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## NUMERICAL WEATHER ANALYSIS AND PREDICTION

By E. KNIGHTING, B.Sc.

Less than 20 years ago a meteorologist could write of the current papers in meteorology "In the course of this reading I have been introduced many times to the equations of motion on a rotating globe, the hydrostatic equation and the equation of continuity . . . But alas! the science of meteorology, in particular of dynamical meteorology, remains substantially where it was . . . The emphasis in recent years on the study of convergence and divergence to explain pressure variations has opened up splendid opportunities for mathematical juggling, but in its practical application has proved disappointing." (F. E. Lumb, *Weather*, 1, 1946, p. 244). This was not an isolated opinion; reviews of books and comments on papers written at that time show that it was indeed a prevalent view. Twenty years before, L. F. Richardson had made what was taken as a crucial test of the possibility of forecasting the pressure field by proceeding from the differential equations of motion of the atmosphere, integrating them approximately by finite difference methods, and he obtained a resulting pressure change which was an order of magnitude too great. The arithmetic involved, carried out necessarily by hand computer, was so great in volume that apparently no-one cared to repeat the experiment nor examine very carefully why the computation had led to incorrect results, and papers on dynamical meteorology continued to be divorced from synoptic meteorology as the hydrodynamics of a perfect fluid is divorced from that of a real fluid. This was largely owing to the difficulty of obtaining solutions of the non-linear differential equations and many papers dealt with linearized forms of the equations, essentially using perturbation methods. It would be quite wrong to suppose that these investigations were of little value, for perturbation theory is capable of indicating the way in which things are going to develop, even if unable to give correct quantitative answers.

During the past fifteen years the developments in dynamical meteorology have been rapid. Dr. Thompson's book\* is the first published text in English that deals anything like adequately with these developments, which have led to

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\* *Numerical weather analysis and prediction*, by P. D. Thompson. 9½ in. × 6¼ in., pp. xiv + 170, illus., The Macmillan Company, New York, 1961. Price: \$6.50, 45s. 6d.

numerical weather prediction, and would be an important book in this respect alone, even if it did not have other qualities which will be noted later.

There were several contributing factors to the rapid development which started about 1946. First, there was new emphasis on the relevance of the scale of atmospheric motions and in particular on the size of the various terms in the equations describing synoptic scale motions. Second, there were the new upper air observations which had been made for military use during the Second World War and which, for the first time, gave an *adequate* picture of the three-dimensional structure of the atmosphere instead of the two-dimensional picture of the pressure field near the earth's surface. Fortunately these observations were continued and increased in number during the years following, owing to the large increase in civil aviation. Third, there was the development of high-speed electronic computers which made possible, in a few hours, computations which would have taken years with the aid of desk computers. This led to increased interest in the mathematics of computation. Dr. Thompson deals with these aspects of the possible emergence of a computational scheme for forecasting prebaratics in his first chapter.

The guiding principles in making numerical weather prediction are clear. One must set up the equations which govern the system, that is the dynamical, kinematical and thermodynamical equations. These will be very general and one must next inquire what distinguishes one kind of motion, say motions on a synoptic scale, from another, say sound waves. The differences are revealed by observations, in this case in the speed and amplitude of the wave motions and so on. The difficult next step is to discover what modification or constraint of the initial equations is necessary to admit one kind of motion and reject another kind. It is sometimes thought that such constraining is mathematical jugglery designed to make the mathematics tractable but this is not so; the principal function of such constraining is an economic one. If one had a large zoo full of different animals and one wished to investigate the habits of, say, sheep then one could either examine the habits of all animals and discard those of non-sheep or one could just pass all the animals through a sieve which separated sheep from non-sheep and examine the habits of the first class; needless to say the latter is the commonly accepted method. The constraining of the equations is just of this type. Finally the constrained equations must be solved and it is usually only possible to do this by finite difference methods. Dr. Thompson deals most effectively with these principles. Particularly to be commended are the chapters which deal with the possible types of wave motion in the atmosphere and the finite difference methods of solving linear wave equations. In the former he shows most clearly what physical processes give rise to sound, gravity and synoptic wave motions and how these physical processes are written as simple mathematical equations. Finite difference methods often appear abstruse to those not acquainted with the subject, largely because of the technical jargon—words such as “relaxation”, “sweep”, “Liebmann process” are used elliptically to embrace quite elementary ideas and processes. The author deals clearly with the use of finite difference methods from the simplest concepts in the chapter mentioned and also in a later chapter on solving the modified non-linear equations and can be followed by anyone whose mathematics rise to the calculus at sixth-form level.

The constrained, or filtered, equations which describe the way in which the large-scale atmospheric motions evolve are still too difficult to solve, even by

finite difference methods using an electronic computer and one must now construct an atmospheric "model" which reflects the rather more specific properties of the atmosphere as noted from observations, such as the static stability and the variation of wind speed with height. These new constraints are on a different footing from those described above, for they are mathematical simplifications designed to allow the equations to be solved without losing the essential physics of the problem. An example of such a simplification would be the assumption that the wind shear at any point is always in the same direction and varies linearly in the vertical. Almost any particular hodograph would contradict the assumption in detail but in the mean over a large number of cases the assumption is approximately true in the lower troposphere. By making such an assumption we replace the real atmosphere by a model atmosphere, which everywhere has this property, for the purpose of integrating the equations. Dr. Thompson discusses the effect of making such simplifying assumptions, showing very clearly the resulting equations and also how these equations are solved by using finite difference methods, firstly dealing with the equivalent barotropic model and later with more complicated models.

A little more than half the book deals with these basic ideas concerning numerical weather prediction and the practical problems of carrying out the computations. A later chapter caps this exposition by describing in fair detail the organization of the Joint Numerical Weather Prediction Unit, Washington, where numerical forecasts are computed on a routine basis for use by forecasters. This chapter will dispel any scepticism that may linger about the practical value of the application of the ideas that Dr. Thompson has been dealing with; one must hope that those who are concerned with the communication of meteorological information will realize that fresh problems in their field have already been raised by the possibility of using high-speed electronic devices.

The remaining chapters are a little more recondite. It is not sufficient that the method be possible, but also that understanding of the dynamical processes be clear, partly as an intellectual gain and partly because such clarity is suggestive of further lines of investigation which should improve both understanding and practical application. Perhaps the easiest problem to pose is "Why does the atmosphere organize motions on the synoptic scale?" and Dr. Thompson deals with the arguments concerning instability and energy transfer which are the first line of attack. He discusses also in a more sophisticated manner, the methods of filtering out the unwanted motions and, very briefly, the problems associated with a direct attack on the fundamental system of equations, and other problems which are of current concern.

In the preface the author writes that the book is designed to provide a text in numerical weather prediction for students of meteorology at graduate level and also for those with a general background of physics and mathematics, but no special knowledge of meteorology. He has certainly succeeded in the former aim and I expect that he has in the latter. The level of mathematics required to read the text looks formidable at a casual glance. I would like to emphasize that this is not so when the text is read. Nothing much more than some knowledge of vector and ordinary calculus is required and these are acquired at a lower level than graduate level. Moreover, this is a book about the *physics* of the atmosphere and the mathematics is a handmaiden. I wish that more meteorologists would recognize that the idea of numerical weather prediction

is essentially simple in concept, as easily understood as many of the other meteorological ideas that they accept as commonplace, and this text provides a proof of the assertion.

This is an important book in more ways than one. Clearly the first text to deal adequately with a quickly developing subject must be an important one. But, further than that, it replaces much of the dynamical writing to be found in the older texts, which has been repeated time and again, and in doing so has reached much nearer to the heart of the important problems. Those who have heard Dr. Thompson talk and have read his papers will be aware of his economy of thought and lucidity of expression; both are evident in this book. I commend it to every meteorologist whether he has mathematical training or not.

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## **A SYNOPTIC METHOD FOR THE INTERNATIONAL COMPARISON OF GEOPOTENTIAL OBSERVATIONS**

By C. L. HAWSON, B.A. and P. G. F. CATON, M.A., Ph.D.

**Introduction.**—The ever higher levels at which modern aircraft fly and the consequent demand for the analysis of higher and higher upper air charts have brought the question of the accuracy of upper air observations into increasing prominence. This paper describes a method of assessing both the systematic differences between the geopotential observations of the radiosondes of different countries and the random errors to which these observations are subject, using only routine observations and analyses on upper air charts.

Errors in the geopotential of isobaric surfaces determined from radiosonde observations tend to accumulate with height. Thus the higher the level of a synoptic chart, the greater are the inconsistencies between the observed winds and the contour gradients obtained from the geopotentials deduced from the pressure and temperature observations at the various stations. The inconsistencies arise mainly from errors or differences in the geopotential determinations which are partly systematic and partly random. Systematic errors are characteristic of the design of the radiosonde, although they may also result from differing operational techniques even with one type of instrument. Random errors are those which tend to be systematic from level to level on a particular individual sounding, but random in their incidence from sounding to sounding at a single station. Another form of random error also occurs in the temperature and pressure observations; this is random in its incidence from level to level on a particular sounding, but from the nature of the geopotential computation such errors tend to have very little effect on the geopotential calculated for isobaric surfaces and are not assessed by the method described below.

The problem presented by the reported 100 mb geopotential observations over and around Europe can be compared with that which would arise on a mean-sea-level surface pressure chart if each country provided only a few observations and used barometers set to national standards subject to diurnal change and differing between the highest and lowest by 25 mb or so. There would also be random errors having an even chance of being greater or less than anything from about 2 to 5 mb. Happily such a chaotic picture is purely

hypothetical for the mean-sea-level chart, and wind observations materially assist the analysis at the 100 mb level.

**The method.**—Over an area where, at a particular level, the acceleration of the air particles is very small the actual flow will be very nearly in geostrophic balance. In these circumstances the geostrophic relationship can be used with a high degree of accuracy to construct contour lines whose directions and gradients are in geostrophic balance with all the winds observed in the area. The facts that for the charts selected the large majority of the wind observations did readily fit into such contour patterns, and that these patterns were coherent, lent strong support to the premise that the vector errors in the observed winds were sufficiently small to enable adequate patterns of contours to be constructed. Very occasionally a wind observation was nevertheless encountered which did not accord with those from other stations or those from other levels at the same station. These were attributed to observational or transmission errors and rejected. The wider the contour spacing the smaller is the error in estimating the true differences between the geopotentials at particular stations, and a contour spacing corresponding to winds of the order 15 knots or less is suitable for comparisons over quite large distances. Wind fields of this order involving only very small accelerations of air particles in the flow occur quite frequently in summer over much of Europe and the North Atlantic at 100 mb, 50 mb and even higher levels. In this investigation several series of 100 mb charts were used and wind situations involving a rather wide variety of directions were included in the selection in order to minimize the effects of errors of technique on the mean values for the differences between stations.

Once suitable charts have been selected, and the contour patterns constructed from the wind observations, the contours only show relative geopotential over the area. It is necessary to relate the contour lines on each chart to some reference standard and number them accordingly. In this investigation the standard adopted was the mean of the values indicated for each set of contours by the eight radiosonde stations in the United Kingdom. These stations form a compact radiosonde and radarwind network controlled by a single authority, and by taking the mean value from eight observations much of the random error inherent in any single observation is materially reduced. This choice of standard is arbitrary and is not intended to attribute any particular quality to British ascents. Nevertheless it must be mentioned that examination of the time variation in the local geopotential over London derived from the charts using this standard, showed a slow smooth change and a diurnal 00h GMT to 12h GMT increase of less than  $+0.5$  decametres. A difference of this order is consistent with the diurnal variation of wind at 100 mb found by Johnson<sup>1</sup>, and it suggests that for practical purposes the chosen reference standard is the same at 12h GMT as at 00h GMT as well as being stable from chart to chart.

Comparison between the heights derived from the contour lines, constructed and numbered as described above, and the reported heights of the 100 mb surface at each station on each chart, then reveals inconsistencies. The difference, observed height minus the height indicated by the contours for a particular station on a particular chart, we have called the "Anomaly" ( $A$ ) for that sounding. The "Anomalies" or  $A$  values were tabulated chart by chart for each station. The average values of  $A$  for each station at 00h and at 12h GMT were designated  $S_0$  and  $S_{12}$  respectively and the standard deviations of  $A$  were called  $Q_0$  and  $Q_{12}$  respectively.  $S_0$  and  $S_{12}$  measure the systematic differences

from the chosen (United Kingdom) standard at 00h and 12h GMT whilst  $Q_0$  and  $Q_{12}$  indicate the internal scatter (random error) of the reported heights at each station. When the tabulations indicated that two or more stations apparently were subject to similar anomalies, mean values  $S_0$  and  $S_{12}$  were evaluated for the  $A$  values of the group and  $Q_0$  and  $Q_{12}$  formed about the group means.

