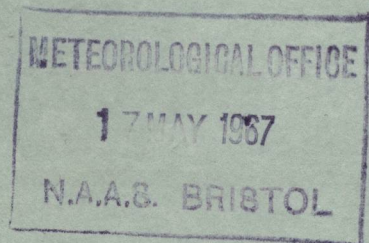


Met.O.785

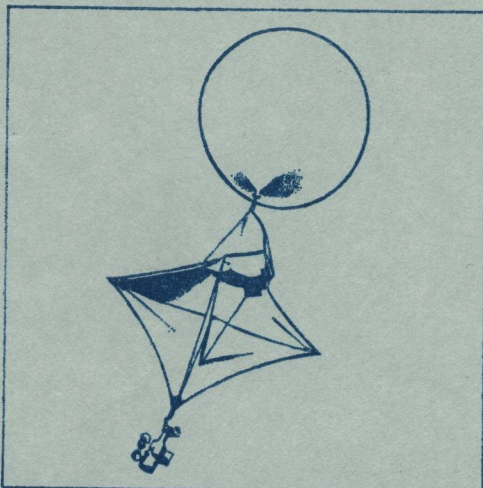
METEOROLOGICAL OFFICE

*the*  
*meteorological*  
*magazine*



MAY 1967 No 1138 Vol 96

Her Majesty's Stationery Office



*high  
performance*

**BERITEX SEAMLESS SOUNDING  
BALLOONS · PILOT BALLOONS  
CEILING BALLOONS AND  
HIGH ALTITUDE BALLOONS**

Beritex seamless Meteorological Balloons, made from top-grade rubber, fly higher more consistently. Supplied to Meteorological Stations in fifty-five countries, Beritex balloons set the standard in Meteorological Balloons.

Produced under the strictest laboratory controls, Beritex balloons are available to users in this country. Ask for the full catalogue to be mailed to you from:

**GUIDE BRIDGE RUBBER CO. LTD., BURY, LANCS., ENGLAND**  
A Member of the Phillips Group of Companies



*Beritex*

# MARK 111 RAINGAUGES

**THE STANDARDISED RAINGAUGE  
SYSTEM PRODUCED IN PLASTICS BY**

# ARTECH

**APPROVED BY AND SUPPLIED TO  
THE METEOROLOGICAL OFFICE**

**MANUFACTURED WITH 150 SQ. CM.  
AND 750 SQ. CM. INTERCHANGEABLE  
COLLECTORS**

**ARTECH METEOROLOGICAL LTD.**  
**The Parade . Frimley . Camberley . Surrey**

# THE METEOROLOGICAL MAGAZINE

Vol. 96, No. 1138, May 1967

551.577.36(420+429):519.2

## SEQUENCES IN MONTHLY RAINFALL OVER ENGLAND AND WALES

By R. MURRAY

**Summary.**—Monthly rainfall totals over a 100-year period for England and Wales were classified by size into terciles (dry, average and wet) and various tables are presented. The frequency of runs of 1, 2, 3, etc., months of the various types is generally in close agreement with the frequency expected based on the climatological probability of occurrence of the type, i.e. the weather of one month is in general independent of the weather of another month. Runs beginning in specified months show general agreement with expected frequencies but a few of these runs show differences which should be borne in mind until further evidence is available. It is not possible at present to reach firm statistically based conclusions about their significance.

**Introduction.**—Earlier work on sequences of wet and dry months has been done by various meteorologists, notably by Glasspoole,<sup>1</sup> Hawke,<sup>2</sup> Bilham<sup>3</sup> and McIntosh.<sup>4</sup> In general it appears to have been concluded that rainfall persistence is of some importance although the chance of any month being 'wet' or 'dry' is not much different from random expectation. In long-range forecasting, monthly rainfall is dealt with in terciles and therefore it was thought worthwhile finding out whether runs of one, two, three, etc., months of various types as specified by rainfall terciles are more likely or less likely to occur than might be expected by chance at different times of the year. For this purpose 100 years of monthly rainfall data for England and Wales (1866–1965), taken as a whole, were classified as nearly as possible into terciles  $R_1$ ,  $R_2$  and  $R_3$ , and analysed by computer. The tercile boundaries used in the classification each month are shown in Table I.

TABLE I—TERCILE BOUNDARIES OF ENGLAND AND WALES MONTHLY RAINFALL IN INCHES (1866–1965)

Tercile		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	<	2.7	1.8	1.7	1.8	1.9	1.8	2.3	2.7	2.3	2.9	2.7	3.0
3	>	4.2	3.3	2.9	2.7	2.8	3.0	3.8	3.9	3.6	4.4	4.3	4.2

**Sequences of months with rainfall tercile one ( $R_1$ ).**—There were 258 spells with below average rainfall ( $R_1$ ), and the mean length of the spells was 1.54 months, ranging from 1.40 months for spells starting in March to 1.70 months for those starting in April.

Let  $p_c$  be the climatological probability of occurrence of a  $R_1$  month. If we make the hypothesis that there is no predictive value in knowing whether

or not the preceding month is  $R_1$ , then the probability of the forecast month being  $R_1$  is equal to  $p_c$  (i.e. the climatological probability).

Calling  $N_r$  the number of  $R_1$  spells which last at least  $r$  months then (see also Chatfield<sup>5</sup>)

$$\begin{aligned} N_2 &= N_1 \times p_c \\ N_3 &= N_2 \times p_c = N_1 \times p_c^2, \text{ and so on.} \end{aligned}$$

Thus the number of  $R_1$  months which last  $r$  months exactly is given by

$$\begin{aligned} f_r &= N_r - N_{r+1} \\ &= N_1 (1 - p_c) p_c^{r-1} \quad (\text{i.e. the geometric distribution}). \end{aligned}$$

The values of  $p_c$  vary a little from month to month, since it is not possible to classify the rainfall data so that each class contains equal numbers. The average value of  $p_c$  for all months equals 0.3325; with this  $p_c$  and  $N_1 = 258$  (total number of  $R_1$  spells) the theoretical distribution is shown in Table II along with the observed distribution.

