a hollow core was clearly visible at least 2 miles away from the phenomenon. This hollow core subsequently disappeared, most probably lost in the slowly rotating mist which then surrounded the spout.

A point worth noting, perhaps, is the change in the upper winds between the Eleuthera (Coffin Hill) 0300 G.M.T. ascent on the 12th and the 1500 G.M.T. upper wind on the 12th for Eleuthera and Oakes Field. At 0300 G.M.T. the south-westerlies do not set in below 12,000 feet, but they are apparent both at Eleuthera and Oakes Field above 4,000 feet at 1500 G.M.T. There is a 90-degree wind veer in the first 6,000 feet at Eleuthera at 1500 G.M.T. and a 60-degree wind veer in the first 6,000 feet at Oakes Field.

The facts seem to support a tentative theory based on observations that waterspouts only form if there is a marked veer of wind with height in the first 6,000–8,000 feet and that stratification occurs in the cloud about two-thirds of the way up from the base, the cloud itself not being particularly thick.

METEOROLOGICAL OFFICE DISCUSSION

Clear-air turbulence

The Meteorological Office discussion at the Royal Society of Arts on Monday, 20 October 1958 was on the subject of "Clear-air turbulence" and was opened by Messrs. J. K. Bannon and H. S. Turner.

Mr. Bannon, who restricted his remarks to turbulence occurring at heights above 20,000 feet, traced the subject from the late days of the Second World War, when the existence of this phenomenon was first discovered, to the present day, describing the results of various investigations in this country and in North America.

Data became available from a number of sources. A series of experimental flights was made from the Royal Aircraft Establishment from 1946 to 1948; in these an aircraft made regular ascents to 40,000 feet, any turbulence encountered above 20,000 feet being recorded on an accelerometer.[1] These observations were considered free from any bias towards particular weather types. British European Airways, under contract to the Ministry of Supply, made an important series of flights from 1948 to 1950 over several standard European air routes to investigate turbulence. The layer 20,000–37,000 feet was explored and bumps recorded on accelerometers.[2] Pilots of the Royal Air Force made many qualitative observations of turbulence. The Meteorological Research Flight has also made many observations of the phenomenon, both qualitative and quantitative. In Canada, Clodman[3] analyzed qualitative observations of turbulence by Royal Canadian Air Force personnel. In the United States of America, Clem[4] discussed the results of a special series of flights to investigate turbulence in jet streams and Anderson[5] analyzed the observations made by gust-sondes at four stations for more than a year. The gust-sonde consists of an accelerometer which is released automatically from a free balloon at a great height (usually about 70,000 feet) and descends on a parachute, transmitting any accelerations experienced to a ground receiving station. From these observations and investigations a general picture of this turbulence and its associated weather has been built up.

Mr. Bannon then gave a brief description of the phenomenon and showed a few statistics relevant to it, taken from different papers.[1,2,5] Its effect on an aircraft is sometimes similar to the irregular bumps experienced in convection currents near the ground but at other times it has a characteristic sharp regularity, which some pilots have likened to riding over rough cobble-stones in a car. The suddenness and unexpectedness of this turbulence are two of its most disturbing features, especially to passenger transport. It is usually much less severe than the turbulence in cumulonimbus clouds. Clear-air turbulence has a maximum frequency of occurrence at a level in the upper troposphere near 30,000 feet; it is often found in the region of the tropopause. Severe clear-air turbulence has been reported as high as 55,000 feet over the British Isles. Turbulent layers are usually quite shallow, though on occasions they can be 10,000 feet or so thick.

Turbulence at high altitude is very often associated with strong shear of wind in the vertical but not with any particular lapse rate. It is associated with small values of the Richardson number and also to a lesser extent with strong horizontal shear of the wind. The neighbourhood of the jet stream is, therefore, the most favourable weather region for the occurrence of this turbulence and it has been found[6,7] that the regions to the left of the jet, looking downwind, and to the right of the jet and above the level of the axis are the most turbulent parts. Travelling along a jet stream the most turbulent region is where the stream is strongest.[4] Several examples of turbulent jet streams were shown. It was emphasized, however, that many flights across or in jet streams do not encounter turbulence.

High-altitude turbulence is probably encountered over mountains more often than over the sea or level country and there is the suggestion[8] that conditions favourable for standing waves at low or high altitudes also produce turbulence at high altitude. These points were elaborated by Mr. Turner.

From its association with strong wind shears it is possible to get some idea of the regions of the world which may be liable to clear-air turbulence. The subtropical jet stream has been found to be turbulent over the Middle East and over Australia, and turbulence has also been experienced near the strong easterly winds which blow above 40,000 feet in the northern summer, south of Asia. Similar regions of strong shear may also be expected to be liable to turbulence.

Mr. Bannon gave his opinion that this clear-air turbulence, which is nearly always a patchy, spasmodic phenomenon, occurs in the local breaking down of an instability in the flow (not necessarily a convective instability in the usually accepted sense), which has been gradually built up by ordinary dynamic means. He also pointed to the need for further work on the fine structure of the gusts in the turbulence as aircraft engineers are worried about possible resonance effects on modern aircraft from turbulence having a regular pattern or periodicity. More information is also required on the "climatology" of this turbulence—in which parts of the world it is most frequent or severe—and on its meteorological causes or associations.