**Trials of the method.**—The method was first applied at 100 mb on 28 occasions for 00h GMT and for 32 occasions for 12h GMT, selected from the months April, May and June 1959 on the basis of the observed winds, that is wind fields involving only very small acceleration of air particles and low wind speeds. In a second investigation 20 occasions for 00h and 20 for 12h GMT were similarly chosen from May and June 1960. The area covered in the first work was broadly  $40^\circ$  to  $60^\circ\text{N}$ ,  $10^\circ\text{W}$  to  $25^\circ\text{E}$ , but in the second study this was extended to  $35^\circ$  to  $75^\circ\text{N}$ ,  $10^\circ\text{W}$  to  $30^\circ\text{E}$  and also to the Iceland–Greenland region. Because of the limitations imposed by the wind field considerations however, comparisons were not necessarily attempted over the whole area on each chart. A few analyses were also made covering eastern Canada and the north-east United States. Although in the extended regions it is still possible to intercompare stations hundreds of miles apart it is not practical to ensure that the zero relative to the United Kingdom is maintained. The 1959 and 1960 values of  $S_0$ ,  $S_{12}$ ,  $Q_0$  and  $Q_{12}$ , together with the number of comparisons made for the stations investigated are shown in Table I.

It will be seen that the majority of sondes indicate higher values of geopotential (higher temperatures) than the United Kingdom standard. In general the excess is greater at 12 h than at 00h GMT. The sondes used at West German, Canadian and American land stations, and at Vienna and Keflavik show the lowest standard deviations. For some stations, for example, the French group, Lisbon and the north-west German group, the 1959 and 1960

TABLE I—INTERCOMPARISON OF RADIOSONDES AT 100 MB, SUMMER SEASONS 1959 AND 1960

Group no.	Stations in group	1960						1959					
		00h GMT			12h GMT			00h GMT			12h GMT		
		$N$	$S_0$	$Q_0$	$N$	$S_{12}$	$Q_{12}$	$N$	$S_0$	$Q_0$	$N$	$S_{12}$	$Q_{12}$
1	Eight United Kingdom reference stations	151	0	$4\frac{1}{2}$	152	0	$4\frac{1}{2}$	209	0	4	243	0	4
1a	Valentia	19	0	4	19	0	5						
1b	U.K. ships on stations "A", "I" and "J"	39	0	$4\frac{1}{2}$	40	0	3						
1c	Gibraltar, Malta, *Tobruk, *Nicosia	74	0	5	75	— 2	$4\frac{1}{2}$	19	0	3	28	— 2	3
2	De Bilt	17	0	$5\frac{1}{2}$	19	+ 6	$5\frac{1}{2}$	26	+ 1	$5\frac{1}{2}$	29	+ 8	$5\frac{1}{2}$
2a	Dutch ships	19	0	6	20	+ 4	$7\frac{1}{2}$						
3	Uccle	18	+ 1	5	20	+ 13	$5\frac{1}{2}$	24	+ 1	4	30	+ 10	$4\frac{1}{2}$
4	Brest, Trappes, Nancy, Bordeaux, Lyons, *Nîmes, Ajaccio, *Algiers	104	+ 2	$6\frac{1}{2}$	144	+ 8	7	78	+ 5	5	137	+ 10	7
4a	French ships	20	+ 2	5	19	+ 8	5						
5	Payerne	18	+ 3	7	18	+ 4	8	14	+ 1	$4\frac{1}{2}$	18	0	6
6	Chateauroux, Zarazoga, *Kenitra, *Wheelus Field, *Athens	82	0	$3\frac{1}{2}$	78	+ 3	3	42	+ 2	3	38	+ 4	3
7	Madrid, Corunna, Palma	12	+ 3	$7\frac{1}{2}$	19	+ 9	7						
8	Lisbon	12	0	$7\frac{1}{2}$	12	+ 6	5	11	+ 10	$5\frac{1}{2}$	9	+ 22	$3\frac{1}{2}$
8a	Madeira	—	—	—	17 (+30)		6						

TABLE I—INTERCOMPARISON OF RADIOSONDES AT 100 MB, SUMMER SEASONS  
1959 AND 1960—continued

		1960						1959					
Group no.	Stations in group	00h GMT			12h GMT			00h GMT			12h GMT		
		<i>N</i>	<i>S</i> <sub>0</sub>	<i>Q</i> <sub>0</sub>	<i>N</i>	<i>S</i> <sub>12</sub>	<i>Q</i> <sub>12</sub>	<i>N</i>	<i>S</i> <sub>0</sub>	<i>Q</i> <sub>0</sub>	<i>N</i>	<i>S</i> <sub>12</sub>	<i>Q</i> <sub>12</sub>
9	Milan, Udine	28	0	3½	29	0	4	54	0	4	64	+ 2	4½
9a	Rome	19	+ 2	4½	19	+ 8	5						
9b	Elmas	14	0	3	15	+ 2	6						
9c	Brindisi	19	- 3	5	19	- 1	5						
9d	Messina	17	- 5	5	18	- 3	5						
10	Split, Zagreb	28	0	3½	—	—	—	6	+ 4	5	2	+ 22	—
10a	Beograd	19	+ 6	3	17	+ 12	3½						
11	Budapest	8	+ 13	6	8	+ 24	5						
12	Bucharest	14	+ 12	5	8	+ 17	9						
12a	Cluj	8	+ 3	6	—	—	—						
13	Sofia	13	+ 10	6½	13	+ 10	11½	21	+ 10	4½	29	+ 11	6½
14	Thessaloniki	5	(- 3)	—	3	(- 4)	—						
15	Istanbul	11	(+ 1)	8½	6	(+ 10)	—						
15a	Ankara	13	(- 4)	4½	18	(+ 3)	4						
16	Mersa Matruh	12	(- 5)	5½	13	( 0)	6						
16a	Cairo	10	(- 1)	6	8	(+ 4)	4½	81	+ 6	2½	90	+ 8	2½
17	Schleswig, Emden, Hannover, *Bonn	59	+ 4	2	65	+ 6	2½						
17a	Stuttgart	20	+ 2	2½	19	+ 3	2½						
17b	Munich	20	+ 4	2	20	+ 4	2½						
18	Greifswald, Lindenberg, Wahnsdorf	55	+ 7	5	52	+ 11	5						
19	Prague, Poprad	26	+ 7	6	29	+ 13	6	28	+ 1	2½	30	+ 2	3½
20	Vienna	19	0	1½	20	+ 2	2½						
21	Poznan, Wroclaw, Warsaw	8	+ 10	6	19	+ 35	7½				2	- 1	—
22	Uzhgorod, Lvov, Brest, Kaliningrad, Kaunas, Riga, *Tallin	121	+ 7	7	125	+ 12	6	65	+ 9	5½	75	+ 13	8½
22a	Murmansk, Kandalaksha	33	+ 4	7	31	+ 7	6½						
23	Sodankylä, Jokioinen	35	+ 1	5	33	+ 3	5						
24	*Östersund, Stockholm, Göteborg	54	- 1	4	53	+ 4	5½	42	- 2	5	44	0	5
25	Copenhagen, Thorshavn	38	0	4½	39	+ 5	5						
26	Oslo, Sola	39	- 1	3½	38	+ 2	5						
26a	Bodö, Tromsø, Björnöya, Norwegian ship "M", Jan Mayen	93	+ 2	6	89	+ 7	5½	52	+ 2	5	54	+ 6	5½
26b	Isfjord (Spitsbergen)	17	(+ 4)	5	20	(+ 8)	5½						
27	Nord	15	(- 1)	3	15	(+ 2)	2½						
27a	Danmarkshavn	14	( 0)	2½	—	—	—	17	(+ 1)	3½	20	(+ 4)	4
27b	Kap Tobin	18	(- 5)	4	17	(+ 1)	3½						
27c	Angmagssalik	18	(+ 1)	3	20	(+ 4)	4						
27d	Narsarsuaq	16	(- 7)	3	12	(- 5)	5½	15	(+ 4)	5½	16	( 0)	5
27e	Egedesminde	18	(+ 3)	4	15	(+ 4)	5½						
27f	Thule	18	(+ 1)	3½	16	( 0)	5						
28	Keflavik	20	(- 1)	1½	19	(+ 1)	1½	45	(+ 4)	3	10	(+ 2)	—
29	American ships on stations "B", "C" and "D"	44	(+ 1)	3	45	(+ 4)	3						
30	Lajes	10	( 0)	—	10	(+ 2)	—						
31	21 Canadian and Ameri- can stations east of 75°W	178	( 0)	2	177	(+ 1)	2						

Units for  $S$  and  $Q$  are tens of geopotential metres;  $S$  values are positive when observations are higher (warmer) than reference; stations marked with an asterisk are not included in the group in the 1959 study;  $N$  is the number of comparisons from which the  $S$  and  $Q$  values are derived.

Note (i) It is probable that further grouping of stations should take place. For example, the sondes of groups 6, 28, 29, 30, 31 and possibly others are believed to be of one type. (ii) The values in brackets are considered less reliable than the average since, due to the isolation of the stations combined with substantial distance from the United Kingdom starting point, it was difficult to construct the streamlines without some reference to reported heights. As a further consequence the  $Q$  values probably underestimate the true standard deviations.

$S$  values appear to differ significantly. In the case of Lisbon, the authors are confident from this evidence alone that some change of sonde or technique has occurred; (examination of the January 1961 charts suggests a further alteration to the Lisbon values as follows:  $S_0 - 11$  decametres,  $S_{12} - 7$  decametres). The changes in the French and German values may have arisen individually from small changes in technique or, in view of their similar magnitude, they indicate the possibility of a shift in the United Kingdom standards. An annual check on  $S$  values is obviously desirable and future changes in these values must be expected as radiosonde techniques advance. It may be mentioned that the  $Q$  values derived for the United Kingdom sonde are in good agreement with the instrumental standard deviation of 100 mb height found by Harrison through the evaluation of observations from pairs of sondes flown together (report as yet unpublished).

**Estimation of the accuracy of the trial.**—The probable error in the chosen contour height reference standard derived from the mean of eight stations is about  $\pm 1$  decametre (that is,  $0.67 \times 4.5/\sqrt{8}$ ). With wind speeds of 10 knots (and accelerations involving geostrophic departures of less than 1 knot or  $3^\circ$ ), a typical value, a systematic error of  $10^\circ$  in the direction of a contour corresponds to an error of  $1\frac{1}{2}$  decametres in the estimated relative contour height 900 miles downstream; whilst a systematic speed error of 2 knots involves a comparable relative contour height error at the same distance cross-stream. Systematic errors in the construction of the contour lines on a single chart are considered likely to be of this order. Thus within the 1959 area of operation the estimated probable error of a single  $A$  determination was less than  $2\frac{1}{2}$  decametres and the contribution of this error to the derived  $Q$  values was small in most cases. The standard error in the  $S$  value for a group of stations is  $Q/\sqrt{(N-1)}$  where  $N$  is the number of comparisons; this error is less than  $\frac{1}{2}$  decametre for several groups but, of course, is materially greater for those stations or groups for which only a few comparisons were possible.

The difference  $S_{12}-S_0$ , which is interpreted below, is subject to substantial uncertainty when, for single stations, the  $S$  values are estimated from 20 or fewer chart analyses. An improved estimate of  $S_{12}-S_0$  is then often possible through comparison with the difference between three-monthly mean reported heights at 00h and 12h GMT ( $H_0$  and  $H_{12}$ ). These comparisons were made extensively for the May–July 1960 period, especially for stations in the Greenland, Iceland and Scandinavian areas. The difference  $H_{12}-H_0$  for United Kingdom stations was  $\leq + 0.5$  decametres, so that to a first approximation (see next paragraph)  $H_{12}-H_0 = S_{12}-S_0$ .

During consideration of these latter data and in particular of the mean heights at 00h, 06h, 12h and 18h GMT for Keflavik, Lajes, Stephenville, and Goose Bay, it became apparent that there was a real diurnal variation of 100 mb geopotential in addition to the instrumental variation ( $S_{12}-S_0$ ) which alone it is desired to eliminate. Separation of the two components was difficult, but it appeared that the real diurnal variation had a range of about 3 decametres with a minimum soon after 06h *local time* and a maximum about 18h. These figures are broadly consistent with the diurnal variation of 100 mb wind, described by Johnson<sup>1</sup>. Following Johnson's work it seems that the true difference in 100 mb mean height at 00h and 12h GMT over Europe (say longitude  $10^\circ\text{W}$  to  $30^\circ\text{E}$ ) should be very small, but that over America (longitude  $60^\circ\text{W}$  to  $120^\circ\text{W}$ ) the 00h GMT value should exceed that at 12h GMT.



This expectation was verified by comparing ooh and 12h GMT May to July mean 100 mb heights for two stations (Columbia and Trout Lake) at about 90°W, where solar elevations during the ooh GMT soundings are comparable to, or a little less than, those for the 12h GMT soundings.