TABLE II—FREQUENCY OF  $R_1$  SPELLS WHICH LASTED EXACTLY 1, 2, 3, ETC., MONTHS COMPARED WITH THE EXPECTED FREQUENCY FROM THE GEOMETRIC DISTRIBUTION

Length of spell (months)	1	2	3	4	≥5
Observed distribution	168	57	23	6	4
Geometric distribution	172	57.3	19.0	6.3	3.4

The observed and computed frequencies shown in Table II are clearly in close agreement. Indeed a chi-square test shows that there is no statistically significant difference between the two frequency distributions.

The statistics in Table II refer to spells in which no account has been taken of the starting month. Table III breaks down the spells according to the month in which the sequence began.

TABLE III—FREQUENCIES OF RUNS OF AT LEAST 1, 2, 3, ETC., MONTHS OF  $R_1$  TYPE (DRY) BEGINNING IN SPECIFIED MONTHS

Starting month	Runs equal to or greater than the specified length in months						
	1	2	3	4	5	6	7
Jan.	20	6	2	1	0	0	0
Feb.	19	6	3	1	0	0	0
Mar.	25	8	1	1	0	0	0
Apr.	23	9	3	2	1	1	0
May	23	9	3	0	0	0	0
June	22	6	5	1	0	0	0
July	22	8	3	1	1	0	0
Aug.	19	7	3	0	0	0	0
Sept.	22	7	2	1	1	1	0
Oct.	21	6	2	2	1	0	0
Nov.	23	10	2	0	0	0	0
Dec.	19	8	4	0	0	0	0

The following points are worth noting about Table III :

- (i) No spell which started in May, August, November or December lasted more than three months.
- (ii) All but one of the 25 spells which began in March changed to types  $R_2$  or  $R_3$  in May.
- (iii) Of the six years of  $R_1$  type beginning in June and lasting into July five persisted as  $R_1$  type into August.

The observed frequencies of spells of specified length which started in the various months were compared with the frequencies expected from the geometric distribution; for this purpose the geometric frequencies given in Table II were reduced in the proportion of 20 to 258 for January, 19 to 258 for February, etc. In general the agreement between the observed and expected frequencies was close. For spells which started in June and lasted 1, 2 and at least 3 months the observed frequencies were 16, 1 and 5 compared with expected frequencies of 14.7, 4.9 and 2.4 respectively. These data are probably inadequate for a satisfactory chi-square test on the basis of the null hypothesis, nevertheless such a test does suggest that the differences between the two frequencies could have occurred by chance once in 20 trials. Since 12 chi-square statistics were computed (one for each set of spells classified according to the starting month), it is evident that the high chi-square value for the June case might have occurred by chance. The chi-square statistic in each of the other eleven comparisons was smaller than the June chi-square value.

**Sequences of months with rainfall terciles one or two ( $R_{1,2}$ ).—**

The mean duration of such sequences was 3.10 months, ranging from 2.43 months in September to 4.10 months in April and June. The computed geometric distribution (using the observed average value of  $p_i = 0.6675$ ) and the observed distribution of  $R_{1,2}$  sequences are compared in Table IV.

TABLE IV—FREQUENCY OF  $R_{1,2}$  SPELLS WHICH LASTED EXACTLY 1, 2, 3, ETC., MONTHS COMPARED WITH THE EXPECTED FREQUENCY FROM THE GEOMETRIC DISTRIBUTION

Length of spell (months)	1	2	3	4	5	6	≥ 7
Observed distribution	84	56	44	23	17	9	25
Geometric distribution	86	57.3	38.2	25.5	17.0	11.4	22.6

From Table IV it is evident that there is no significant difference between the two distributions when no account is taken of the starting month of the sequences. A breakdown of the sequences according to the starting month is shown in Table V.

TABLE V—FREQUENCIES OF RUNS OF AT LEAST 1, 2, 3, ETC., MONTHS OF  $R_{1,2}$  TYPE (DRY OR AVERAGE) BEGINNING IN SPECIFIED MONTHS

Starting month	Runs equal to or greater than specified lengths in months																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Jan.	19	10	9	8	6	4	4	4	4	2	2	1	1	1	0	0	0	0
Feb.	26	16	11	8	5	2	1	1	0	0	0	0	0	0	0	0	0	0
Mar.	21	14	9	5	2	2	1	1	1	1	0	0	0	0	0	0	0	0
Apr.	20	17	11	7	5	4	3	3	2	2	2	1	1	1	1	1	1	0
May	23	15	9	6	5	4	3	2	1	0	0	0	0	0	0	0	0	0
June	20	14	11	8	6	6	5	3	3	1	1	1	1	1	1	0	0	0
July	21	11	8	6	3	2	2	1	1	1	1	1	0	0	0	0	0	0
Aug.	24	15	9	5	4	3	1	1	1	1	1	1	0	0	0	0	0	0
Sept.	21	16	9	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Oct.	20	14	10	5	3	2	0	0	0	0	0	0	0	0	0	0	0	0
Nov.	19	12	9	6	6	2	2	1	0	0	0	0	0	0	0	0	0	0
Dec.	24	20	13	7	5	2	2	2	1	1	0	0	0	0	0	0	0	0

The main features of Table V are as follows :

- (i) Of the 10 spells which began in January and still existed in February, 9 persisted into March and 8 into April.
- (ii) Only about 50 per cent of the spells which started in January or July lasted another month; in contrast about 85 per cent of the April and December spells persisted for an additional month.
- (iii) Long sequences of more than three months were least frequent for spells which started in September; moreover none of the long spells which began in September or October lasted more than 6 months.

Comparisons between the observed frequencies of  $R_{1,2}$  type and expected frequencies calculated from the geometric distribution did not show any significant difference between the two distributions except possibly for the January and September cases. Classifying the January spells into those which lasted 1, 2 or 3, and 4 or more months gave respectively 9, 2 and 8 occurrences compared with expectations of 6.3, 7.0 and 5.6: on the null hypothesis a chi-square test suggests that the two frequencies could have occurred by chance once in 15 selections. For the September spells a chi-square test also suggested that the difference between the two frequencies could have occurred by chance once in 15 trials.

**Sequences of months with rainfall tercile three ( $R_3$ ).**—The mean duration of these spells was 1.55 months, ranging from 1.19 months in August to 1.81 months in April (July and September were nearly 1.8 months).