Mr. Turner spoke of experience and problems at outstations. He hoped forecasters from other stations would speak later, as his remarks were confined to experience at London Airport. The presence of jet streams or marked wind shear which fell short of jet limits were the principal factors used in forecasting clear-air turbulence. A considerable minority of forecasters used the passage of air over hills as a factor and Mr. Turner discussed this at some length. This matter is described in an article "The geographical distribution of clear-air turbulence" on p. 33.

Mr. A. E. Parker advanced some physical arguments for the suggestion that spontaneous turbulence occurs in a layer of the atmosphere if

$$\frac{U\partial^2 U}{\partial z^2} > \frac{g}{\theta}\frac{\partial\theta}{\partial z}, \qquad \ldots\ldots (T)$$

in which U is the horizontal wind at a height z and θ is the potential temperature. It follows from (T) above, that turbulence is likely where the velocity–height profile has a large positive curvature, as at a suitable discontinuity in the velocity–height profile. Jet streams are also likely places for turbulence since U is large but not all jet streams are turbulent since in some cases $\partial^2 U/\partial z^2$ may be negative. Furthermore, if the criterion (T) is satisfied in a layer in the upper troposphere and conditions are suitable for standing waves below this level, then when the upper layer is given a finite perturbation by the standing waves, severe turbulence could result. It should be emphasized that the criterion (T) will not indicate turbulence produced by horizontal shears.

What is the mechanism which causes large values of $\partial U/\partial z$ (as in Richardson's criterion) and $\partial^2 U/\partial z^2$ to occur? Mr. Parker suggested that this is brought about by development. For example, if the air at 200 millibars has a horizontal velocity of 30 knots and no vertical velocity, while the air at, say, 250 millibars has a horizontal velocity of 50 knots and a vertical velocity of, say, 20 centimetres per second then it is clear that vertical wind shear in the layer 250–200 millibars is increasing and so is the value of $\partial^2 U/\partial z^2$. This process will continue until the flow breaks down into a turbulent flow. A similar effect can occur at other levels in the atmosphere but is probably most frequent in the upper levels of the troposphere. A rough calculation showed that the process could double an existing shear in from 5 to 6 hours. However, a complete investigation of the process is complicated as horizontal motions have to be taken into consideration.

To conclude his remarks, Mr. Parker showed six slides to illustrate the application of criterion (T) to some actual cases of clear-air turbulence in the atmosphere and the agreement between the heights of the turbulent layers as given by his criterion and pilots' reports was striking.

Mr. Wallington said that wave motion in the upper air, set off by hills or mountains, could provide a mechanism for maintaining strong shears. For example, with waves whose amplitude decreased with height, stronger shears would be found at the crests of the waves. In another type of wave motion the stronger shear might be at the bottom of the troughs. He pointed out that though the air was usually very smooth in wave motion, sailplane pilots had often encountered turbulence at the top of a soaring ascent in such waves.

Mr. Oddie said that it was not correct to say, when an aircraft was flying obliquely, that it passed through layers of turbulence. All that could be said was that it passed through turbulence at certain points. Mr. Bannon agreed, but said that investigating aircraft sometimes avoided this difficulty by ascending in spirals. Mr. Oddie asked Mr. Turner to comment on the large number of turbulence reports near Troyes and the small number over the Alps. He also wanted to know if the positions of turbulence reported by Mr. Turner could not be explained by the synoptic situation prevailing. Mr. Turner did not think that the effect of hills was proportional to their height. The Alps would sometimes act as a complete barrier to the airflow. He thought that turbulence near coasts was too often and too widely reported to allow of a synoptic explanation.

Mr. Marshall described an unpleasant experience of turbulence at 21,000 feet over the southern North Sea in anticyclonic weather when he had been thrown to the floor by a sudden gust. Radio-sonde observations from Downham Market indicated that there was strong shear in the vertical at that height.

Mr. Willis gave an example of turbulence which could not be detected again in the same place about a minute after it was first experienced. He also described turbulence experienced in a Comet aircraft as a sudden jolt, as if the aircraft had hit something, rather than the usual up or down "bump".

Mr. Crossley asked if there were any possibility of investigating clear-air turbulence by radio-sonde, or if the scale of the phenomenon was too small.

Dr. Scrase, replying to Mr. Crossley, said that the scale was probably too small but that observations with the new radio theodolite might throw some light on the matter.

Mr. Borrett commented on the temporary nature of the phenomenon by describing a patch of turbulence to the east of the Isle of Wight, roughly the size of the island, which persisted all one morning but was not traceable in the afternoon.

Mr. Ogden queried Mr. Bannon's statement that shear in the horizontal was not an important factor. Certainly there were relatively few reports from aircraft flying on top of a jet stream. Reports were more frequently received from aircraft flying alongside the maximum flow. These reports indicated, in his experience, that clear-air turbulence was related to horizontal shear. Mr. Bannon replied that turbulence appeared to be related both to shear in the vertical and in the horizontal.

Mr. Sawyer said that in seeking an explanation of this phenomenon it would be necessary to consider developments at other levels as well as those at which the turbulence occurred.

The *Director-General* said that, during the few years that the phenomenon had been known, good progress had been made in investigating it. He became more and more inclined to the view that fluids do not flow in a straight line unless they are made to.

In reply to a question from the Director-General, Mr. Bannon said that turbulent patches were often only a mile or two across but could be as large as 50 or 100 miles. The Director-General also asked if there existed a good instrumental record of "cobble-stones" turbulence.