**Seasonal changes of  $S_0$  and  $S_{12}$ .**—The values of  $S_0$  and  $S_{12}$  directly determined apply only to 100 mb observations in summer, when the solar elevation over Europe during the 12h GMT sounding is of the order of 60°. The problems arise of extending these values to other seasons and also of applying them to other levels.

To derive values for different seasons the authors attribute the difference  $S_{12}-S_0$  for a particular station to the difference in solar radiation incident on the sonde at 12h and ooh GMT. Leaving aside those stations (broadly north of 65°N) at which the ooh GMT ascent in summer is wholly or partially in sunlight, it is assumed that  $S_0$  remains constant in darkness and that the difference  $S_{12}-S_0$  varies in accordance with seasonal changes of solar elevation. It is further assumed that to a first approximation the  $S_{12}-S_0$  difference for all sondes varies with solar elevation in the same way as does the radiation correction of the United Kingdom sonde for which the radiation corrections as a function of pressure and solar elevation are readily available. These assumptions are not expected to be strictly true, but sufficiently so to have practical worth. Computations on these lines suggest that the  $S_{12}-S_0$  difference appropriate to a solar elevation of 60° at 12h and darkness at ooh GMT should be varied with solar elevation as in Table II.

TABLE II—EFFECT OF VARIATION OF SOLAR ALTITUDE

Solar elevation at 12h (Darkness at ooh)	Fraction of $S_{12} - S_0$ for 60° solar elevation at 12h (Darkness at ooh)
—3° to 2°	one-quarter
3° to 20°	one-half
21° to 40°	three-quarters

The results for stations where the ooh GMT ascent is in sunlight may similarly be interpreted to give  $S$  values for ascents in darkness.

After consideration of Table II and the changes in solar elevation at ooh and 12h GMT throughout the year, and also bearing in mind the undesirability of frequent changes of correction at irregular dates, it was decided to divide the year into the following seasons:

Winter	16 October to 28 February.
Equinoctial	1 March to 15 April, and 1 September to 15 October.
Summer	16 April to 31 August.

The 100 mb  $S_0$  and  $S_{12}$  corrections for each station for each of the above seasons were then derived on the lines indicated above. As examples a few values are shown in Table III.

Although in the winter season wind speeds are usually far too high to justify application of the technique described, a check on the deduction from the summer results is sometimes possible, for example (i) by comparison of the means of about 30 reported heights for, say, Kap Tobin and Jan Mayen (both 70°–71°N) in prevailing westerly winds and (ii) for single stations by the evaluation of monthly mean 100 mb heights at ooh and 12h GMT. A number of such checks was carried out and gave support to the values derived from the summer results.

TABLE III—EXAMPLES OF CORRECTIONS TO BE APPLIED TO OBSERVED 100 MB HEIGHTS TO REDUCE THEM TO THE UNITED KINGDOM STANDARDS

Group no.	Stations	Winter		Equinox		Summer	
		00h	12h	00h	12h	00h	12h
				<i>decimetres</i>			
3	Uccle ... ..	— 1	— 9	— 1	— 11	— 1	— 13
4	French stations ... ..	— 2	— 6	— 2	— 7	— 2	— 8
17	N.W. German stations ... ..	— 4	— 5	— 4	— 6	— 4	— 6
21	Polish stations ... ..	— 10	— 27	— 10	— 32	— 10	— 35
26	Oslo, Sola (60°N) ... ..	+ 1	— 1	+ 1	— 2	+ 1	— 2
26a	Norwegian ship "M" (66°N)	+ 1	— 3	+ 1	— 5	0	— 7
26a	Jan Mayen (71°N) ... ..	+ 1	— 2	+ 1	— 5	— 2	— 7
26a	Björnöya (75°N) ... ..	+ 1	— 1	+ 1	— 5	— 3	— 7
28	Keflavik (64°N) ... ..	0	— 1	0	— 2	0	— 3
30	Lajes (39°N) ... ..	0	— 2	0	— 3	0	— 3

**Assessing the interstation differences at levels below 100 mb.**—To assess the interstation differences at lower levels it is assumed that the 100 mb geopotential anomalies are caused by various simple kinds of instrumental error and the effects of these on calculated heights in an ICAO environment have been separately investigated. By this means it has been possible to evaluate the approximate percentage of the 100 mb anomaly which would be contained in the 700, 500, 300 and 200 mb geopotential determinations if the anomaly were solely due to any one of the simple instrumental errors postulated. These are shown in Table IV. The assumptions of error types are not exhaustive, in reality they will be more complex, the environment will have a second order effect and the height anomalies induced by pressure and temperature may be of opposite sign. Thus a wide variety of possible percentages at the lower levels can be appropriate to individual soundings.

TABLE IV—EFFECT OF INSTRUMENTAL ERRORS ON COMPUTED HEIGHTS IN AN ICAO ATMOSPHERE

Pressure <i>mb</i>	Nature of error				
	A	B	C <i>per cent</i>	D	E
700	15	3	7	13	2
500	30	11	16	30	15
300	52	33	34	68	56
200	70	57	52	100	100
100	100	100	100	100	100

Anomaly (expressed as percentage of 100 mb anomaly) assumed to be due solely to:

- Constant temperature error.
- Temperature error changing linearly with difference of temperature from ground level temperature.
- Temperature error varying with height in same way as temperature corrections due to radiation vary in British sonde at solar elevation 60°.
- Constant pressure error.
- Pressure error changing linearly with difference of pressure from ground level pressure.

Nevertheless the bigger the 100 mb anomaly the more likely are the contributions of the errors due to pressure, temperature and radiation to be all of the same sign, and the narrower the limits of the possible percentages of the 100 mb anomaly appropriate to lower levels. As a tentative practical expedient the authors suggest that the following percentages of the 100 mb anomaly be applied at analysis centres to lower levels: 500 mb 10 per cent, 300 mb 35 per cent and 200 mb 60 per cent (these percentages the authors believe are probably a little, say 5 to 10 per cent less, than the most likely mean values).

If, after application of the  $S$  value at 100 mb as a first approximation, it is clear that a random error is present on an individual sounding, the 100 mb anomaly to be used for the purpose of estimating lower-level corrections should be the difference between the reported height and the value estimated from the current 100 mb analysis, not just the appropriate  $S$  value.

The figures derived from the 1959 investigation were used experimentally in the analysis of upper air charts at the Central Forecasting Office, Dunstable, commencing in March 1960. They were found to have practical value and revised figures based on the 1960 study were introduced in January 1961. It may be mentioned that the advice in the final sentence of the last paragraph has led to a change in the order of analysis of the upper air charts. Instead of the 100 mb chart being drawn last, that is after the 700, 500, 300 and 200 mb charts, it is now common practice to analyse the 100 mb chart first, at least over Europe, and to use the observed height anomalies at 100 mb to estimate corrections to heights at lower levels. It is believed that the change has improved the standard of chart analysis at 500 mb and higher levels.

**Additional comments.**—The possibility has been considered that the winds used to construct the contour lines may, on average, have referred to a level above or below 100 mb (due to errors in the measurement of pressure) and may therefore have been systematically too light or too strong. On 28 occasions at 00h GMT the construction of contour lines was extended as far as Malta, where British radiosondes are used and the technical control is the same as in the United Kingdom. The systematic height anomaly at Malta for these occasions was zero, which indicated that any error arising from the above possibility was very small. The negative value of  $S_{12}$  at Malta (and Gibraltar) was thought to indicate over-correction for solar radiation by the British sonde in those latitudes at 12h GMT.

As already stated the application of the results of these studies in the form of corrections to observed geopotentials has been found to have substantial practical value in routine chart analysis. However, it is apparent that a regular reassessment of  $S$  values is necessary as radiosonde technique advances are made in different countries. It seems desirable not only that there should be an annual review, but also that all changes in equipment or technique should be notified internationally to the practising forecasters, as well as the instrumental specialists, to aid in the interpretation of the observations. It is clear that a substantial number of comparisons must be made before significant results are obtained for any one trial, and a technique utilizing routine soundings represents a substantial economy over any national or international study involving pairs of sondes flown together. The authors foresee extension of the methods outlined to the 50 mb surface and in particular that the differences in the height anomalies at 100 mb and 50 mb on an individual ascent may be utilized to assess temperature errors on that sounding.

**Summary.**—The methods described in this paper provide a cheap convenient means of estimating the systematic differences between the geopotential observations from the various kinds of radiosonde and also the standard deviation of the random errors of each model. The main technique is dependent on the existence, at high levels in the atmosphere, of large areas of light winds involving only low particulate accelerations in the air motion, where there is also a sufficiently dense network of upper wind observations. Such conditions occur quite frequently in summer in our latitudes at 100 mb. Methods are

suggested for extending the results of investigating these summer situations to other seasons and also for utilizing particular 100 mb synoptic analyses for estimating corrections (to a common standard) for geopotential values observed at lower isobaric surfaces on individual soundings. A summary of the results of trials based on the summers of 1959 and 1960 is presented.

**Acknowledgments.**—We wish to thank Mr. C. J. Boyden and our colleagues of the upper air section at Dunstable for their ready co-operation in this work.

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## RELATION BETWEEN THE TERMINAL VELOCITY AND THE DIMENSIONS OF SNOWFLAKES

By F. E. LUMB, M.Sc.

**Summary.**—It is shown that the relationship between the terminal velocity ( $v$ ) of snowflakes and their maximum dimension ( $l_{\max}$ ) can be approximately represented by equations of the form  $v = kl_{\max}^{\frac{1}{2}}$ , where  $k$  is a constant for snowflakes of a particular type.

**Introduction.**—In deriving an expression for the terminal velocity of non-rimed and rimed snowflakes (assumed to be spherical) in terms of the radius, Magono<sup>1</sup> has assumed that a part of the air which collides with the snowflakes passes through them. On physical grounds, one would expect the percolation of air through falling rimed snowflakes to be small and it will be shown that a statistical analysis of the terminal velocities of snowflakes of various sizes confirms that any percolation of air through falling rimed snowflakes is probably very small. Even for non-rimed snowflakes, there is no justification for rejecting the hypothesis that they are impervious to the airflow, but the data for non-rimed snowflakes on which this conclusion is based are rather meagre.

**Theory.**—If snowflakes are in fact impervious to the airflow, a theoretical relationship between the terminal velocity and the size (for any given shape and structure) can be derived as follows:

Let  $V$  = volume of the snowflake

$\sigma$  = density of the snowflake

$\rho$  = density of the air

$g$  = acceleration of gravity

$C_D$  = drag coefficient (a function of the Reynolds number)

$S$  = maximum horizontal cross-sectional area

$v$  = terminal velocity.

In the terminal state, gravitational attraction balances the drag force. Hence

$$V(\sigma - \rho)g = C_D \frac{1}{2} \rho v^2 S. \quad \dots \dots (1)$$

For snowflakes which are three-dimensionally similar in shape, if  $l$  is a specified dimension,  $S \propto l^2$ . Hence for snowflakes of given shape equation (1) becomes:

$$V(\sigma - \rho) \propto C_D \rho v^2 l^2. \quad \dots \dots (2)$$

Magono<sup>2</sup> has measured the density of snowflakes, and given the mean

density of non-rimed snowflakes as  $0.01 \text{ gm cm}^{-3}$ , and of the rimed type as  $0.02 \text{ gm cm}^{-3}$ . Hence  $\rho$  which is of the order of  $10^{-3}$  can be neglected in comparison with  $\sigma$  and equation (2) can be written:

$$d_e^3 \propto C_D \rho v^2 l^2 \quad \dots \dots \dots (3)$$

where  $d_e$  is the diameter of the equivalent raindrop.

Measurements by Langleben<sup>3</sup> have revealed that to a close approximation

$$v \propto d_e^{\frac{1}{16}} \quad \dots \dots \dots (4)$$

for snowflakes of given structure.

Hence combining (3) and (4) we get

$$v \propto C_D^{\frac{1}{3}} \rho^{\frac{1}{3}} l^{\frac{2}{3}} \quad \dots \dots \dots (5)$$

for snowflakes of given shape and structure.

**A test of the theory.**—During a heavy snowfall on 9 December 1950, Magono<sup>1</sup> measured the terminal velocities of snowflakes of various sizes with a stop-watch over a period of four hours and estimated the maximum dimension ( $l_{\max}$ ) by eye.

He classified them by shape as follows:

- (i) horizontal type — flat snowflakes whose shape approximates to that of a thin plate or disc
- (ii) vertical or inverted cone type } —irregular lumpy conglomerations of snow crystals

The maximum dimensions ranged from  $\frac{1}{8}$  cm to 5 cm, and terminal velocities from  $75 \text{ cm sec}^{-1}$  to  $250 \text{ cm sec}^{-1}$ . Hence the Reynolds number  $Re$  varied from  $10^2$  to  $10^4$ .