The observed frequencies of  $R_3$  spells are compared with frequencies computed from the geometric distribution ( $p_c = 0.3325$ ) in Table VI.

TABLE VI—FREQUENCY OF  $R_3$  SPELLS WHICH LASTED EXACTLY 1, 2, 3, ETC., MONTHS COMPARED WITH THE EXPECTED FREQUENCY FROM THE GEOMETRIC DISTRIBUTION

Length of spell (months)	1	2	3	4	$\geq 5$
Observed distribution	17.0	55	21	7	5
Geometric distribution	17.2	57.3	19.0	6.3	3.4

There is no statistically significant difference between the two frequency distributions shown in Table VI. When the starting month of sequences is taken into account the results are shown in Table VII.

TABLE VII—FREQUENCIES OF RUNS OF AT LEAST 1, 2, 3, ETC., MONTHS OF  $R_3$  TYPE (WET) BEGINNING IN SPECIFIED MONTHS

Starting month	Runs equal to or greater than specified lengths in months							
	1	2	3	4	5	6	7	8
Jan.	19	5	2	2	1	0	0	0
Feb.	26	10	3	1	0	0	0	0
Mar.	23	10	3	0	0	0	0	0
Apr.	21	8	4	2	2	1	0	0
May	16	5	1	0	0	0	0	0
June	24	9	2	1	0	0	0	0
July	24	8	6	2	1	1	1	0
Aug.	21	4	0	0	0	0	0	0
Sept.	19	9	4	1	1	0	0	0
Oct.	22	9	3	2	0	0	0	0
Nov.	20	5	4	1	0	0	0	0
Dec.	23	6	1	0	0	0	0	0

Noteworthy points from Table VII are the following :

- (i) No  $R_2$  spell which started in August lasted more than two months.
- (ii) Persistence from initial to following month was least from August to September (21 occasions dropped to 4) and greatest from September to October (19 to 9).
- (iii) When a sequence began in November and persisted to December there followed a  $R_2$  type of January on four out of five occasions. Similarly on six occasions a  $R_2$  September followed the eight cases with the same type of July and August.

The observed frequencies were compared with the frequencies expected from the geometric distribution but chi-square tests do not suggest any significant differences between the distributions.

**Sequence of months with rainfall terciles 2 or 3 ( $R_{2,3}$ ).**—The mean length of spells with average or above average rainfall ( $R_{2,3}$ ) was 3.11 months; the minimum mean duration was 2.19 months for spells which started in February and the maximum mean duration was 4.17 months for the May sequences.

Comparison between the observed frequencies and those computed on the basis of the geometric distribution ( $p_c = 0.6675$ ) is made in Table VIII.

TABLE VIII—FREQUENCY OF  $R_{2,3}$  SPELLS WHICH LASTED EXACTLY 1, 2, 3, ETC., MONTHS COMPARED WITH THE EXPECTED FREQUENCY FROM THE GEOMETRIC DISTRIBUTION

Length of spell (months)	1	2	3	4	5	6	$\geq 7$
Observed distribution	78	60	41	31	12	13	23
Geometric distribution	86	57.3	38.2	25.5	17.0	11.4	22.6

A chi-square computation shows that the difference between the two frequency distributions shown in Table VIII is not statistically significant. The frequencies of spells throughout the year are set out in Table IX.

TABLE IX—FREQUENCIES OF RUNS OF AT LEAST 1, 2, 3, ETC., MONTHS OF TYPE  $R_{2,3}$  (AVERAGE OR WET) BEGINNING IN SPECIFIED MONTHS

Starting month	Runs equal to or greater than the specified length in months																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	..... 22
Jan.	20	14	10	6	2	1	1	1	1	1	1	1	1	1	1	0	..... 0
Feb.	21	13	7	4	1	0	0	0	0	0	0	0	0	0	0	0	..... 0
Mar.	23	18	11	7	3	3	2	1	1	1	0	0	0	0	0	0	..... 0
Apr.	21	16	11	7	7	5	1	1	1	1	1	0	0	0	0	0	..... 0
May	24	18	13	11	7	6	2	2	2	2	2	1	1	1	1	1	..... 1
June	21	14	9	7	4	2	1	1	1	0	0	0	0	0	0	0	..... 0
July	24	14	10	7	4	4	4	3	0	0	0	0	0	0	0	0	..... 0
Aug.	19	11	8	4	3	2	2	1	1	1	0	0	0	0	0	0	..... 0
Sept.	21	15	9	5	4	3	2	1	0	0	0	0	0	0	0	0	..... 0
Oct.	23	20	16	8	5	4	3	2	2	2	2	1	1	0	0	0	..... 0
Nov.	22	13	9	8	6	5	4	2	2	0	0	0	0	0	0	0	..... 0
Dec.	19	14	7	5	2	1	1	0	0	0	0	0	0	0	0	0	..... 0

The most interesting features in Table IX are :

- (i) Nearly 90 per cent of the  $R_{2,3}$  spells which started in October lasted into November.
- (ii) When a  $R_{2,3}$  spell began in October and continued over November, then it was also observed in December on 80 per cent of occasions.

- (iii) When a  $R_{2,3}$  spell began in November and was in existence in January, it generally persisted into February (persistence in 8 out of 9 occasions).
- (iv) When a  $R_{2,3}$  spell started in May and was in existence in July, it continued into August in most cases (11 out of 13 occasions).
- (v) All seven years when the four months April, May, June and July had  $R_2$  or  $R_3$  rainfall were followed by a  $R_{2,3}$  type of August.

None of the chi-square statistics computed by comparing the observed and expected frequencies was sufficiently large to suggest any statistically significant difference, although the highest value was for the October spells.

**Sequences of months with rainfall tercile two ( $R_2$ ).**—The mean length of  $R_2$  spells was 1.55 months; the minimum average duration was 1.26 months for June and the maximum was 1.84 months for October (1.82 months for March).

The observed distribution and the distribution computed from the geometric series ( $p = 0.335$ ) are compared in Table X.