Mr. Helliwell said that the Meteorological Research Flight had obtained several records but these had not yet been fully analyzed. The technique employed in looking for turbulence was to fly round the sides of a square; sometimes turbulence would be found on one or more sides but not on all and, on returning to what had been a bumpy area within a few minutes, the turbulence would have ceased.

Mr. Gold said that he would expect that the region of mackerel clouds would be turbulent and suggested that a study of these clouds might be profitable. Mr. Bannon replied that upper cloud was sometimes associated with turbulence, sometimes not. There was one case on record where an aircraft had experienced turbulence near the tops of high cloud which could be seen to form in regular bands and then appear to curl up like waves breaking.

Dr. Stagg said that the information in *Professional Notes* No. 104[1] and in an article in the *Meteorological Magazine*[6] had been the basis of knowledge on the subject for several years. It appeared from the discussion that topography and wave motion of the air were also important and he thought that the practising forecaster, after hearing this discussion, would want further guidance as to the emphasis to be placed on these newer ideas and the best methods of forecasting the occurrence of high-altitude turbulence.

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LETTERS TO THE EDITOR

Low humidity in the Cairngorms, 2 April 1958

R. C. Smith's article, on pp. 35–39 of the *Meteorological Magazine* for February 1958, refers to the low humidity (approximately 8 per cent) recorded at Achnagoichan, in the Cairngorms Nature Reserve, in June 1956. It may be worth putting on record that a hygrograph, at about 1,600 feet O.D. (above Ordinance Datum), in Glen Derry, on the Aberdeenshire side of the same Reserve, recorded 14 per cent relative humidity, at about 1500 G.M.T. on 2 April 1958. At Achnagoichan (circa 1,000 feet O.D.), the relative humidity appears to have fallen to 20 per cent during the same day, but unfortunately the pen trace on the graph is indistinct at the critical period, so that one can be certain only that it fell below 40 per cent. Neither instrument had been tested as recently as had the Achnagoichan instrument on the June 1956 occasion, but it is unlikely that the errors were much greater than can usually be expected with a hair hygrograph.

The screen temperature rise in Glen Derry on 2 April was from 32°F. to 66°F. The temperature was nearly at its maximum at the time of the Leuchars radio-sonde ascent, which gave dry-bulb temperatures of 30°F. and 34°F., at 975 and 954 millibars (1272 and 1829 feet) respectively, and dew-points of 14°F. at both of these heights. Saturation at the temperature there, corresponding with the height of the Glen Derry hygrograph, would therefore have given a relative humidity of 16 per cent if the temperature had risen to 60°F. At Achnagoichan the temperature rise was only from 27°F. to 50°F.; saturation at 27°F. would have given a relative humidity of 42 per cent at 50°F.

Perhaps the most striking feature of these observations is the great difference between the temperatures at the stations and in the free air. There was at the time a wedge over Scotland extending from an anticyclone over Russia, and the wind was a light south-easterly.

F. H. W. GREEN
The Nature Conservancy, 19 *Belgrave Square, London.*

Forecasting precipitation

As I read with interest the report in your June issue[1] on the Meteorological Office Discussion of 18 February last on "Forecasting precipitation" two points occurred to me which I believe are germane to the subject.

Mr. Wallington dwelt on the part played by instability in warm front precipitation. No reference was, however, made to thunder on the warm front, which is probably very rare, if not entirely unknown, in the United Kingdom. Thunder on the warm front is common in North America. It is supposed that the warm air masses are so sufficiently unstable that ascent over the cold air can lead to the local development of cumulonimbus within the altostratus. The effect occurs in maritime polar as well as in maritime tropical air. In my recollection thunder on the warm front was also experienced in the Persian Gulf.

Again, I think that it will be agreed that during the Second World War, when reports from mass traverses of fronts were available, variations of cloud structure in time and distance were frequently noted, especially in connection with cold fronts. These were attributed to the passage of minor waves along the front.

The figures you publish give experimental support to surmise.

485 *Victoria Avenue, Westmount, Quebec.* J. L. GALLOWAY

REFERENCE

1. London, Meteorological Office; Meteorological Office discussion.—Forecasting precipitation. *Met. Mag., London,* **87,** 1958, p. 179.

Rainbow; Port-of-Spain, Trinidad

An interesting rainbow was observed by Mr. K. V. W. Nicholls and me in Port-of-Spain at 1830 Trinidad Standard Time on 30 June 1958.

There were a number of cumulonimbus clouds around and there were several showers, mainly in the N.E. quadrant of the sky; the sunset was a particularly brilliant one giving a bright bronze-yellow light on the clouds and rain. There was a very bright primary rainbow, with a fairly bright secondary above. Some 10° south from the zenith along the primary bow, near the edge of the rain falling from the cloud to the east, there was a section where the colours of the rainbow were repeated four times inwards from the main bow, the colours being in the same order in each case, i.e. violet to red outwards. The section was triangular in shape, some 2° wide on the main bow, and it narrowed inwards as did also the width of each band of colour.

The sun had set at 1819 and was thus about 3° below the horizon at 1830.