As  $Re$  decreases from  $10^4$  to  $10^2$ , the proportional increase of  $C_D$  for circular and square plates, spheres, cylinders and cones of given semivertex angle is not more than 50 per cent\*. Hence it is reasonable to assume that over this range of  $Re$  the variation of  $C_D^{\frac{1}{3}}$  for snowflakes of given shape is not more than 6 per cent, and  $C_D^{\frac{1}{3}}$  can be regarded as a constant without serious error. Also over a period of four hours, and at a fixed level of observation,  $\rho^{\frac{1}{3}}$  is practically constant.

Hence equation (6) becomes:

$$v \propto l_{\max}^{\frac{1}{3}} \quad \dots \dots \dots (6)$$

Regression coefficients  $b$  of  $\log v$  on  $\log l_{\max}$  have been calculated using the data given by Magono for the following four categories of snowflakes:

- (a) non-rimed horizontal type
- (b) non-rimed vertical or inverted cone type
- (c) rimed horizontal type
- (d) rimed vertical or inverted cone type

The values of the regression coefficients and their standard errors are given in Table I.

TABLE I—REGRESSION COEFFICIENTS AND STANDARD ERRORS

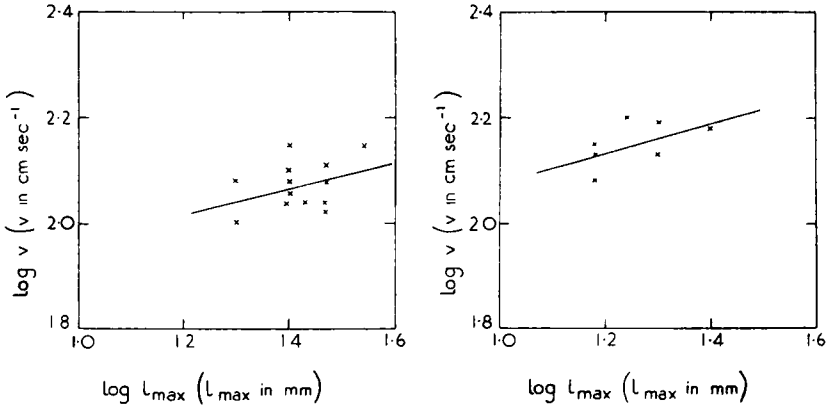
Type of snowflake	No. of observations	Range of $l_{\max}$ in cm	$b$	Standard error of $b$
(a)	13†	2 to $3\frac{1}{2}$	0.242	0.205
(b)	7	$1\frac{1}{2}$ to $2\frac{1}{2}$	0.268	0.191
(c)	28	$\frac{1}{4}$ to $4\frac{1}{4}$	0.239	0.036
(d)	19	$\frac{1}{8}$ to $3\frac{1}{4}$	0.265	0.033

† Excluding one isolated observation for which  $l_{\max} = \frac{1}{8}$  cm,  $v = 90 \text{ cm sec}^{-1}$

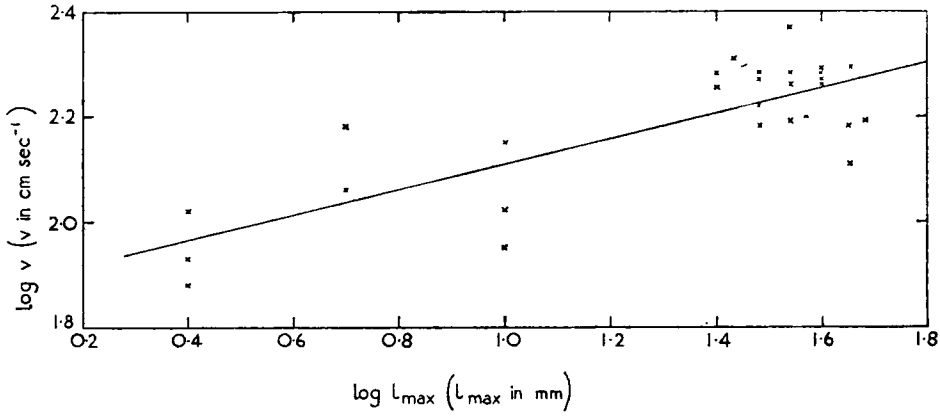
\* I am indebted to Mr. E. W. E. Rogers of the Aerodynamics Division, National Physical Laboratory, for this information.

The corresponding regression lines of  $\log v$  on  $\log l_{\max}$  are shown in Figure 1.

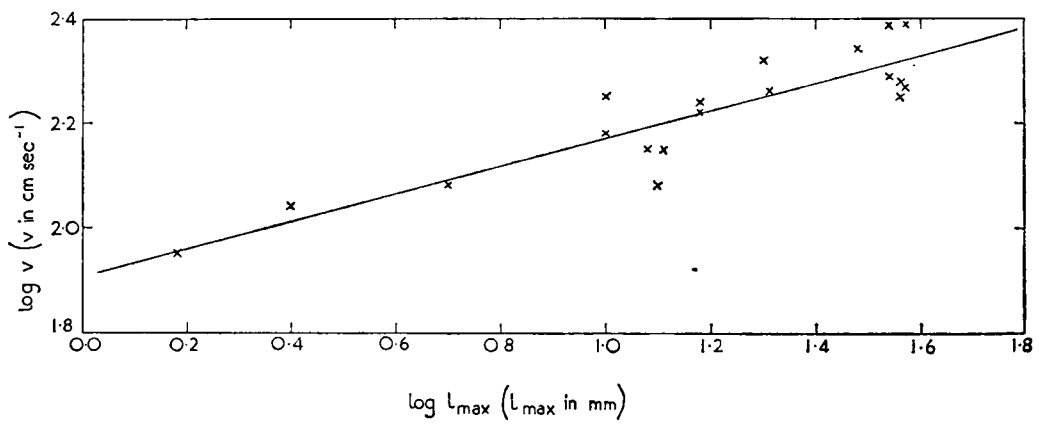
Bearing in mind the visual estimation of  $l_{\max}$  and the crude classification by shape, the differences between the calculated values of  $b$  and the theoretical value of 0.25 are surprisingly small. Applying Student's  $t$ -test, the differences



(a) Non-rimed horizontal type      (b) Non-rimed vertical or inverted cone type



(c) Rimed horizontal type



(d) Rimed vertical or inverted cone type

FIGURE 1—REGRESSION LINES OF  $\log v$  ON  $\log l_{\max}$  FOR FOUR TYPES OF SNOWFLAKE

Based on Magono's data for 9 December 1950

are found to be not significant for all four categories even at the 50 per cent level.

As is clear from Figure 1, the number and range of the measurements for the two rimed categories (c) and (d), are such as to justify the positive conclusion that rimed snowflakes are probably impervious to the airflow. The samples of measurements for the non-rimed categories (a) and (b) are much poorer than for the rimed categories (c) and (d); nevertheless, on the available evidence, there is no justification for rejecting the hypothesis that falling non-rimed snowflakes also are impervious to the airflow.

We therefore conclude that the relationship between  $v$  and  $l_{\max}$  for snowflakes of given shape and structure can be approximately represented by an equation of the form

$$v = k l_{\max}^{\frac{1}{4}} \quad \dots \dots (7)$$

Expressing  $v$  in  $\text{cm sec}^{-1}$  and  $l_{\max}$  in cm, the equation to the best fitting curve (using Magono's data) for each of the four types is obtained by substituting the values of  $k$  given in Table II.

TABLE II—VALUES OF  $k$

Type of snowflake	$k$
(a) non-rimed horizontal	93
(b) non-rimed vertical or inverted cone	123
(c) rimed horizontal	132
(d) rimed vertical or inverted cone	148

These curves are shown in Figure 2 for values of  $l_{\max}$  from  $\frac{1}{4}$  cm to the largest value observed for each category.

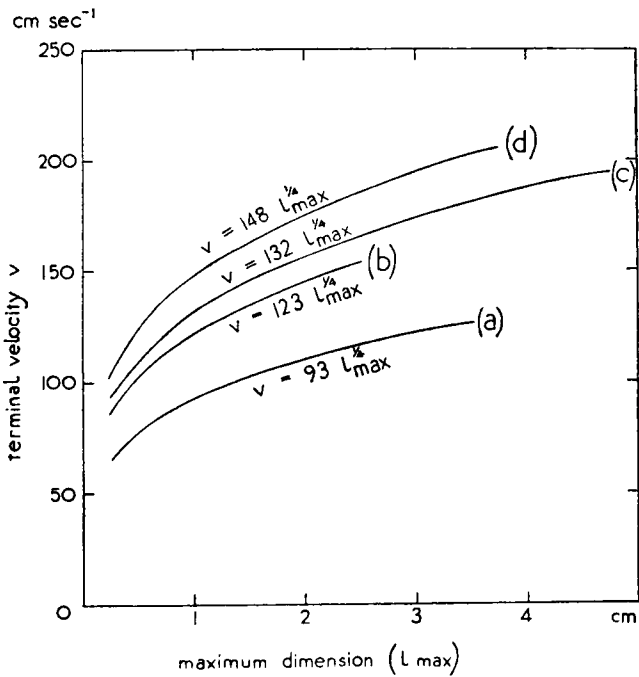


FIGURE 2—TERMINAL VELOCITY OF SNOWFLAKES IN RELATION TO TYPE AND SIZE

Based on Magono's data for 9 December 1950

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551.574 / 13 : 551.576.11

## CIRRUS DEVELOPMENT OBSERVED OVER SINGAPORE AND SOUTH MALAYA

By R. FROST, B.A.

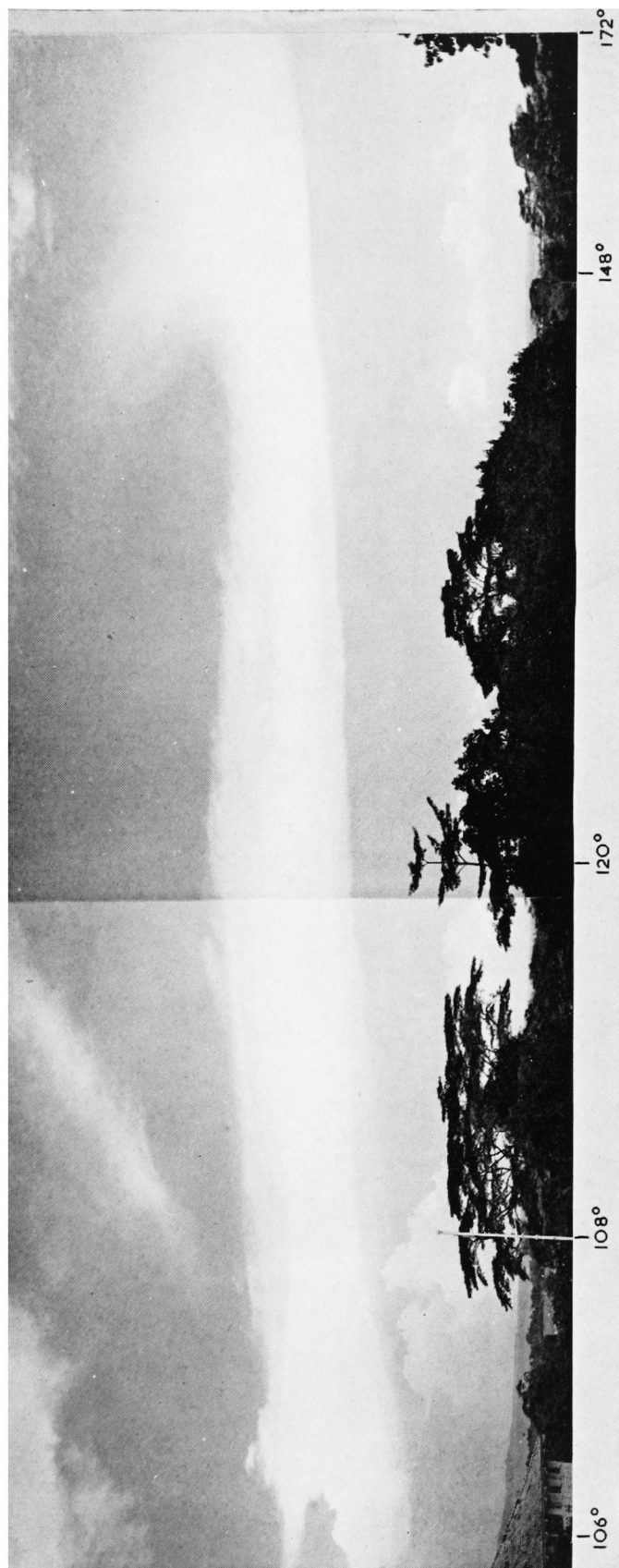
**Introduction.**—Layers of cirrus and cirrostratus cloud are frequently present over Singapore and Malaya, and Littlejohns<sup>1</sup> in an examination of pilots' reports of high cloud between 1954 and 1956 found that cirrus and cirrostratus, but not cirrocumulus, was found on about 90 per cent of all occasions in April, May, June and July. Much of this high cloud is probably explicable in terms of the southern shearline, where the air from the southern hemisphere converges with the belt of equatorial westerlies, which moves northwards with the sun and affects Singapore and Malaya during this period, but the example of cirrus development discussed here, and which has been noted on other occasions, suggests that a not inconsiderable number of occasions is due to false cirrus streaming for long distances downwind from the tops of cumulonimbus clouds which have penetrated into upper layers of very strong winds.