TABLE X—FREQUENCY OF  $R_2$  SPELLS WHICH LASTED EXACTLY 1, 2, 3, ETC., MONTHS COMPARED WITH THE EXPECTED FREQUENCY FROM THE GEOMETRIC DISTRIBUTION

Length of spell (months)	1	2	3	4	$\geq 5$
Observed distribution	167	58	21	10	3
Geometric distribution	172	57.7	19.3	6.5	3.5

The two frequency distributions shown in Table X are not significantly different. When the starting month is taken into account the observed frequencies are as set out in Table XI.

TABLE XI—FREQUENCIES OF RUNS OF AT LEAST 1, 2, 3, ETC., MONTHS OF TYPE  $R_2$  (AVERAGE) BEGINNING IN SPECIFIED MONTHS

Starting month	Runs equal to or greater than the specified length in months						
	1	2	3	4	5	6	7
Jan.	20	6	2	1	0	0	0
Feb.	26	7	1	0	0	0	0
Mar.	22	10	4	3	1	0	0
Apr.	17	6	2	0	0	0	0
May	27	8	5	3	1	1	0
June	19	3	2	0	0	0	0
July	22	10	4	2	0	0	0
Aug.	19	5	2	0	0	0	0
Sept.	25	11	3	1	0	0	0
Oct.	19	8	5	2	1	1	0
Nov.	22	7	1	0	0	0	0
Dec.	21	11	3	1	0	0	0

Noteworthy features of Table XI are :

- (i)  $R_2$  spells which began in June persisted into July on only 15 per cent of occasions.
- (ii)  $R_2$  Decembers were followed by the same class of January on just over 50 per cent of occasions.
- (iii)  $R_2$  spells which started in February or November rarely lasted more than two months.

None of the frequency distributions is statistically different from the geometric distribution.

**Conclusions.**—This analysis of rainfall in the practical form of terciles confirms that average monthly rainfall over England and Wales is not in general a parameter with much predictive value. This result is not very surprising in view of the many different rainfall distributions and synoptic situations which make up the rainfall totals which fall into a particular tercile class. Nevertheless, certain types of sequences of rainfall are undoubtedly interesting. It is not possible at present to reach firm statistically based conclusions about the significance of the occurrence of these particular patterns of behaviour of monthly rainfall, since the data are generally inadequate. However, it seems prudent to take note of them until additional information becomes available to support or refute the evidence from the past.

#### REFERENCES

1. GLASSPOOLE, J.; The reliability of rainfall over the British Isles. *Jnl Instn Wat. Engrs, London*, **35**, 1930, p. 174.
2. HAWKE, E. L.; Frequency distribution of wet and dry months from 1815 to 1914 and of warm and cold months from 1841 to 1930 at Greenwich. *Q. Jnl R. met. Soc., London*, **60**, 1934, p. 71.
3. BILHAM, E. G.; Notes on sequences of dry and wet months in England and Wales. *Q. Jnl R. met. Soc., London*, **60**, 1934, p. 514.
4. MCINTOSH, D. H.; The occurrence of spells in London rainfall and temperature. *Met. Mag., London*, **84**, 1955, p. 366.
5. CHATFIELD, C.; Wet and dry spells. *Weather, London*, **21**, 1966, p. 308.

551.524.36(426):551.524.37:551.584.41

## FURTHER STUDIES OF MINIMUM TEMPERATURE IN THE FOREST OF THETFORD CHASE

By G. W. HURST

**Summary.**—Minimum temperatures at various sites in Thetford Chase were taken during 1966 at heights varying from 2 to 72 inches above bare soil and above grass-covered soil. Temperatures below 32°F were more frequent above grass than above bare soil especially in the lowest 24 in. The gradient of the minimum temperature over bare soil was different from that over grass and was slightly negative from 2 to 6 in. A site which had increased its grass-covered area since 1965 was found to have lower temperatures in 1966 than in 1965.

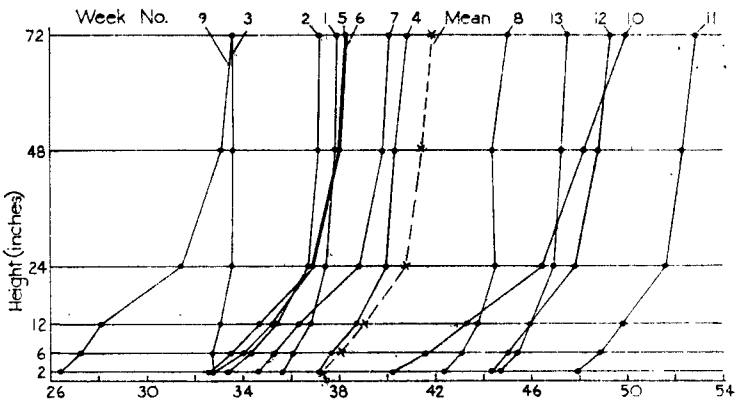
Minimum temperatures taken at 4 ft and at 6 in in forest rides and forest showed that shading gave considerable protection from frost.

The number of years in 10 that frost may be expected after particular dates is quoted for various sites for a height of 4 ft. Narrow grass-covered rides, under-cover sites and bare-soil sites are relatively free from frost after the first week in June.

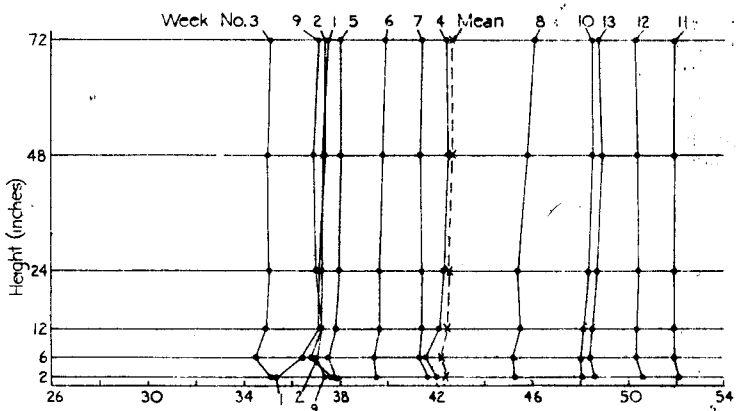
**Introduction.**—In an earlier article Hurst<sup>1</sup> described experiments with minimum thermometers exposed in different locations in the forest of Thetford Chase in 1964 and 1965, and some conclusions were noted. Experiments, with modifications, were again conducted in spring and early summer of 1966 and some interesting additional information has come to light.