Port-of-Spain, Trinidad W. A. GRINSTED

[The triangular shaped section probably contained a clear set of supernumerary (diffraction) bows. Supernumerary bows occur inside the primary bow and outside the secondary bow and follow the colour sequence of the bow with which they are associated. Their clarity increases rapidly with drop size so that it seems probable that in the direction referred to there was a region of rain of large drops, of diameter certainly over 1 mm., of a size not present elsewhere. Ed. *M.M.*]

An exceptionally sunny and unusually warm and dry February in Athens, Greece

February 1958 has been the most sunny February in Athens within the 65-year period of observation (1894–1958) with a 220·1 hours' duration of bright sunshine. This value is greatly (77·9 hours) above normal with a 73 percentage of possible. A search of the sunshine records dating back to 1894 shows that this exceptional February figure is the only one within the three winter months (Dec. Jan. Feb.). Only one November and 9 per cent of the months of March have exceeded this value of 220·1 hours. It must be taken into consideration that February is the shortest month and that there was a February (1895) with only 62·3 hours of duration of bright sunshine.

As the data of the last century (1858–1958) indicate, the highest and lowest February temperatures (mean of daily maximum and minimum) were in Athens 13·38°C. (1955) and 5·01°C. (1858) respectively with a normal value of 9·70°C. February 1958 takes the fourth place in the series of warm February months with an average temperature of 12·54°C, which value very closely approaches the values of two of the three warmer months of February. This 12·54 figure exceeded the temperatures of all the 101 January months except three, and also 85 per cent of the months of December.

The February 1958 rainfall totalled only 7·5 millimetres, about one fifth of the normal (40·1 millimetres), making it the sixth driest February since records were commenced in 1858. This figure must be compared with the Athens lowest 1·3 millimetres in 1861 and the highest February rainfall 127·6 millimetres in 1930. The rainy days (three), including traces, of this February comprised one quarter of the normal value (twelve), a number which is the same as for the previous February and the lowest of the records. The highest number of rainfall days was twenty, a number which occurred three times in the 101-year period under consideration.

Finally, the predominating synoptic situation over Greece in this month was rather unusual. The Greek peninsula was mostly under the influence of high pressures due to anticyclonic extensions or to secondary highs of the eastern Mediterranean. The few depressions passed to the north of Greece.

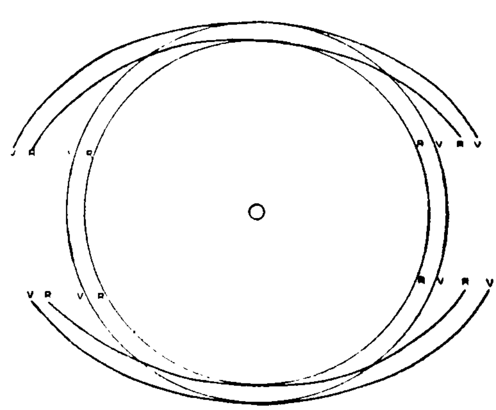
Athens, Greece PHOTIOS P. KARAPIPERIS

NOTES AND NEWS

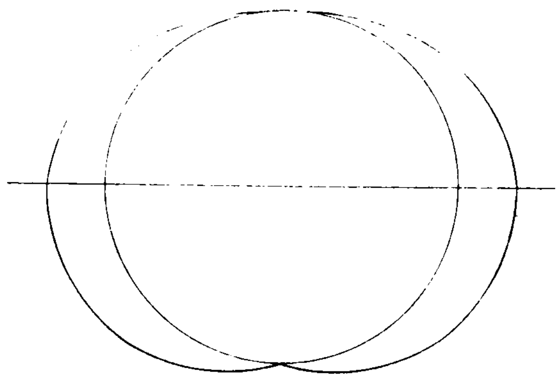
Circumscribed halo

Mr. A. R. Belton of the Meteorological Office saw the very rare circumscribed halo from Empingham, Rutland, at 1500 G.M.T. on 26 May 1958. He writes:

The 22° halo, although the colours were visible, was not particularly bright, but the elliptical halo was extremely bright and all the colours were as distinguishable as in a rainbow. The morning had been cloudy with 8/8 medium cloud altocumulus/altostratus but around mid-day this cloud began to disperse and cumulus cloud began to form. At the time of observation of the phenomena there was 7/8 cirrostratus and about 3/8 large cumulus but fortunately the cumulus cloud did not obscure the halo.



CIRCUMSCRIBED HALO—1500 G.M.T. 26 MAY 1958



COMPUTED HALO FOR ELEVATION OF THE SUN OF 45°

[The elevation of the sun at the time of Mr. Belton's observation was 43°, and the computed figure of the halo for an elevation of 45° copied from Pernter and Exner, *Meteorologische Optik*, p. 391 is given after Mr. Belton's sketch.

Ed. *M.M.*]

Rime ice photographs

The photographs facing p. 48 were taken at Little Hale (near Sleaford) at 1030 G.M.T. on December 20, 1956. There had been dense fog, visibility not exceeding 100 yards, for almost 36 hours. The wind was southerly, mainly light, but had reached 15 to 20 knots for a time.

The air temperature at Cranwell fell rapidly on the morning of the 19th, being 36°F. at 0635 G.M.T. and 24°F. by 0815 G.M.T. Thereafter the temperature ranged between 24° and 30°F. during the period of persistent fog. The rime was mainly 1½ to 2 inches thick.

W. N. BURTON

Pakistan Meteorological Service

The Director of the Pakistan Meteorological Service has recently published a report on the administration and development of meteorology and geophysics in Pakistan up to 31 March 1956[1].

The Pakistan Department of Meteorology and Geophysics was formed on 15 August 1947 when Pakistan became independent. The Department was developed under great difficulties because all the central technical organizations, laboratories, libraries and geophysical observations of the former Indian Meteorological Department were situated at places in the new India. Regional meteorological offices existed at Karachi and Lahore but there was none in East Pakistan before the Day of Independence. One was established on that day at Chittagong.