**Observations.**—The photograph facing p. 348 of a false cirrus canopy was taken by the photographic section at Royal Air Force, Changi at my request at 1500 local time on 19 June 1961. The cumulonimbus cloud seen on the extreme left of the photograph is over Bintan Island in Indonesia about 38 nautical miles east-south-east of Changi, which is on the eastern tip of Singapore Island. (The precise location of this storm and the other storms discussed in this note were obtained from the storm warning radar located at Changi.)

When first noticed at 1330 local time the developing cumulus cloud over Bintan Island was, as indicated by the fibrous appearance of its protuberances, in the process of transformation into a cumulonimbus cloud. Shortly afterwards the characteristic anvil cloud began to form but, owing to an obvious increase in wind speed from the east at high levels, the ice particles were sheared off by the wind to form an extensive canopy which by 1500 hours local time extended some 35 nautical miles downwind from its source. The leading edge of the canopy, unfortunately partially cut off in the photograph, shows the rapid increase of wind with height at the lower levels and also the veering and decreasing of the wind at greater heights. A similar but more extensive cloud canopy also developed from a series of cumulonimbus clouds over south Johore to the east-north-east of Singapore and this streamed downwind over Singapore Island. The southern edge of this cloud sheet is just apparent at the top left-hand corner of the photograph.

The upper winds at Paya Lebar at 0730 and 1830 local time are given in Table I and, as can be seen from this table, are moderate westerly from the surface up to about 20,000 feet falling off to light westerly or variable between 20,000 and 30,000 feet and becoming easterly 30 knots at 32,000 feet, while above this height the easterly winds increase up to 46,000 feet and then fall off





*Crown copyright*

FALSE CIRRUS CANOPY TO SOUTH-EAST OF SINGAPORE, 19 JUNE 1961  
(see p. 348)

[To face p 348.



*Photograph by A. Richardson*

RIME ON A STONE WALL AT 2390 FT ON CROSS FELL, CUMBERLAND, AT 1400 HOURS  
18 MARCH 1961



*Photograph by R. M. Brass*

**"JACOB'S LADDERS" ON THE NORTH ATLANTIC**



Crown copyright

TOWNS CO-OPERATING IN THE NATIONAL SURVEY OF ATMOSPHERIC POLLUTION  
(see p. 359)

Each side panel lights up in turn, with the corresponding lights on the map, showing the positions of the conurbations (the six bright patches) and of the towns of population over 100,000, between 50,000 and 100,000, and of 10,000 to 50,000.

TABLE I—UPPER WINDS AT PAYA LEBAR, 19 JUNE 1961

Heights (feet)	Winds at 0730 local time	Winds at 1830 local time
1000	210/03	260/10
3000	270/15	280/16
5000	270/17	280/17
7000	280/23	280/20
10,000	250/15	270/25
12,000	230/14	260/17
14,000	280/05	270/14
19,000	290/09	230/07
25,000	020/03	170/05
32,000	090/30	100/31
36,000	090/36	070/26
41,000	060/43	050/37
46,000	080/58	090/43
50,000	130/32	130/34
54,000	270/05	030/16
62,000	280/12	060/04
63,000	290/13	
68,000		260/24

to light and variable at the tropopause at about 56,000 feet. In the stratosphere the winds become westerly. It is of interest to note that Mr. Sharp, the Senior Meteorological Officer at Changi, with the aid of a clinometer compass found that the angle at which the false cirrus sheared from the cumulonimbus was eight degrees which, with the cumulonimbus located at a distance of 38 nautical miles, gives the height at which the shear commenced as 32,350 feet, in extremely good agreement with the radar winds at Paya Lebar.

The upper air temperatures at Paya Lebar at 0730 local time, given in Table II, show that at 300 millibars (32,000 feet) the air temperature is  $-34^{\circ}\text{C}$  and at 100 millibars (54,000 feet) the air temperature is  $-80^{\circ}\text{C}$ , and it can be seen from these tables that the temperature at the level where the false cirrus sheared from the cumulonimbus cloud was  $-34^{\circ}\text{C}$ . This is consistent with a conclusion by the present writer<sup>2</sup> who, in a discussion of cumulus and cumulonimbus cloud over Malaya, noted that the change-over from cumulus to cumulonimbus cloud occurred between 30,000 feet and 33,000 feet where the

TABLE II—UPPER AIR TEMPERATURES AT PAYA LEBAR ON 19 JUNE 1961 AT 0730 LOCAL TIME

Pressure levels (mb)	Temperatures ( $^{\circ}\text{C}$ )
Surface	24
1000	24
850	27
700	18
600	2
500	-1
400	-17
300	-34
200	-55
150	-70
100	-80

temperatures were between  $-30^{\circ}\text{C}$  and  $-35^{\circ}\text{C}$  with a standard deviation of about  $2^{\circ}\text{C}$ , and pointed out that this was in good agreement with the laboratory experiments of Findeisen and Schultz<sup>3</sup> who, using an expansion chamber of two cubic metres, found with an expansion equivalent to a vertical speed of  $5\text{ m sec}^{-1}$  that there was a very rapid increase in the number of ice crystals at  $-35^{\circ}\text{C}$ .

At 1520 hours local time the pilot of a Meteor aircraft on return to Tengah

on the western side of Singapore Island came out of the canopy of false cirrus from the south Johore cumulonimbus about 30 nautical miles away at a true height of 28,500 feet.

It was observed that the cumulonimbus clouds over Bintan Island and south Johore had all dispersed soon after 1630 hours but the two canopies continued to move downwind and to spread laterally and by sunset, at about 1845 hours, appeared to have merged into one sheet of thin cirrostratus stretching at least 100 miles from their birthplaces. A lunar halo of 22° which was also observed at 2200 hours indicated the presence of ice crystals in the form of hexagonal plates and/or prisms with axes distributed at random in the thin cirrostratus sheet.

**Discussion.**—If for simplicity it is assumed that the ice crystals had fallen from an initial height of 31,500 feet one hour earlier this gives a falling rate of  $\frac{1}{4}$  m sec<sup>-1</sup> for the crystals, which for an approximately spherical crystal corresponds to a radius of 50μ. In actual practice the shapes in which ice crystals are normally found in cirrostratus are not spheres but are hexagonal prisms or hexagonal plates according to photographs by Weickmann<sup>4</sup> and also to the theoretical explanation of the 22° halo, but this value of 50μ appears to be of the right order of magnitude for spherical crystals equivalent in size to the actual crystals.

If the ice crystals move downwind in an environment which is not in general saturated with respect to ice they will commence to evaporate and it is of interest to estimate the “evaporation times” of such crystals. Following Jeffreys<sup>5</sup> if we assume that the ice crystals are at rest relative to the air then the rate of evaporation of an ice crystal of mass *M* in an unsaturated atmosphere is given by

$$\frac{dM}{dt} = 4\pi CD(\rho_a - \rho_s) , \qquad \dots \dots (1)$$

where  $\rho_s$  is the vapour density at the surface of the crystal,  $\rho_a$  is the vapour density at a point remote from the crystal, *D* is the coefficient of diffusion of water vapour in air and *C* is the electrostatic capacity of the crystal. This equation may be used to evaluate the evaporation times of any ice crystals whose shapes approximate to those of conductors of known capacity.

For a sphere of radius *r*, *C* = *r* and *M* =  $\frac{4}{3}\pi r^3 \rho_i$  where  $\rho_i$  is the crystal density, so that equation (1) may be written

$$r \frac{dr}{dt} = \frac{D}{\rho_i} (\rho_a - \rho_s) \qquad \dots \dots (2)$$

If, therefore, *r* is the radius of the crystal at a time *t* and *r*<sub>0</sub> is the radius of the crystal initially

$$r^2 = r_0^2 - \frac{2tD}{\rho_i} (\rho_s - \rho_a) \qquad \dots \dots (3)$$

and it follows, therefore, that the half-life of a spherical crystal of radius *r*<sub>0</sub> is

$$t = \frac{3\rho_i r_0^2}{8D(\rho_s - \rho_a)}$$

so that the larger the ice crystal, and the higher the humidity of the environment, the less rapidly does it evaporate.

The capacity of an ellipsoidal conductor differs only slightly from that of a spherical conductor of the same volume and if the axes of the ellipsoid are

$2r(1 + \alpha)$ ,  $2r(1 + \beta)$ ,  $2r(1 + \gamma)$  where  $(1 + \alpha)(1 + \beta)(1 + \gamma) = 1$ , the capacity is approximately given by

$$C = r \left[ 1 + \frac{2}{15}(\alpha^2 + \beta^2 + \gamma^2) \right]. \quad \dots \dots (4)$$

Initially, therefore, an ice crystal which is ellipsoidal would commence to evaporate at a slightly faster rate than a spherical ice crystal of the same volume. In the case of an ellipsoidal crystal, however, the evaporation would be greatest at the ends of the major axis and least at the ends of the minor axis and would thus tend to promote spherical symmetry and thereby reduce the differential rate of evaporation so that the evaporation times of an ellipsoidal crystal should be of the same order as those of a spherical crystal.

The capacities of hexagonal plates and prisms are difficult to calculate but Mason<sup>6</sup> found that to a first approximation hexagonal plates could be treated as oblate spheroids and hexagonal prisms as prolate spheroids. It can be seen from equation (4) that the capacities of an oblate spheroid and a prolate spheroid are approximately the same and if to get some idea of the shape effect we take  $\alpha = \frac{1}{2}$ ,  $\beta = 0$  and  $\gamma = -\frac{1}{2}$  which corresponds to the case of an oblate spheroid in which the major axis is approximately double the minor axis,  $C = 1.06r$  approximately.

It would thus appear that the theoretical evaporation times of a spherical ice crystal may be taken as representing to a first approximation the actual evaporation times of ice crystals of equal volume but of different shapes.

The only observation of frost points made in the tropics appear to be those made by Kerley<sup>7</sup> between Aden and Nairobi in June 1958 and these suggest that between 20,000 feet and 40,000 feet there is little latitudinal variation in frost point in the tropics. If, therefore, we assume that the frost points over Singapore in June are the same as those at Aden and Nairobi, then the half-life of an ice crystal of  $50\mu$  radius at 300 millibars where the frost point is  $-43^\circ\text{C}$  would be of the order of seven minutes whilst that at 200 millibars where the frost point is  $-63^\circ\text{C}$  it would be about two hours. At 150 millibars where the frost point is  $-77^\circ\text{C}$  the half-life would be about 11 hours and at 100 millibars where the frost point is about  $-85^\circ\text{C}$  the half-life would be about three days.

On the basis of these calculations and assuming a settling rate of  $\frac{1}{4} \text{ m sec}^{-1}$  it would appear that false cirrus cloud originally extending to near the tropopause would have a life of several hours and could during its life be carried several hundreds of miles from its point of origin.

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## A METHOD OF DERIVING 700 MB CHARTS FROM 500 MB THICKNESS PATTERNS

By J. C. GORDON, M.A.

**Introduction.**—Prior to 5 November 1956 composite forecast upper air charts for 500 mb and 700 mb only were issued every six hours at London Airport though, on occasion, composite forecast charts at 200 mb were attempted for research purposes. After this date 300 mb fixed-time forecast charts were issued once daily for planning purposes to three recipients engaged in civil aviation. After 1 June 1957 the routine 500 mb and 700 mb forecast charts were issued with isotachs to all companies at London Airport. Before this date route winds and temperatures were given for each flight across the Atlantic. In addition a twice-daily issue of forecast 300 mb and 200 mb charts was begun. This has been extended so that forecast charts for 700 mb, 500 mb, 300 mb and 200 mb are now issued every six hours with the exception of the period midnight to 0600 GMT. No forecast 200 mb chart is issued for this period as there is a restriction on the departure of turbo-jet powered aircraft from London Airport between those times. The area covered by the forecast upper air charts is from 50°E to 110°W and from 75°N to 25°N. Tropopause and level-of-maximum-wind charts have become necessary and forecast tropopause charts are issued every twelve hours for an area similar to that above. All this brought a big increase in both the plotting and the drawing of upper level charts and some thought was given to finding a method of decreasing this work. The most hopeful line of attack lay in the 700 mb chart, as the number of aircraft flying below 14,000 feet had decreased considerably with the increasing number of turbo-prop and turbo-jet aircraft flying between Europe and North America.