**Vertical array.**—In 1965, an array of grass minimum thermometers (i.e. thermometers with black sheaths over the ends opposite the bulb, and no other form of protection) was arranged at Mundford to provide minimum temperatures in a vertical profile from 2 in to 72 in, the intermediate readings being at 6, 12, 24 and 48 in. In 1966, such an array was again erected at Mundford (a grass-covered fairly large open clearing of 17 acres) and an exactly similar array was installed at Harling Nursery, a large open bare-soil surface. All thermometers were read and set at approximately 0900 GMT,

as in previous years. Differences between 1965 and 1966 at Mundford were slight; 1965 values are put in brackets in the following discussion. Figure 1 shows each week, from week 1 (1-7 April) to week 13 (24-30 June) in 1966, the average night minimum temperatures at each height for Mundford and Harling Nursery. The difference between the two profiles is striking; above grass at Mundford the temperatures were markedly lower nearer the ground, with, over the whole period, an average difference between temperatures at heights of 72 in and 2 in of 4.5 degF (compared with 3.9 degF in 1965); the corresponding difference over bare soil was 0.2 degF. Over the 13 weeks



Mundford weekly average minimum temperature(°F)



Harling Nursery weekly average minimum temperature(°F)

**FIGURE 1—VERTICAL TEMPERATURE SOUNDINGS AT MUNDFORD AND HARLING NURSERY, APRIL-JUNE 1966**

— Average night minimum temperatures for each week.                      x --- x Mean.

the average difference in the temperatures at 2 in between the two places was 5.1 degF, but at 72 in Harling was only 0.8 degF warmer than Mundford. These averages take into account dull nights as well as clear, radiation nights, and considering the average of the three coldest nights each week (i.e. those with the lowest temperatures at 2 in) differences were 6.2 degF at Mundford (5.6 degF in 1965) and 0.3 degF at Harling Nursery. Extreme differences in any night in the three months were 11.3 degF in early June (9.0 degF in 1965) at Mundford, and 2.7 degF at Harling Nursery in late May. Figure 2 brings out these differences. At Mundford, the coldest soundings are those with the biggest temperature difference between 72 in and 2 in, but week 6 at Mundford (when fog prevented a really low night temperature at Mundford and not at Harling Nursery) represented one of the few exceptions to this rule.

Table I has been prepared to show the difference in frequencies of minimum temperatures below 32°F and 28°F (the word frost has been avoided, bearing in mind the type of experiment) and this strikingly demonstrates both the difference with height at Mundford, and the difference between that site and Harling Nursery.

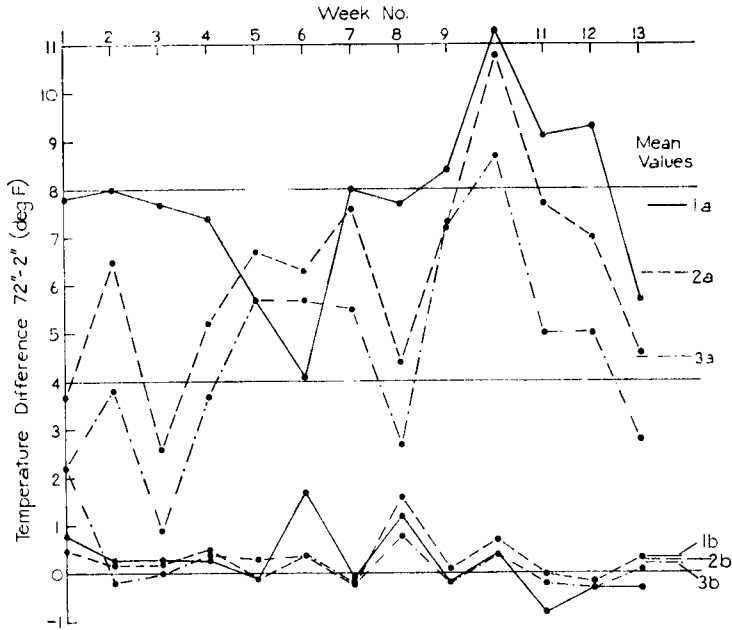


FIGURE 2—TEMPERATURE DIFFERENCE BETWEEN 72 AND 2 INCHES AT MUNDFORD AND HARLING NURSERY, APRIL-JUNE 1966

· ——— · Coldest sounding each week, · - - - · Average of 3 coldest soundings each week  
 · - · - · Average of all soundings each week.      a = Mundford, b = Harling Nursery.

TABLE I—FREQUENCY OF OCCASIONS EACH WEEK APRIL–JUNE 1966 WITH MINIMUM TEMPERATURES BELOW 32°F AND BELOW 28°F AT MUNDFORD AND AT HARLING NURSERY AT HEIGHTS FROM 2 IN TO 72 IN.

Week		Mundford (grass-covered)												Harling Nursery (bare soil)											
		below 32°F						below 28°F						below 32°F						below 28°F					
No.	Starting	2"	6"	12"	24"	48"	72"	2"	6"	12"	24"	48"	72"	2"	6"	12"	24"	48"	72"	2"	6"	12"	24"	48"	72"
1	April 1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	15	1	2	2	1	2	2	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
4	22	2	2	2	2	2	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
5	29	3	3	3	2	1	1	2	2	2	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
May																									
6	6	4	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	13	4	4	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	20	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	27	6	6	6	5	4	3	5	5	5	2	0	0	2	2	2	2	2	2	0	0	0	0	0	0
June																									
10	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	24	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for																									
1966		25	26	19	13	10	7	11	10	9	5	3	3	5	7	5	5	5	5	1	1	1	1	1	1
1965		23	19	17	16	13	13	14	11	9	8	4	2												

It is not thought that the slightly greater number of low temperatures at 6 in than at 2 in at Mundford is significant; the apparent anomaly is based on readings of 32.0°F and 31.8°F at 2 in and 6 in respectively on a particular night at Mundford. Differences between 1965 and 1966 were slight, both years being less frosty than average; the slightly greater difference between 72 in and 2 in in 1966 is reflected in the greater number of low temperatures near the surface in 1966, and the smaller number at 72 in. The higher frequency at 6 in than at 2 in at Harling Nursery is however probably significant. In Table II are given the average weekly temperatures, the average of the three coldest temperatures each week (defined as those at the 2 in level) and the average of the coldest sounding each week for both places at all heights.