In the next eight years the Department was developed into a full and thoroughly modern organisation to meet all requirements for services and research in all branches of meteorology, geomagnetism, seismology and ionospheric studies. The observatories of the Department now comprise two for radio-sonde work, one for "Sferics", three for seismology, one for geomagnetism and the ionosphere, two for agricultural meteorology and forty-three for hydrometeorology. Only one of these, one of the two for agricultural meteorology, existed before independence.

The headquarters organization includes a workshop making nearly all the instruments required for routine meteorological observations including radiosondes. Research is in progress in many fields notably agricultural meteorology, the meteorology of arid and humid tropics and cloud physics and artificial stimulation of precipitation. A comprehensive series of publications, ranging from a *Daily Weather Report* to the *Geophysical Review*, has gradually been brought into production. The report includes a list of members of the staff on the Day of Independence, a list of the 110 papers published by the staff to March 1956 and various climatological data.

Great credit is due to the successive Directors, Mr. M. N. Husain, Mr. M. Aslam, and Mr. S. N. Naqvi who have built up the new Department from so little.

G. A. BULL

REFERENCE

1. Pakistan, Meteorological Service. Report on administration and development of meteorology and geophysics in Pakistan up to 31 March, 1956. Karachi, 1958.

OBITUARY

Mr. Frederick Metcalfe.—It is with deep regret that we learn of the death on 6 December 1958 of Mr. F. Metcalfe, Experimental Officer, at the age of 43 years. Mr. Metcalfe joined the Office in May 1931 and during his service worked in the Climatology and Forecast Divisions at Headquarters, ocean weather ships and aviation outstations. Since 1955 he has served at London Airport.

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

HONOUR

The appointment of *Miss D. G. Lee*, lately Senior Experimental Officer, to be a Member of the Most Excellent Order of the British Empire, was announced in the New Year Honours List, 1959.

METEOROLOGICAL OFFICE NEWS

Retirements.—The Director-General records his appreciation of the services of:

Miss A. J. Clapham, Senior Assistant (Scientific) who retired on 31 December 1958. She joined the Office from the London Telephone Service in November 1918 as a Clerk Computer in the Accounts Section of the General Services Division. In 1921 she was transferred to the Climatology Division and from then until her retirement all her service was spent in the British and Overseas Climatology Divisions.

Mr. W. J. Tomkins who relinquished his temporary appointment as Clerical Officer on 31 December 1958. He had previously retired from the grade of Senior Assistant (Scientific) in 1951. He joined the Office, then in Victoria Street, S.W.1, in September 1902 as a Boy Clerk and, prior to the First World War, served in the Statistical and Forecast Divisions. In 1914 he joined the

East Surrey Regiment, saw active service in France and spent eighteen months as a prisoner of war in Germany. He returned to the Office in March 1919 and was posted to the Statistical Division. In 1920 he was selected to take charge of the *Daily Weather Report* Despatch Section and he remained in that post until his retirement.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

GEOPHYSICAL MEMOIRS

No. 100—*World distribution of atmospheric water vapour pressure.* By G. A. Tunnell, B.Sc.

Part 1 of this publication is an atlas of the distribution over the whole world of the daily mean of atmospheric water vapour pressure for the months January, April, July and October.

All available data from about 3,500 stations have been used to produce the maps. Where there was insufficient information to give true average values they have been estimated by means of statistical analysis.

A formula is given for the variation of long-period mean of day averages of vapour pressure with height. This formula has been used to reduce mean of day values to sea level. The maps, when used in conjunction with the formula, can give values for any position or height throughout the world.

Part 2 of the publication gives a brief survey of the world distribution of diurnal variation of vapour pressure and its variation with climate.

It is hoped that this publication will provide information concerning atmospheric humidity in all parts of the world to scientists, technicians and businessmen who require estimates of average values at many different places.

REVIEW

Light scattering by small particles. By H. C. van de Hulst. 6 in. × 9 in., pp. xiii + 470, *illus.* John Wiley & Sons, New York; Chapman & Hall, London, 1957. Price: 96*s*. net.

Although the subject of light scattering by particles is purely physical, it is not now of great interest to the pure physicist. Since the work of the classical physicists, such as Rayleigh and Mie, investigations in the field have been made principally by scientists whose interest in the subject has been attracted by its value as a tool to solve their varied problems. Such a scientist is Dr. van de Hulst, an astrophysicist who studied the subject and made valuable original contributions in order to investigate certain astrophysical problems such as the nature of the cosmic dust particles existing in interstellar space. He presents in this book a unified treatise on the scattering of light by small particles, for which he has not only collected together the widely dispersed literature, but has also made new contributions in order to fill some gaps.

The book is limited to the case of independent scattering: it is assumed that the individual particles in a cloud are sufficiently separated as to act independently of each other. A rough criterion for independence is that the particles must be separated by more than three times their radii. This is the case in most practical problems; even in a very dense fog the mutual distances between droplets are of the order of twenty times their radii. A further limitation is that only single scattering, as occurs in an optically thin cloud, is considered. In a very dense cloud, where the light may be scattered several times before emergence, the mathematical evaluation of the problem becomes extremely involved and is not dealt with here. However, the book should serve to acquaint the reader sufficiently with the scattering properties of individual particles to allow the tackling of problems of multiple scattering, important examples of which are the scattering of sunlight by the clouds of Venus and the white terrestrial clouds, the transfer of radiation in a stellar atmosphere and the scattering of neutrons in an atomic pile.