**The method.**—A method was suggested in a paper by Treidl<sup>1</sup> dealing with thickness-temperature relationships over the North Atlantic. He found that the following numerical relationship held for 700–1000 mb thicknesses in the range 9200–9700 geopotential feet:

$$D_{700-1000} = D_{500-700} + 1000 \text{ gpft.}$$

By adding  $D_{700-1000}$  to both sides this gave the relationship

$$\begin{aligned} 2 D_{700-1000} &= D_{700-1000} + D_{500-700} + 1000 \\ &= D_{500-1000} + 1000 \text{ gpft} \end{aligned}$$

and from this the following restricted equivalence table was formed:

$D_{700-1000}$	$D_{500-1000}$
9200 gpft	$\equiv$ 17,400 gpft
9400 gpft	$\equiv$ 17,800 gpft
9600 gpft	$\equiv$ 18,200 gpft.

Because of the simplicity of the relationship it was decided to extend the equivalence table in both directions to cover all thicknesses on the 700–1000 mb thickness chart. The best fit was expected to be found in the region 9200–9700 geopotential feet, but it was hoped that a reasonable agreement would be found outside that range and within the range of the 700–1000 mb thicknesses existing over the North Atlantic routes.

To check the validity of the above relationship two methods were used. In the first the actual 500–1000 mb thickness pattern was used to derive an equivalent 700–1000 mb pattern and then a 700 mb chart was derived by using the actual 1000 mb chart. This 700 mb chart was then compared with the actual



700 mb chart. Such a comparison was carried on for a year and in all 128 pairs of charts were available for comparison. The centres of the highs and lows in nearly every case bore a close relationship to each other especially when strong gradients were present. The main method of comparing the charts was by measuring on both charts the equivalent headwind component on a great circle between Shannon and Gander as described by Harley<sup>2</sup>.

The following is a synopsis of the results of these measurements:

Standard deviation of abbreviated method against actual charts = 3.3 kt

*Distribution of errors*

Errors (kt)	0	1	2	3	4	5	6	7	8
No. of cases	18	30	22	16	17	12	8	3	2
Mean error (kt)	2.6								

Errors greater than five knots were investigated. It was discovered that most of these large errors were associated with strong wind belts near the great circle route with a fairly rapid decrease in gradient to the north. There were also occasions when observations from ocean weather stations Juliett or Coco were not available at either level or available at 700 mb only. These could and did lead to inconsistent drawing of the 700 mb and 500 mb actual charts.

The second method of checking was by using the forecast charts. In a similar manner to that used in the first method a 700 mb forecast chart was derived from the forecast 500–1000 mb thickness pattern. Again this was compared visually with the forecast 700 mb chart derived by the normal method. Again the centres of highs and lows bore a close relationship to each other. The equivalent headwind components were measured on both charts, but in this method these components were not compared with each other. They were compared against the appropriate 700 mb actual chart. This actual chart was the one for a time three hours after the operative departure time from London Airport to which the forecast chart referred. Thus the forecast chart for a departure time of 0900 GMT was compared with the actual chart three hours later at 1200 GMT. Similarly the chart for a 2100 GMT departure was compared with the following actual midnight chart. These comparisons are acceptable as the forecast charts are composite and the time at 30°W, which is approximately halfway between Shannon and Gander, is three hours after departure time. In this way it was possible to compare the two methods of forecasting the 700 mb chart against one another.

At first the equivalent headwind components were measured only between Shannon and Gander but later they were extended to the routes between London and Keflavik and between Keflavik and Gander so as to encompass the area normally used for low-level flights over the North Atlantic. Tables I and III give the standard deviation of the two methods over the various routes, and the standard deviation seasonally over the route Shannon–Gander. Table II is the contingency table giving the errors of the abbreviated method against the

TABLE I—STANDARD DEVIATIONS

Route	Period	No. of cases	Standard deviation (kt)	
			Normal method	Abbreviated method
Shannon–Great Circle–Gander	21 June 1959–22 June 1960	112	6.4	5.7
London–Keflavik	2 Feb. 1960–22 June 1960	40	6.7	7.1
Keflavik–Gander	2 Feb. 1960–22 June 1960	40	10.0	10.1



TABLE III—SEASONAL STANDARD DEVIATIONS

*Route : Shannon—Great Circle—Gander*

	No. of cases	Standard deviation (kt)	
		Normal method	Abbreviated method
March–May ... ..	30	6·7	5·9
June–Aug. ... ..	37	4·9	4·7
Sept.–Nov. ... ..	20	7·2	6·7
Dec.–Feb. ... ..	25	7·1	5·9

normal method on the route Shannon–Gander. The seasonal differences were measured to see whether or not they would show a deterioration in the equivalence table of thicknesses, but such a deterioration is not obvious.

The large standard deviation in the equivalent headwinds between Keflavik and Gander is, in all probability, due mainly to the difficulty in forecasting the movement of surface lows in that area and only slightly to the forecast thickness pattern.

The results in themselves were surprising as it had been expected that the errors of the abbreviated method would at best be of the same order as those of the normal method. Even the distribution of errors as given in the contingency table shows a decrease in the larger errors. A possible reason for the decrease in the errors is that the greater number of lines in the 500–1000 mb thickness pattern leads to a greater discipline in their placing and to a subsequent improvement in the drawing of the associated 700 mb forecast chart. An investigation of the larger errors shows that they usually occurred on both forecast charts simultaneously and that the most probable reason for this was an error on the basic forecast surface chart.

Forecast 700 mb charts are now derived at London Airport by the abbreviated method described above and the area covered by the forecast charts has been extended with success to cover Europe and the Mediterranean as well as the North Atlantic routes. Because of the above results it is possible that some similar method could be used for forecasting the 300 mb chart and work to this end has been started at London Airport.

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## FREQUENCIES OF POOR AFTERNOON VISIBILITIES IN ENGLAND AND WALES

By L. P. SMITH, B.A.

**Introduction.**—The light intensity is a factor of great importance in horticulture, especially where crops are raised under glass. Unfortunately it is only in recent years that accurate measurements of this factor have been attempted on a regular basis. It was therefore desirable to attempt an oblique approach to the subject by considering the extent of haze present in the atmosphere and the simplest way to do this was by analysing the visibilities in the afternoon, when water fogs were most likely to be absent.

**Method.**—This work was carried out some years ago by the Agricultural Branch at Harrow and the records of visibility contained in the *Monthly Weather Report* from 1923 to 1951 were used. Two difficulties were encountered. Firstly the time of the afternoon observation changed twice during this period. From 1923 to July 1944 it was at 1300h; from then until December 1944 it was at

1200h; from 1945 onwards it was at 1500h. These changes had perforce to be ignored. Secondly of the 61 stations which made such reports for periods longer than five years only 17 had complete records.

Two parameters were considered: (a) the number of occasions per month with afternoon visibilities less than 4400 yards (Code Figure 5 or less), and (b) similar occasions with visibilities less than  $6\frac{1}{4}$  miles (Code Figure 6 or less) and a system of weighting had to be adopted. Of the 44 stations with incomplete records, 19 were weighted with respect to three neighbouring stations, the final answer being taken as the mean of the three weightings. Of the remainder, 16 were weighted with respect to two stations and nine with respect to one only. In this process it was clear that some stations had unreliable records, probably owing to the absence of suitable visibility points. The suspected results are enclosed in brackets in the accompanying tables.

**Results.**—The network of stations is shown in Figure 1. Such a network obviously leaves large gaps but the results were found to be generally consistent

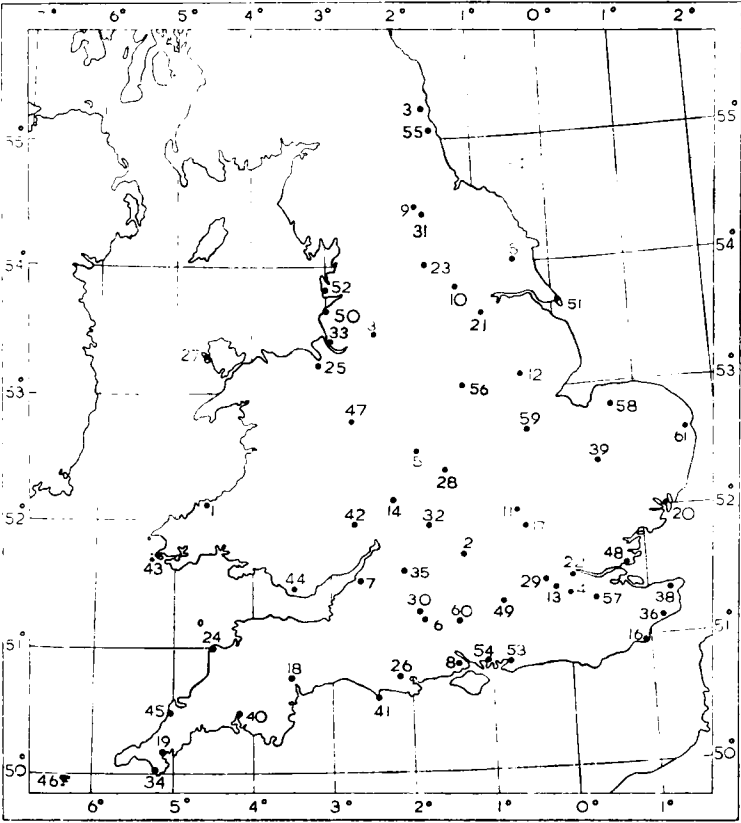


FIGURE 1—STATION MAP

Table I gives the place names represented by the numbers on this map.

in other areas. Table 1 shows the final results in a seasonal summary; winter was assumed to comprise December to February, spring March to May and so on.

About half the days of the year when the afternoon visibilities are below 4400 yards occur during the winter quarter, except in the south-west where the proportion is lower. As might be expected the summer fraction is very small, and about a quarter of the yearly total occurs in autumn. Inland in spring such days