TABLE II—AVERAGE MINIMUM TEMPERATURES AT VARIOUS HEIGHTS FROM 2 TO 72 IN DURING APRIL TO JUNE 1966 AT MUNDFORD AND HARLING NURSERY

Classification	Mundford					
	Height above ground (in)					
	2	6	12	24	48	72
			<i>degrees Fahrenheit</i>			
All readings	37.3	38.1	39.0	40.7	41.4	41.8
3 Coldest nights	31.6	32.2	33.6	36.2	37.4	37.8
Coldest night	26.6	27.7	29.1	32.1	33.8	34.3
Classification	Harling Nursery					
	Height above ground (in)					
	2	6	12	24	48	72
			<i>degrees Fahrenheit</i>			
All readings	42.4	42.2	42.4	42.5	42.6	42.6
3 Coldest nights	38.1	37.8	38.0	38.0	38.2	38.4
Coldest night	34.7	34.4	34.5	34.6	34.7	34.9

Table III gives the temperature gradient between different points of the array height for average weekly minimum temperatures, the average of the three coldest temperatures each week and the average of the coldest soundings each week. These suggest that over the grass surface at Mundford, the fall of temperature is more or less steady from 2 in to 24 in (and is of the order of 0.25 degF per inch on the marked radiation nights) and decreases fairly

TABLE III—DIFFERENCE IN MINIMUM TEMPERATURE PER INCH HEIGHT BETWEEN THE VARIOUS ARRAY LEVELS

Classification	6/2	12/6	Mundford Height range (in) 24/12	48/24	72/48
			<i>degrees Fahrenheit</i>		
All readings	+ 0.20	+ 0.15	+ 0.14	+ 0.03	+ 0.02
3 Coldest nights	+ 0.15	+ 0.23	+ 0.22	+ 0.05	+ 0.02
Coldest night	+ 0.27	+ 0.23	+ 0.25	+ 0.07	+ 0.02

Classification	6/2	12/6	Harling Nursery Height range (in) 24/12	48/24	72/48
			<i>degrees Fahrenheit</i>		
All readings	- 0.05	+ 0.03	+ 0.01	0.00	0.00
3 Coldest nights	- 0.07	+ 0.03	0.00	+ 0.01	+ 0.01
Coldest night	- 0.07	+ 0.02	+ 0.01	0.00	+ 0.01

sharply above 24 in, becoming much smaller towards 72 in. At Harling Nursery on the other hand, the gradient is slightly negative from 2 in to 6 in. This is thought to be a real effect, possibly due to the slight movement of air horizontally from areas where the surface is colder so that the soil of Harling Nursery is slightly warming the lowest air.

A similar effect was found in experiments near Reading in March 1955 by Lake,<sup>2</sup> who exposed normal grass minimum thermometers at heights of 0.25, 1, 3, 6, 18 and 54 in above a bare-soil surface, but took readings on only a very few radiation nights. He found that the height of the minimum temperature varied but was mostly in the range 4–7 in; these minima were about 5–7 degF lower than the soil surface minimum temperature. Lake's explanation of the lowest temperatures being above, and not at the earth's surface lay partly in the suggestion above of surface warming of air flowing in from colder (vegetation-covered) land, and partly in the radiative heat loss from the air itself.

It is perhaps worth making the point that the lowest temperatures will not normally occur simultaneously at all heights, so that although Table III represents the gradient of lowest temperatures it does not necessarily represent the actual profile at any particular instant.

**Narrow rides and under-cover thermometers.**—Before 1966, temperatures measured at Thetford and analysed by the author had all been obtained with thermometers placed in what might be termed 'conventional' positions, in more or less large clearings and exposed to at least a wide sector of the sky; Santon Nursery was the narrowest site with a minimum sector reading of about 110°. In 1966, some thermometers were placed in a forest ride and some under cover, that is within the forest itself with the sky partially hidden by foliage. The ride used was Santon Ride, a close-cropped grass surface near Santon Nursery. The ride was about 18 yards wide, and the angle of the sky visible was 75 to 80° at the narrowest. Two thermometers were exposed here about 50 yards apart, one squarely in the very slight downslope of about  $\frac{1}{2}$ ° northwards, and the other about 50 yards away in a very slight dip in this slope. The under-cover thermometers were installed near Mundford and near High Lodge. The position of these two areas does not matter much as far as this discussion is concerned; the ground at both was fairly flat and the

proportion of canopy cover was 65 per cent at Mundford and 70 per cent at High Lodge, estimated by horizontal light-meter readings within the forest compared with those in a nearby clearing. The ground was rough-grassed or litter-covered within the forest—much the same as in many open areas (and Harling litter described earlier). Table IV shows weekly average differences between the various stations and Mildenhall, which was chosen as a standard station. Values for Harling Nursery, Harling (grass, bare soil and litter) and Mundford are also given, and for these stations a comparison is made with differences found in 1965 (except for Mundford where 1965 observations were vitiated by a faulty thermometer). The differences between the two years are slight and self-consistent; several locations are omitted from the table but the only two at which fairly great temperature differences between 1965 and 1966 occurred were Grime's Graves and Kings. It is not clear why the difference at the former should be fairly great (though it was noticed that Grime's Graves was outstandingly cold during periods with particularly low night temperatures, such as week 9) but the difference at the latter is explicable and is discussed later.