Van de Hulst divides his book into three sections. The first part presents the basic theorems necessary for tackling the problem, which can be stated thus:—when an arbitrary particle is illuminated by light from a distant source, what is the angular distribution of the intensity of the scattered light, as seen by a distant observer, for different wave-lengths and states of polarization? The answer depends on the shape, size and nature (as represented by the complex refractive index) of the particle and is treated in the second section, which occupies the major part of the book. The solution of the problem is very much simplified in certain limiting cases which are dealt with first. These include particles small compared to the wave-length of the incident light (Rayleigh scattering as evidenced by the molecules in our atmosphere), particles with refractive index near unity and size not too large (Rayleigh-Gans scattering) and particles very large compared to the wave-length, for which the familiar concepts of geometric and physical optics apply. For other types of particles it is first necessary to obtain a rigorous solution of the problem by fitting the necessary boundary conditions (imposed by the shape of the particle) to Maxwell's electromagnetic equations. Laborious computations are then required to reduce this solution to numerical results for different refractive indices. The case of the sphere receives the fullest treatment available in the literature. Mie's formal solution is derived and numerical computations are given for transparent and absorbing spheres. A similar treatment is sketched for the circular cylinder and other shapes discussed are the circular disc and parallel strip.

Many of the results given for scattering by a sphere are directly applicable to meteorology. Indeed one chapter is devoted entirely to the optics of a raindrop and embraces some of the most beautiful of natural phenomena such as the diffraction coronae, rainbows and glory. The development of the theory of the rainbow is sketched and examined in the light of the rigorous Mie formula. A complete theory of the glory does not exist but van de Hulst advances his own explanation of a toroidal wave-front originating from grazing incidence, one internal reflection and a piece of surface wave.

The third and final section of the book deals with the application of scattering theory to chemistry, meteorology and astronomy. A chapter on biological applications could easily have been inserted but the biologist will profit by reading the section on chemistry, where the techniques and problems are similar. Whereas the preceding sections of the book are exhaustive with an excellent bibliography, this final section is intended only to indicate the practical problems involved and the best methods and techniques to invoke for their solution. The best chapter on applications is probably the one dealing with meteorology, where the various effects of scattering by the aerosol are summarized. In addition to the raindrop phenomena, the extinction and scattering by atmospheric haze is dealt with. Also treated are the scattering phenomena caused by aerosols from volcanic eruptions and forest fires, such as the "blue sun" of 1950. The important new subject of radar meteorology receives honourable mention and scattering theory is used to determine the attenuation and back-scatter of microwaves by fog and rain. These problems are quite different to those at optical frequencies, not only because the particle size is now smaller (usually) than the wave-length of incident radiation, but also because water absorbs radiation of radar frequencies. The astronomical problems reviewed by van de Hulst are the scattering by planetary atmospheres, the interplanetary dust and zodiacal light, and the solid grains in interstellar space.

This is an admirable book which fills a gap in the existing literature. It is written for, and can be recommended to, research scientists in various fields of endeavour, for whom scattering theory and techniques provide a powerful additional tool for the solution of their problems. R. WILSON

BOOKS RECEIVED

Annual Meteorological Tables 1955. *Falkland Islands and Dependencies Meteorological Service.* $13\frac{1}{2}$ in. $\times$ $8\frac{1}{2}$ in., pp. iv + 164, Falkland Islands Dependencies Survey, Stanley, 1957. Price: 15*s.*

Annual Meteorological Tables 1956. *Falkland Islands and Dependencies Meteorological Service.* $13\frac{1}{2}$ in. $\times$ $8\frac{1}{2}$ in., pp. iv + 176, Falkland Islands Dependencies Survey, Stanley, 1958. Price: 15*s.*

1958 catalogue of books on geology, minerology and mining. $8\frac{1}{2}$ in. $\times$ $5\frac{1}{2}$ in. pp. 20, H. K. Lewis and Co. Ltd., 136 Gower Street, London, W.C.1.

1958 catalogue of books on mathematics, physics, astronomy and meteorology. $8\frac{1}{2}$ in. $\times$ $5\frac{1}{2}$ in., pp. 68, H. K. Lewis and Co. Ltd., 136 Gower Street, London, W.C.1.

WEATHER OF OCTOBER 1958

Northern Hemisphere

The Icelandic low was centred near its normal position but was 8 millibars deeper than usual. The North Atlantic high pressure area was centred approximately midway between the Azores and England and was 4 millibars more intense than usual. Mean pressures were above normal over all Europe apart from Scandinavia and Iceland, the largest anomaly (+9 millibars) occurring over the Bay of Biscay. Associated with this pressure distribution was an abnormally strong south-westerly flow from the Atlantic west of Ireland to Norway.

The usual polar high was not present; in fact a low pressure area was centred at about 80°N., 180°W. and gave rise to negative pressure anomalies of up to −10 millibars. Over North America conditions were more anticyclonic than usual and mean pressures were generally above normal with anomalies of +4 or +5 millibars in the Hudson Bay region. Further positive anomalies occurred over a wide area to the south and west of the Aleutians in association with a westward displacement of the North Pacific high. The Aleutian low was near normal in both position and intensity.

In all parts of Europe, and over a large area of Russia, mean temperatures were near or above the October average. The largest departures from normal, +4°C., were over Scandinavia, and probably resulted from the intensified south-westerly flow. It was also warmer than average over much of the North

American continent where, as in the previous few months, the two regions with the largest anomalies were the Canadian Arctic and California, temperatures being about 3°C. above average in both areas. Maximum temperatures of up to 40°C. were reported from stations in California.