TABLE I—AVERAGE DAYS PER SEASON, OVER PERIOD 1923–51, WITH AFTERNOON  
VISIBILITIES (a) <4400 YARDS AND (b) <6¼ MILES

	Spring		Summer		Autumn		Winter		Year	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
	<i>number of days</i>									
1. Aberporth	3.0	13.0	2.5	10.3	1.9	12.4	3.7	19.2	11.1	54.9
2. Abingdon	3.5	22.0	1.3	12.1	7.9	27.6	15.2	37.2	27.9	98.8
3. Acklington	7.3	22.5	4.7	20.8	10.2	25.0	14.4	29.0	36.6	97.3
4. Biggin Hill	8.7	37.1	3.3	20.7	16.7	44.3	28.3	60.3	57.0	162.4
5. Birmingham	22.4	49.0	5.9	19.3	26.4	50.4	46.5	70.7	101.2	189.4
6. Boscombe Down	5.3	25.0	1.4	13.1	7.7	29.7	18.6	41.3	33.0	109.1
7. Bristol	6.4	23.5	1.4	11.2	13.9	34.6	21.7	52.4	43.4	121.7
8. Calshot	5.3	31.4	1.8	18.1	7.3	31.7	16.5	50.2	30.9	131.4
9. Catterick	11.5	32.1	5.6	23.9	17.4	34.9	27.6	45.4	62.1	136.3
10. Church Fenton	11.2	47.1	3.6	36.2	16.8	47.2	32.8	64.6	64.4	195.1
11. Cranfield	5.7	26.3	1.3	14.8	9.1	31.2	16.6	47.0	32.7	119.3
12. Cranwell	6.4	35.1	2.0	20.4	13.5	44.8	29.7	65.1	51.6	165.4
13. Croydon	15.1	48.3	2.7	17.6	22.2	53.0	41.2	82.2	81.2	201.1
14. Defford	4.7	31.8	1.6	16.2	6.4	27.6	19.2	42.5	31.9	118.1
15. Driffield	7.1	32.2	2.1	24.0	12.4	38.9	25.4	50.6	47.0	145.7
16. Dungeness	9.0	38.4	5.8	29.5	8.5	33.9	16.1	47.3	39.4	149.1
17. Dunstable	7.3	34.4	3.2	21.3	11.9	39.8	22.9	58.3	45.3	153.8
18. Exeter	3.1	13.9	1.2	7.1	3.8	15.3	6.8	19.0	14.9	55.3
19. Falmouth	5.9	20.3	1.8	13.5	2.7	16.0	3.2	21.4	13.6	71.2
20. Felixstowe	8.5	31.6	2.3	17.5	10.4	35.5	23.9	51.2	45.1	135.8
21. Finningley	9.3	35.1	2.8	34.9	14.0	49.6	31.4	66.0	57.5	185.6
22. Greenwich	19.3	69.4	1.1	22.6	33.1	72.7	64.8	90.3	118.3	255.0
23. Harrogate	(16.6)	32.8	(11.8)	25.0	(27.1)	37.7	(37.5)	50.2	(93.0)	145.7
24. Hartland Point	3.1	16.2	4.1	12.6	2.4	14.3	4.9	16.1	14.5	59.2
25. Hawarden	13.0	40.3	4.2	22.4	18.0	42.4	29.2	53.1	64.4	158.2
26. Holton Heath	7.3	26.7	3.4	15.4	9.6	30.4	16.9	41.8	37.2	114.3
27. Holyhead	6.3	27.5	4.7	18.7	4.9	19.9	8.2	29.8	24.1	95.9
28. Honiley	10.7	36.9	4.2	19.9	16.6	42.1	29.3	54.2	60.8	153.1
29. Kew	13.1	45.7	1.4	13.6	19.9	49.7	42.5	79.0	76.9	188.0
30. Larkhill	3.5	17.4	0.8	8.9	6.1	22.7	14.0	38.1	24.4	87.1
31. Leeming	9.4	30.8	4.5	22.5	12.8	32.4	22.2	39.6	48.9	125.3
32. Little Rissington	8.8	22.1	1.8	9.1	14.1	28.2	26.1	41.3	50.8	100.7
33. Liverpool	15.6	35.5	6.4	22.2	19.8	36.6	29.0	43.4	70.8	137.7
34. Lizard	7.7	20.8	8.0	17.1	6.6	17.0	7.2	20.6	29.5	75.5
35. Lyneham	5.1	23.1	1.1	9.1	7.6	27.0	14.2	43.8	28.0	103.0
36. Lympne	8.7	30.8	3.6	17.4	12.6	36.1	26.3	54.4	51.2	138.7
37. Manchester	14.5	45.1	4.9	29.4	22.1	53.8	37.5	69.8	79.0	198.1
38. Manston	8.7	33.7	2.3	21.1	11.7	35.7	22.5	53.7	45.2	144.2
39. Mildenhall	3.6	21.7	0.9	9.9	7.9	33.0	21.9	52.3	34.3	116.9
40. Plymouth	5.0	24.0	4.1	15.6	5.8	25.7	11.2	39.3	26.1	104.6
41. Portland Bill	4.9	24.9	3.0	16.8	3.5	19.5	4.9	24.5	16.3	85.7
42. Ross-on-Wye	6.2	24.7	2.0	12.4	11.3	28.9	15.6	37.9	35.1	103.9
43. St. Ann's Head	9.0	29.9	6.2	22.2	5.7	22.7	9.5	29.3	30.4	104.1
44. St. Athan	12.5	30.5	4.7	20.8	17.9	30.0	22.2	40.9	57.3	122.2
45. St. Eval	5.0	24.3	2.6	13.5	6.3	20.0	10.4	25.6	24.3	83.4
46. Scillies	6.4	27.2	6.4	19.4	6.3	23.0	6.0	25.6	25.1	95.2
47. Shawbury	8.4	31.7	1.9	17.4	11.1	31.9	20.9	41.4	42.3	122.4
48. Shoeburyness	6.4	29.5	1.6	17.3	10.5	35.2	21.6	53.2	40.1	135.2
49. South Farnborough	6.9	30.6	1.2	15.2	11.4	35.0	22.8	52.9	42.3	133.7
50. Southport	(22.5)	40.7	(9.2)	23.2	(33.6)	47.6	(45.6)	65.1	(110.9)	176.6
51. Spurn Head	11.3	43.2	5.5	36.1	11.6	47.4	24.6	60.2	53.0	186.9
52. Squire's Gate	11.1	25.9	4.0	18.1	19.3	46.5	41.6	61.4	76.0	151.9
53. Tangmere	6.4	36.2	1.9	20.9	9.3	33.4	20.0	56.4	37.6	146.9
54. Thorney Island	4.6	27.3	1.4	16.1	6.6	34.3	17.2	52.2	29.8	129.9
55. Tynemouth	8.5	38.9	5.1	32.5	14.1	46.5	28.0	62.0	55.7	179.9
56. Watnall	14.2	37.4	4.7	25.9	22.9	56.7	42.1	70.8	83.9	190.8
57. West Malling	12.8	27.2	4.3	14.7	15.2	32.7	30.6	56.0	62.9	130.6
58. West Raynham	4.2	26.3	1.2	15.0	7.7	41.3	18.9	50.6	32.0	133.2
59. Wittering	6.3	32.6	2.8	22.4	12.0	43.5	21.2	60.8	42.3	159.3
60. Worthy Down	4.1	18.8	2.5	10.2	8.6	26.6	16.3	39.3	31.5	94.9
61. Yarmouth	8.2	(57.0)	2.7	(43.3)	6.9	(53.9)	17.6	(66.4)	35.4	(220.6)

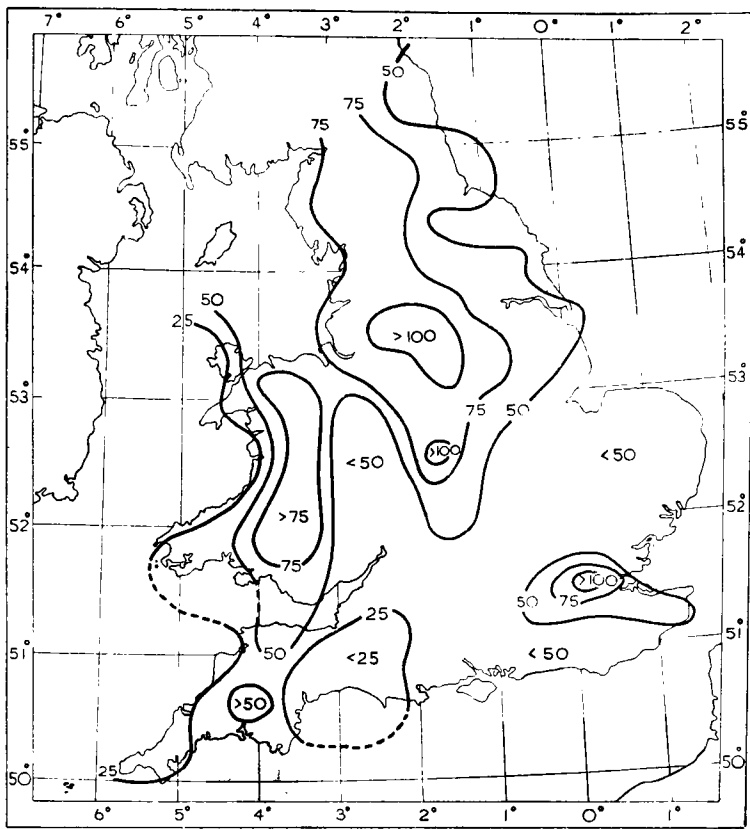


FIGURE 2—AVERAGE NUMBER OF DAYS PER YEAR WITH AFTERNOON VISIBILITIES  
LESS THAN 4400 YARDS

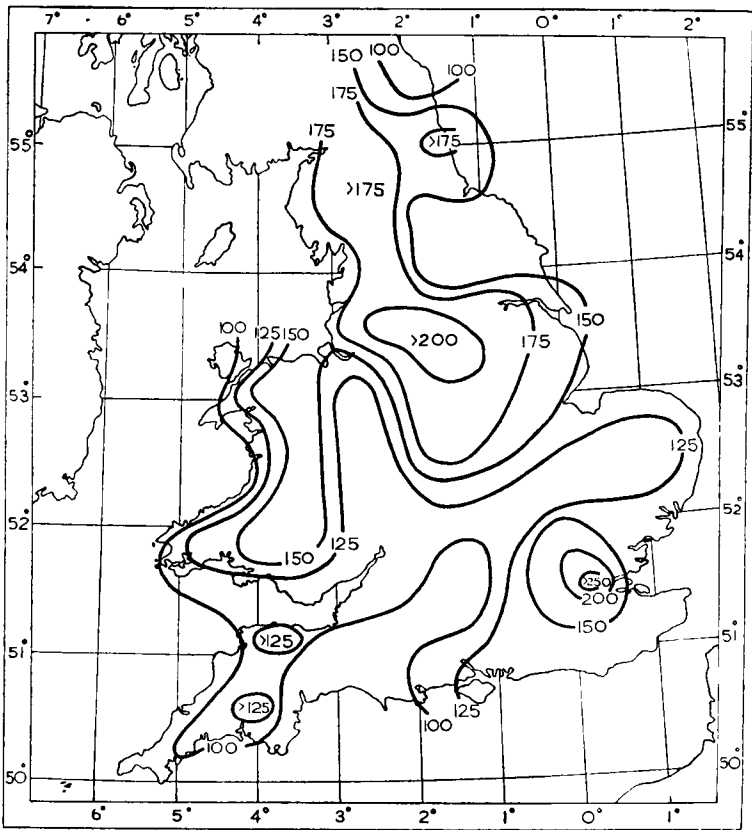


FIGURE 3—AVERAGE NUMBER OF DAYS PER YEAR WITH AFTERNOON VISIBILITIES  
LESS THAN 6  $\frac{1}{4}$  MILES

are relatively rare but on the coast, especially in the south-west, the proportion is higher, which suggests that such occasions are more likely to be due to the low cloud or sea fog rather than haze.

The yearly totals have been illustrated in two maps, Figures 2 and 3. The extrapolation of the isopleths over high ground called for a certain degree of imagination, but the general picture is reasonably satisfactory and bears a close resemblance to maps of coal consumption. The effect of the main industrial areas is obvious, and it is worthy of note that Kent seems to suffer London smoke more than Essex.

To obtain the clearest representation of the monthly distribution, the stations were grouped together as follows:

(i) town (ii) country (iii) north-east coastal (Tynemouth to Yarmouth) (iv) south-east coastal (Felixstowe to Calshot) (v) south-west coastal (Portland Bill to Holyhead) (vi) north-west coastal (Hawarden to Squire's Gate).

TABLE II—MEAN MONTHLY DISTRIBUTION (PERCENTAGES OF ANNUAL TOTAL) OF POOR AFTERNOON VISIBILITIES

(a) *Afternoon visibilities < 4400 yards*

Type of Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						<i>per cent</i>						
Town	18.2	12.1	9.9	4.2	3.7	1.7	1.6	2.0	3.0	8.2	16.2	19.2
Country	18.8	11.3	9.9	3.7	3.0	1.6	1.9	2.3	3.0	7.8	15.8	20.9
NE coastal	18.4	11.7	10.0	4.9	4.7	3.2	2.6	3.3	3.6	6.4	12.4	18.8
SE coastal	18.7	13.3	10.6	4.2	3.1	1.7	2.2	2.5	4.0	6.8	13.2	19.7
SW coastal	12.4	10.3	12.3	7.6	7.0	6.4	6.3	7.4	6.9	7.1	7.0	9.3
NW coastal	16.8	14.4	10.3	4.1	2.9	2.5	1.1	2.3	2.7	8.9	15.2	18.8

(b) *Afternoon visibilities < 6½ miles*

Type of Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						<i>per cent</i>						
Town	12.9	10.7	10.2	6.8	6.2	4.5	4.0	4.2	5.8	8.9	12.2	13.6
Country	13.5	10.0	10.2	6.3	6.0	4.5	4.3	4.8	5.7	8.8	12.1	13.8
NE coastal	12.1	9.3	9.3	6.6	6.5	5.7	6.5	6.6	6.7	8.1	10.7	11.9
SE coastal	13.3	10.7	10.1	6.6	6.5	4.7	4.6	4.9	5.8	7.6	11.5	13.7
SW coastal	11.3	9.8	12.0	7.8	7.6	6.7	6.3	6.4	6.5	8.5	8.0	9.1
NW coastal	12.6	10.2	10.2	5.7	6.0	4.4	3.7	5.0	6.1	9.6	12.4	14.1

With the exception of the south-west coastal stations, this distribution appears very uniform and, on allowing for the number of days per month, the values fit a fairly smooth curve. In the south-west coastal stations there appears a maximum frequency in March, the most likely time for sea fogs.

The results are given in Table II, and if allowance is made for the differing number of days per month, they fit a series of fairly smooth curves showing the annual variation. The March maximum on the south-west coasts is presumably a sea-fog effect, but it is impossible to eliminate this factor with the simple method of analysis used.

## NOTES AND NEWS

### National Survey of Atmospheric Pollution

*Scope of Survey shown at Clean Air Exhibition, Brighton*

Towns and cities taking part in the National Survey of Atmospheric Pollution were named for the first time by the DSIR's Warren Spring Laboratory at the Clean Air Conference and Exhibition in Brighton from 4-6 October 1961. Atmospheric pollution from various sources costs the country about £250,000,000 a year. The aim of the National Survey, which is organized by the Laboratory, is to provide more detailed information about the two major

sources of pollution—smoke (mainly from domestic chimneys) and sulphur dioxide (from industrial sources).

Measurements of air pollution have been made over a number of years by an increasing number of local authorities and other bodies. The usefulness of this information will now be increased by measurements taken in a number of additional towns, chosen on a valid statistical basis to give a representative picture of the distribution of pollution throughout the country. The National Survey is thus made up of measurements from the representative sample towns and from towns already taking daily readings. The main exhibit by the Warren Spring Laboratory at the Brighton Conference was a large map of Great Britain (facing p. 349), illuminated to show the towns which are co-operating with DSIR in the Survey.