TABLE IV—COMPARISON OF DIFFERENCES IN MINIMUM TEMPERATURES AT 4 FT BETWEEN THE VARIOUS STATIONS AND MILDENHALL, APRIL-JUNE 1965 AND 1966

	Temperature difference, station-Mildenhall for sites:								
	1	8	9	10	11	14	17	19	20
Year	<i>degrees Fahrenheit</i>								
1965		- 1.3	- 2.8	- 3.0	- 2.3				
1966	- 2.2	- 1.8	- 3.4	- 3.4	- 3.0	- 1.4	- 1.6	- 1.5	- 1.6
Difference (1966-1965)		- 0.5	- 0.6	- 0.4	- 0.7				
	1. Mundford				14. Mundford (under cover)				
	8. Harling Nursery				17. Santon Ride (dip)				
	9. Harling (litter)				19. Santon Ride (slope)				
	10. Harling (grass)				20. High Lodge (under cover)				
	11. Harling (bare soil)								

It can be deduced from Table IV that frost frequencies at 4 ft are distinctly lower in narrow rides or under moderately open cover even compared with an open bare-soil surface—and there is a very marked gain (as much as 2 degF per night on all nights) over the grass-covered stagnant area of Harling. Similar results obtained from the thermometers at 6 in are given in Table V.

TABLE V—COMPARISON OF DIFFERENCES IN MINIMUM TEMPERATURES AT 6 INCHES BETWEEN THE VARIOUS STATIONS AND KINGS, APRIL-JUNE 1965 AND 1966

	Temperature difference, station-Kings for sites :								
Year	1	8	9	10	11	14	17	19	20
		<i>degrees Fahrenheit</i>							
1965		2.0	- 2.0	- 2.4	- 0.1				
1966	- 0.2	3.8	- 1.1	- 0.6	1.7	1.9	3.1	3.3	3.3
Difference (1966-1965)		1.8	0.9	1.8	1.8				

Site numbers as in Table IV.

In Table V, temperatures at various stations are compared with Kings (another site in the forest), as no comparable 6-in temperature readings were available at Mildenhall. A consistent and large change has taken place in the temperature differences between the Harling sites and Kings in the two years. This change is similarly reflected at other stations (not shown

in the table) though mostly by smaller amounts. There seems no doubt that the change (over 1.5 degF colder at Kings compared with the Harling sites) is due to the surface at Kings being much more grass-covered in 1966 than in 1965. Table V brings out the advantage of keeping the earth bare in order to avoid low temperatures near the ground and shows that Harling Nursery is warmer at 6 in than any other station, whether under cover or not.

There was little difference between temperatures at High Lodge under cover and in the Santon Rides but the Mundford under-cover reading was much lower; this may possibly have been instrumental in origin—there does not seem much obvious difference in exposures between the two under-cover positions. Differences between the two thermometers in Santon Ride were slight; the instrument in the very slight dip averaged 0.2 degF colder at 6 in than that in the open slope, and the difference was only 0.1 degF at 4 ft; these values probably reflect the very slight, if real, effect of a very minor break in a long very gradual slope.

**Frequency of years in 10 of frosts after certain dates.**—A comparison of frost proneness was made using similar techniques as before, to obtain frost frequencies at the different sites; the thermometers at 4 ft were in special mounts as described in the earlier paper,<sup>1</sup> and readings were corrected to equivalent screen temperatures. A difficulty in interpretation was caused by the very cold week 9 (27 May–2 June) which followed a mild spell. In principle perhaps this should not matter, but in practice, differences in minimum temperatures between Mildenhall and the Thetford sites are considerably greater during cold radiation nights than at other times. The technique of assessing the years in 10 of frost frequency is one which leans heavily on the behaviour in the 8th week, and progressively less on earlier weeks, with modified extrapolation over the weeks 9–13. This approach gave obviously unsatisfactory results in 1966, and a modified procedure was evolved which gave figures of frost frequencies similar to, though a little less than, those of 1965. It is not worthwhile giving figures in full, but specimen values are given in Table VI, which represents a compromise between 1965 and 1966 figures.

TABLE VI—THE EXPECTATION OF FROST AT 4 FT, EXPRESSED AS THE NUMBER OF YEARS IN 10, AT THE VARIOUS SITES AFTER PARTICULAR DATES

(a) Below 32°F								
	Site number							
Date	1	8	9	10	11	14	19	20
Apr. 1	10	10	10	10	10	10	10	10
Apr. 22	10	10	10	10	10	10	10	10
May 13	9	9	10	10	10	8	9	9
June 3	4	2	8	7	6	1	1	1
June 24	+	0	2	1	1	0	0	0
(b) Below 28°F								
	Site number							
Date	1	8	9	10	11	14	19	20
Apr. 1	10	10	10	10	10	10	10	10
Apr. 22	10	9	10	10	10	8	8	8
May 13	6	6	9	9	8	4	4	4
June 3	+	1	3	2	2	+	+	+
June 24	0	0	1	+	+	0	0	0
+ Indicates 0.1 to 0.4. Sites as in Table IV.								

A station such as Kings cannot be included, as change of character has taken place there resulting in a considerably higher frost risk due to the more grass-covered character of the area. It is seen that at 4 ft, freedom from temperatures below 28°F is almost complete from early June onwards within a ride (or very narrow compartment) (site 19) or under light canopy (sites 14 and 20), and the warming effect of bare soil can still be seen clearly at this height at Harling Nursery (site 8) and just at Harling (bare soil) (site 11).

**Soil temperatures at 8 in.**—Ordinary 8-in soil thermometers were installed in 1966 at Harling Nursery and the three Harling sites, but did not give data complete enough to justify much discussion. In April, differences between temperatures under bare-soil surfaces at Harling Nursery and at Harling were not very different from those under grass or litter, but in the hot spell of late June, differences of the 0900 GMT spot readings were about 10 degF as a weekly average. Clearly the important factor here is the heating of the (sandy) ground, and in summer in hot weather the soil is far warmer down to at least 8 in under bare soil than under an insulating grass surface. It would be much more instructive to compare maximum and minimum temperatures in this way, and it is hoped to be able to do this in 1967.

### Conclusions.—

(i) The best ground surface condition for avoiding low temperatures immediately above it is bare soil, and at a height of 6 in freedom from frost is rather greater over a large expanse of bare soil than in a forest ride or under light cover.

(ii) A major advantage of operating over bare soil compared with a vegetated surface is that the fall of temperature from 72 in to near the surface is drastically reduced, and there is almost as much freedom from frost at the surface of the ground as at a height of 4 ft.