The rainfall distribution over Europe and Russia was rather irregular. Amounts were generally below normal over Britain, France, Spain and coastal regions of the Mediterranean, but near or above normal in other parts of Europe. There were early snowfalls over parts of central Europe, and the earliest avalanche warning for 20 years was issued in one district of the Swiss Alps. Apart from a few stations in Labrador, central Canada and eastern coastal districts of the United States, the North American continent had a dry month. A tropical storm moved north across Jamaica and Cuba on 6 October giving torrential rain and some severe flooding. This storm subsequently moved north-east and did not seriously affect the United States.

WEATHER OF NOVEMBER 1958

Great Britain and Northern Ireland

The weather over the British Isles during the first week of November was generally mild and unsettled as a succession of fronts moved eastward across the country, but during the remainder of the month frontal activity was very limited and weather was quiet and mainly dry being dominated by anti-cyclones first to the south-west of the country and later (from the 18th) over Europe.

The month began with a deep depression situated near Iceland, and an associated warm front moving east across the country gave falls of more than 2 inches of rain locally in South Wales and Cornwall. The 2nd also was a wet day as the cold front of the system, owing to developing waves, was slow moving and did not clear the south coast of England until the following morning. A few scattered showers occurred on the 3rd after the passage of this front, but rain from another frontal system, approaching from the Atlantic, had already reached western districts during the afternoon of the 4th and there was heavy rain in south-west England that night associated with a localized development at the tip of a narrow warm sector. A further trough, accompanied by occasional rain, moved eastward across the country on the 6th and, as on the 2nd, the cold front was slow-moving and trailed back along the English Channel where fog and low cloud persisted all day.

An anticyclone became situated in the eastern Atlantic on the 8th and north-westerly winds spread over the British Isles giving cooler weather, with showers in the north and west, but a mainly dry day elsewhere. The next day the anti-cyclone moved a little south and a minor wave, which developed on a warm front near Scotland, moved south-east across England to northern France giving slight rain in many places. On the 10th the anticyclone was centred to the south-west of Ireland with a pronounced ridge of high pressure extending north-eastwards over the British Isles to the Norwegian Sea and weather was generally fine and sunny during the day, apart from a few scattered showers, with widespread frost at night; screen temperature fell to 19°F. at Eskdalemuir. Milder weather, however, soon began to spread across Scotland as the anti-cyclone retreated further south-westwards to the region of the Azores. The associated frontal system, which brought rain and drizzle to most central and western districts on the 11th, was occluded when it reached south-east England on the afternoon of the 12th and dense fog formed in a narrow belt behind it.

The predominant anticyclone was centred near the Azores with a ridge of high pressure over the British Isles on the 14th and 15th, but on the following day it moved north-east becoming centred over the southern North Sea on the 17th, and from then until the 29th an anticyclone was situated over Europe with a ridge of high pressure extending westwards over the British Isles. The fog of the 12th marked the beginning of a period of cloudy and fairly dry weather with widespread fog or mist which lasted until the end of the month. In some areas the fog persisted all day and this occurred on the 17th and 20th and almost every day of the last week of the month with the Midlands and the north-east of England being most affected. Temperatures generally were about, or a little below, average, but in foggy areas it was cold; on the 26th there was continuous frost all day in some places in northern England.

Day maximum temperatures were about average in England, Wales and Northern Ireland but between two and three degrees above average in Scotland. In central southern England and over much of Scotland night minimum temperatures were about two degrees above average but elsewhere in England and Wales they were about normal. Sunshine was below average except in the extreme north of Scotland. Rainfall was 58 per cent of the average in England and Wales, 38 per cent in Scotland, where it was the driest November since 1945, and 53 per cent in Northern Ireland. Less than 25 per cent of the average occurred in east coastal districts from the Humber to the Scottish border, the Lake District—Whernside area, and in the upper Tay and Spey valleys. Rather more than the average was recorded in north Cornwall and the upper Thames Valley. Most of the rain fell during the first week of the month, and absolute droughts were recorded in East Anglia and north-west England during the latter half of the month.

The absence of widespread severe frost meant that fair progress was made on the land. Fruit picking and potato lifting were finished and a start was made on bush and tree pruning. The damp foggy weather increased condensation and disease problems and, in spite of the lack of rain, the heavier soils did not dry out sufficiently for ploughing to proceed. Cattle were left out rather later than usual although mud was a problem.

WEATHER OF DECEMBER 1958

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean†	Per-centage of average*	No of days difference from average*	Per-centage of average†
	°F	°F	°F	%		%
England and Wales ...	58	17	+0·4	119	+2	75
Scotland	54	8	−0·8	112	+1	104
Northern Ireland ...	55	24	−1·1	113	−1	94