Thirty-eight per cent of all the people in England and Wales live in the six conurbations of Greater London, south-east Lancashire, west Midlands, west Yorkshire, Merseyside and Tyneside. These conurbations are large groups of built-up areas and their special air pollution problems require detailed study. Measurements are being made in all six and also in all 30 of the towns outside the conurbations with a population of 100,000 and over, in which 13 per cent of the people of England and Wales live and work. It is planned to include all these towns in the representative section of the Survey.

A further eight per cent live in 32 towns outside the conurbations with a population of between 50,000 and 100,000. About half of these towns are already in the representative section of the Survey and the number will eventually be increased to 27.

A representative sample of about 30 towns is also being chosen from the 66 towns outside the conurbations with a population of between 10,000 and 50,000, which house a further 17 per cent of people in England and Wales. The remaining 24 per cent of the population live in towns of under 10,000 or in rural districts. Although small towns and villages are not shown on the air pollution map, about 70 authorities in this group are making measurements and, in addition, a representative sample of places of this size is now being selected by the Warren Spring Laboratory. Measurements already being made in Scotland and Northern Ireland form a fair representative sample of towns of different sizes in these areas.

## REVIEWS

*The earth's problem climates*, by Glenn T. Trewartha. 10 in. × 7 in., pp. vi + 334, illus., University of Wisconsin Press, 430 Sterling Court, Madison 6, Wisconsin, 1961. Price: \$7.50.

In this major work Professor Trewartha has attempted a new approach to climatology which is to be highly commended. He has covered almost the whole earth and has attempted not only to list and describe the more important of its problem climates but also to suggest explanations for them in dynamical terms.

The book begins by considering the generalized world pattern of climatic distribution that should result from the operation of the planetary controls of solar energy distribution and general circulation as modified by the differential effects of oceans and continents. Climatic features of the actual continents which differ markedly from those which would be expected on a hypothetical continent are the *problem climates* which the author considers and attempts to explain, although his explanations are not claimed to be necessarily the final or correct ones.



Part I deals with "Latin America" and consists of five chapters, the first two of which have the same title—Pacific South America: Part II with "Australia—New Zealand and the Equatorial Pacific" in one chapter: Part III with "Africa" in four chapters: Part IV with "Southern and Eastern Asia" in three chapters: Part V with "Europe and the Mediterranean Borderlands" in three chapters, two of which have the same title—"Mediterranean Lands": and Part VI with "Anglo-America" in four chapters.

Although the book is aimed at a professional audience it is a pity that the author assumes that his readers are already familiar with the modified Köppen classification as outlined in his earlier book *An introduction to climate* and also with Thornthwaite's system. Both of these systems are employed in the book and it would not have added appreciably to its length if it had been made more self-contained in this respect. Neither does it help readers who are not too familiar with these alphabetic classifications that the coloured folding map showing the distribution of climatic types according to the first of these systems faces the wrong way for easy reference. Another minor irritation is the mixture of units that is employed. Most of the discussion concerns anomalies of temperature and of precipitation, but temperatures are sometimes given in °C, sometimes with the scale unstated, and sometimes in °F, while rainfall amounts are given sometimes in inches and sometimes in millimetres.

In the earlier chapters the author's declared aim of describing and attempting to explain problem climates is faithfully followed, but as the work proceeds Professor Trewartha tends to confine himself more to descriptive climatology.

The book is illustrated with a large number of useful and well drawn maps and diagrams and has at the end a lengthy list of explanatory notes and references. It is well produced and clearly printed on good quality paper.

H. C. SHELLARD

*Weathercraft*, by L. P. Smith. 8½ in. × 6 in., pp. 87, *illus.*, Blandford Press, 16 West Central Street, London W.C.1., 1960. Price: 9s. 6d

This book is a creditable and, on the whole, successful attempt to show the layman how a modest knowledge of meteorology can be turned to account in the garden. The author treats first of the weather "in general" and then "in particular", for example with particular reference to the forecasting of frost, climate under glass, soil temperatures, water need and the importance of aspect and site. Twenty-eight simple experiments are suggested. The photographs, pictures and graphs are clear and instructive. There are also some useful tables which relate rainfall at different seasons and in different parts of the United Kingdom to water need.

"Weathercraft" will be of particular interest to amateur and market gardeners and to those schools where agricultural science is taught as a special subject. The author has, however, tried to cast his net too widely and this has led to a sense of unbalance which destroys the unity of the book as a whole. The market gardener is unlikely to waste his time with experiment No. 8: "Select a few old weather sayings which you think likely to be true. Test them against the truth, either from past records or from current happenings." On the other hand there is a largely irrelevant, though interesting, chapter at the end of the book devoted to sailing small boats in squally weather. Although the author has obviously done all he can to cut down instrumentation to a minimum, nothing is said about the cost of essential instruments or where they may be bought: matters of primary importance to school-teachers.

Nevertheless this book can be positively recommended to those who are beginners in the study of agricultural meteorology. It is also to be hoped that Mr. Smith will be encouraged to write again for those who are interested in the practical study of meteorology at a humble level. Why not, in our largely urban and cancer-conscious community, "Air pollution without tears"?

J. B. RIGG

### OFFICIAL PUBLICATION

*Handbook of meteorological instruments, Part II—Instruments for upper air observations.* The *Handbook of meteorological instruments* is a comprehensive survey of the technical equipment necessary for the operation of a modern meteorological service. It gives detailed information on the design, installation, operation and maintenance of the instruments used at the stations of the Meteorological Office, together with some information about other types of meteorological instruments to illustrate different principles. Part I, which deals with the instruments used for surface observations, was published in 1956. Part II, published recently, is concerned with the equipment used for observations in the upper air to heights of about 40 kilometres.

This second volume is a comprehensive guide to the upper air instruments that are now available and it forms a book of reference on the subject. It starts with a survey of the historical development of upper sounding. Six chapters are concerned with the application of radio and radar techniques to the measurement of the physical properties of the free atmosphere and there are chapters on instruments for meteorological observations from aircraft and on the methods of measurement in cloud physics. The volume, which is illustrated with 51 plates and 47 diagrams and is fully indexed, includes a glossary of technical terms and a bibliography.

### CORRIGENDA

#### **Fronts investigated by the Meteorological Research Flight**

In the July 1961 *Meteorological Magazine* the key to wind speed in Figure 5(b), page 199, should read (Positive from SW) and the temperatures in Figure 6(b), page 201, should be negative.

### OBITUARIES

*Mr. B. J. Blower.* It is with deep regret that we learn of the sudden death on 24 August 1961 of Mr. B. J. Blower, Experimental Officer, at the age of 56. "Bill" Blower was a much loved personality—a kindly and genial west countryman with a whimsical sense of humour. He joined the Office in August 1934 after service in the Royal Air Force and served at several stations at home and overseas. During the war he was commissioned as a Flying Officer in the Royal Air Force in which capacity he gave valuable service. In 1949 after a tour of duty at Malta he was posted to the Observations and Communications Branch at Dunstable where he remained until his death. As a member of the staff he was most conscientious and had a reputation for meticulous orderliness in his work, while as a colleague he gained the respect and affection of all who worked with him.

He leaves a widow, one daughter and two sons to whom we extend our deepest sympathy.

*Mr. P. R. Brown.* The death of Paul R. Brown on 30 September 1961 at his home in Wokingham near Bracknell at the early age of 45 came as a great shock to his family and to his friends and colleagues in the Meteorological Office.

He obtained a B.Sc. (Special) degree and A.R.C.S. in physics with subsidiary pure and applied mathematics, together with the D.I.C. and M.Sc. (London) in meteorology, before joining the Meteorological Office as a Technical Officer in October 1938. After undergoing a training course, he transferred to the Irish Meteorological Service in January 1939, where he was employed in forecasting duties at the original Shannon Airport flying-boat base at Foynes, County Limerick. Mr. Brown rejoined the Meteorological Office in November 1944, at Prestwick Airport, and was commissioned as Flight Lieutenant R.A.F.V.R. in April 1945. In March 1946 he was posted to the Far East where he served in Burma, Singapore and Japan. In 1946 he was promoted to Squadron Leader, and was released from the Royal Air Force on return to the United Kingdom in February 1948.

Owing to ill health it was not until October 1950 that Mr. Brown returned to the Meteorological Office and joined the Marine Division as a Scientific Officer. He was promoted Senior Scientific Officer in July 1954 and in November 1960, as a result of reorganization inside the Meteorological Office, was transferred to the Climatological Services Division.

During the first half of his ten years in the Marine Division, Mr. Brown was primarily engaged in marine climatology, for which he showed considerable liking and aptitude. His published work included papers on the meteorological aspect of cargo and ventilation; evaporation, humidity and condensation in enclosed spaces; climatic fluctuation in northern waters; humidity over the Atlantic; wave data for eastern North Atlantic and ice in the Newfoundland region. Further papers by him on climatic fluctuations over the oceans were read for him at the WMO/UNESCO Rome Symposium on Climatic Change a few days after his untimely death. He was responsible for the preparation of the atlas of monthly meteorological charts of the Greenland and Barents Seas. During the latter part of his stay in the Marine Division, he divided his time between climatology and the big task of building up the punched card installation, which was originally employed entirely for the work of the Marine Division, but which gradually extended its activities to the work of the whole Office. How well he did this job is shown in the efficiency of the large and comprehensive punched card installation at Bracknell which now forms part of the Support Services Division. While in the Marine Division, Mr. Brown was also responsible for providing meteorological evidence in connexion with marine inquiries held by the Ministry of Transport into shipping casualties.

Paul Brown was a sincere and friendly colleague who unfailingly gained the confidence of all those who worked with him. He leaves a widow and a young son.

C.E.N.F.

## **METEOROLOGICAL OFFICE NEWS**

### **Gassiot Fellowships**

Mention was made of the two Gassiot Fellowships in our May and July 1961 issues. The second Gassiot Fellow, Dr. H. M. Iyer, has now arrived in this country to take up his appointment. Dr. Iyer is of Indian nationality. He was

born in 1931 and educated in India and at London University, where he took his Ph.D. degree in 1959. He has been concerned with seismological studies for some time and has contributed extensively to the literature of the subject. Apart from theoretical and laboratory studies at Bracknell he will use Kew and Eskdalemuir Observatories as seismological field stations.

### **Report on the first season of the Bracknell Meteorological Office Cricket Club**

The Bracknell Meteorological Office Cricket Club was formed in April 1961 under the chairmanship of Lt. Cdr. L. B. Philpott. The new Club is a merger of three former cricket clubs from Harrow, Dunstable and Victory House.

In spite of the fact that no home ground was available, "away" fixtures were arranged without great difficulty and there was enough cricket throughout the season to keep all members interested. Although a rather limited club membership made it difficult at times to field a strong side, the season was a reasonably successful one, as far as the results of the matches were concerned. However, with the prospect of a larger club membership next season and hopes that the club will then be able to run two teams, the outlook for the future seems even brighter.

Thanks are due to Lt. Cdr. L. B. Philpott and Mr. P. J. Cutting who were largely responsible for the formation of the club and the arrangement of fixtures. Overall results of the matches and the best batting and bowling averages are tabulated below.

		MATCHES				
		Played 14	Won 6	Drawn 0	Lost 8	
BATTING AVERAGES—FOUR COMPLETED INNINGS TO QUALIFY						
Batsman		No. of innings	Not out	Highest score	Runs	Average
R. Burns	...	9	2	47*	199	28.43
C. Hawson	...	6	1	51*	85	17.00
F. Reece	...	12	3	54*	153	17.00
P. Edwards	...	7	3	20	51	12.75
D. Clark	...	8	0	30	82	10.25

\* Not out

BOWLING AVERAGES						
Bowler		Overs	Maidens	Runs	Wickets	Average
B. Butler	...	21.1	4	85	13	6.54
B. Morris	...	12.5	2	77	9	8.55
J. Nicholas	...	50	5	186	21	8.86
F. Reece	...	19	1	97	9	10.78
J. Cockburn	...	45	12	216	17	12.71
P. Edwards	...	55	9	198	15	13.20

### **Staff suggestions scheme**

*Mr. W. Wallace*, Temporary Radio (Meteorological) Technician, was awarded £25 for his suggestion for a modification to "Mufax" chart recorders.

*Mr. M. C. Cottom*, Technical Grade III, was awarded £10 for his suggestion about the adjustment of "Mufax" recorders by means of a locally produced phasing pulse.

*Mr. P. Powell*, Senior Experimental Officer, was awarded £3 3s 0d for his suggestion about the provision of holders and refills in place of the present chinagraph pencils.

*Mr. J. R. Green*, Executive Officer, was awarded £1 1s 0d for his suggestion about the introduction of a standard form for claiming transfer grants.