*1916-1950 †1921-1950

RAINFALL OF DECEMBER 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square	3·08	139	*Carm.*	Pontcrynfe	5·45	82
Kent	Dover	3·65	125	*Pemb.*	Maenclochog, Dolwen Br.	6·31	91
,,	Edenbridge, Falconhurst	4·73	147	*Radnor*	Llandrindod Wells	3·70	85
Sussex	Compton, Compton Ho.	4·76	118	*Mont.*	Lake Vyrnwy	5·63	79
,,	Worthing, Beach Ho. Pk.	3·83	132	*Mer.*	Blaenau Festiniog	6·68	58
Hants	St. Catherine's L'thouse	4·02	122	,,	Aberdovey	3·68	88
,,	Southampton, East Pk.	4·55	134	*Carn.*	Llandudno	2·41	83
,,	South Farnborough	2·34	86	*Angl.*	Llanerchymedd	3·35	78
Herts.	Harpenden, Rothamsted	3·36	134	*I. Man*	Douglas, Borough Cem.	6·53	134
Bucks.	Slough, Upton	3·29	146	*Wigtown*	Newtown Stewart	5·84	114
Oxford	Oxford, Radcliffe	3·32	146	*Dumf.*	Dumfries, Crichton R.I.	3·82	89
N'hants.	Wellingboro' Swanspool	3·00	142	,,	Eskdalemuir Obsy.	5·39	86
Essex	Southend W.W.	3·86	151	*Roxb.*	Crailing...	3·36	171
Suffolk	Ipswich, Belstead Hall	3·58	161	*Peebles*	Stobo Castle	5·59	149
,,	Lowestoft Sec. School	3·03	138	*Berwick*	Marchmont House	4·75	201
,,	Bury St. Ed., Westley H.	2·80	128	*E. Loth.*	N. Berwick	3·98	219
Norfolk	Sandringham Ho. Gdns.	3·57	155	*Midl'n.*	Edinburgh, Blackf'd H.	3·99	189
Dorset	Creech Grange...	4·64	107	*Lanark*	Hamilton W.W., T'nhill	5·05	128
,,	Beaminster, East St.	5·24	114	*Ayr*	Prestwick	3·67	104
Devon	Teignmouth, Den Gdns.	4·31	112	,,	Glen Afton, Ayr. San ...	...	...
,,	Ilfracombe	4·95	113	*Renfrew*	Greenock, Prospect Hill	7·58	108
,,	Princetown	9·41	92	*Bute*	Rothesay, Ardencraig...	...	...
Cornwall	Bude	3·97	104	*Argyll*	Morven, Drimnin	5·56	82
,,	Penzance	6·50	134	,,	Ardrishaig, Canal Office	7·43	99
,,	St. Austell	7·26	129	,,	Inveraray Castle	7·76	85
,,	Scilly, St. Mary	4·71	134	,,	Islay, Eallabus	7·16	120
Somerset	Bath	3·84	131	,,	Tiree	4·60	99
,,	Taunton	3·88	126	*Kinross*	Loch Leven Sluice	7·32	226
Glos.	Cirencester	3·56	114	*Fife*	Leuchars Airfield	3·72	173
Salop	Church Stretton	2·76	83	*Perth*	Loch Dhu	10·64	116
,,	Shrewsbury, Monkmore	2·33	106	,,	Crieff, Strathearn Hyd.	5·99	144
Worcs.	Worcester, Red Hill	3·23	151	,,	Pitlochry, Fincastle	4·29	114
Warwick	Birmingham, Edgbaston	3·33	123	*Angus*	Montrose Hospital	4·12	167
Leics.	Thornton Reservoir	2·96	122	*Aberd.*	Braemar	5·47	145
Lincs.	Cranwell Airfield	2·65	139	,,	Dyce, Craibstone	5·08	161
,,	Skegness, Marine Gdns.	2·91	145	,,	New Deer School House	3·79	124
Notts.	Mansfield, Carr Bank...	3·80	155	*Moray*	Gordon Castle ...	2·41	108
Derby	Buxton, Terrace Slopes	5·20	108	*Inverness*	Loch Ness, Garthbeg	3·85	95
Ches.	Bidston Observatory	3·62	138	,,	Fort William	5·65	65
,,	Manchester, Airport	3·09	112	,,	Skye, Duntulm...	2·87	51
Lancs.	Stonyhurst College	3·61	81	,,	Benbecula	3·98	86
,,	Squires Gate	3·33	106	R. & C.	Fearn, Geanies	2·75	151
Yorks.	Wakefield, Clarence Pk.	3·44	162	,,	Inverbroom, Glackour...	5·83	99
,,	Hull, Pearson Park	3·08	137	,,	Loch Duich, Ratagan...	5·96	67
,,	Felixkirk, Mt. St. John...	2·82	112	,,	Achnashellach	7·98	92
,,	York Museum	3·41	168	,,	Stornoway	3·13	77
,,	Scarborough	2·78	113	*Caith.*	Wick Airfield	3·43	115
,,	Middlesbrough...	2·46	126	*Shetland*	Lerwick Observatory	...	...
,,	Baldersdale, Hury Res.	4·88	139	*Ferm.*	Belleek	6·13	124
Nor'l'd	Newcastle, Leazes Pk....	3·74	152	*Armagh*	Armagh Observatory	5·17	165
,,	Bellingham, High Green	4·81	161	*Down*	Seaforde	5·08	114
,,	Lilburn Tower Gdns	4·69	172	*Antrim*	Aldergrove Airfield	4·24	120
Cumb.	Geltsdale	4·40	140	,,	Ballymena, Harryville...	4·33	99
,,	Keswick, High Hill	3·96	66	*L'derry*	Garvagh, Moneydig	3·95	90
,,	Ravenglass, The Grove	3·98	89	,,	Londonderry, Creggan	3·61	79
Mon.	A'gavenney, Plâs Derwen	5·03	104	*Tyrone*	Omagh, Edenfel	5·83	131
Glam.	Cardiff, Penylan	4·55	105				

* 1916–1950

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