(iii) Minimum temperatures at 4 ft above the ground within a forest and under about two-thirds overhead cover are higher than over bare soil in the open.

(iv) Narrow grass-covered rides (15–20 yards in width) have almost as great a freedom from frost as under-cover sites.

(v) Gradual changes in ground cover (such as more grass at Kings during the 12 months) bring about a changed frost risk.

**Acknowledgements.**—This work has been done in very close collaboration with Dr D. H. Phillips and Messrs J. D. Low and B. J. W. Greig, whose advice and that of Messrs J. M. B. Brown, D. Burdekin and A. I. Fraser (all of Alice Holt Research Station) has been much appreciated. The author also wishes to put on record his recognition of the very high standard of observation at the 17 sites during the experiment.

### REFERENCES

1. HURST, G. W.; Temperatures in the forest of Thetford Chase. *Met. Mag., London*, **95**, 1966, p. 273.
2. LAKE, J. V.; The temperature profile above bare soil on clear nights. *Q. Jnl R. met. Soc., London*, **82**, 1956, p. 187.

## THE MEASUREMENT OF SURFACE WIND

By A./L. MAIDENS

**Summary.**—Instruments for measuring surface wind must be capable of indicating both magnitude and direction. The available methods are grouped according to whether they measure air velocity without the extraction of appreciable energy from the air, or whether they measure the mechanical energy of movement. Whilst recent developments in instrumentation aim at more accurate measurements, any new equipment must be carefully compared under field conditions with that which it is to replace, in order to maintain consistent records. Descriptions of anemometers and wind vanes in use in the Meteorological Office are given as well as details of recent developments in the design of a sensitive photoelectric anemometer, a strain-gauge anemometer and an ultra-sonic anemometer.

As wind velocity in the horizontal plane is a vector quantity two parameters are required for its full expression. These may be speed coupled with direction or speed components along two known directions. Thus the equipment required for the specification of wind may consist of an omnidirectional anemometer for the determination of speed alone, but associated with a vane for the measurement of direction, or one or more anemometers capable of correctly resolving the velocity into its components.

When wind measurements are required for a specific investigation, no pre-conceived rules or conventions need be applied and the anemometer system may be selected or designed with only the desired characteristics in mind. The height of measurement, the size of the atmospheric sample used, the response of the system to rapid changes, and the frequency of observing, may be varied within wide limits to suit the particular investigation. The final measurement may be of the horizontal component of wind, or may recognize the existence of a vertical component.

For routine observations there is no such pre-knowledge of the applications to which the observation will later be applied, and a standard form of measurement, based on conventional conditions, becomes essential, if measurements are to be comparable one with another. The air itself is in every possible scale of movement, from global to molecular, but wind, as a popular conception, is related to those scales which are significant to the human experience, early measurement being made entirely by subjective estimation. Unfortunately, when applying instrumental methods such a 'common sense' approach is not always easy to follow, and in the absence of a comprehensive set of rules, the observation must be accepted as of comparative, rather than absolute, value. Any new equipment must be carefully compared under field conditions with that which it is intended to replace, if comparability is to be maintained.

Some general rules are available to guide the procedure for making routine wind observations with anemographs. The World Meteorological Organization has laid down that measurement shall be made at 10 metres above ground level within an unobstructed area, and that, for synoptic purposes at least, it shall relate to the mean recorded over 10 minutes. Practical considerations of instrumentation appear to have set the cross-sectional area over which the air movements should be integrated. The measurement of peak velocities remains a matter open to discussion. For most routine anemometers the actual maximum velocity indicated during a gust is merely a function of the response time of the instrument employed.

Anemometers in great variety, both as to their principles of operation and details of design, have been brought into use over the past years. In the interests of comparability this is somewhat unfortunate, particularly when the finer details of wind structure are to be examined. In considering the principles of operation which have been employed or are capable of being used, it is convenient to group the methods available under two broad headings—those which detect the wind more or less directly as a velocity, without demanding the extraction of appreciable energy from the air, and those which in, fact, measure the mechanical energy of movement and employ this as a measure of wind speed.

As the movement of a representative parcel of air cannot conveniently be detected directly, instruments in the former group may utilize some separate and more easily identifiable quantity which will travel with the air as a 'marker'. This could be a suitable chemical, an isotope or a sound wave. Even the possibility of using light visible objects (such as smoke, bubbles or more substantial but buoyant solids) cannot be excluded, but these give rise to difficulties if automatic, rather than visual, detection is required. In all such cases the anemometer will consist of an 'emitter', at a known distance from which will be placed one or more 'detectors'; the wind speed is then derived from the time interval needed for travel over the known distance. In such a system a single detector, downwind of the emitter, must be brought into line with the wind, presumably by wind vane, but more elaborate systems may be developed to obtain a direction of movement, without recourse to a vane.

A further possibility within the same group, is to employ the rate of extraction of some quantity as a measure of wind speed. In practice such a method has been reserved almost exclusively for anemometers of the hot-wire type, but it is conceivable that various types of extraction could be considered—for example the rate of evaporation of a substance not otherwise present in free air. Any simple system on these lines, such as the single hot-wire anemometer, is likely to have a limited useful speed range and be dependent upon external factors such as air temperature. In consequence they appear to be more appropriate to wind-tunnel and laboratory measurements, where such effects can be better controlled. They are usually reserved for sensitive measurements at the lower ranges of wind speed, but more elaborate heat-loss anemometers have been designed with success for operation over a useful range of wind speed.

Anemometers demanding the extraction of energy from the air include those which directly measure wind force upon a solid surface, those employing the change of air pressure within an air chamber with an open orifice placed in line with or across the wind flow, and those which convert the air's linear movement into a mechanical rotation. Of the first type, the flat plate anemometer is probably the earliest means of measuring wind speed. It was considered by Leonardo da Vinci in 1500 and was the basis of a practical model made by Hooke in 1667. The early models, in which the flat plate was made to face the wind by hand or, later, by wind vane, merely measured the deflection of a relatively heavy plate, hinged along its top. This design has two main disadvantages—the need to present the surface perpendicular to the wind direction at all times, and the far-from-linear response to changes of wind

speed. The system works quite well where wind direction can be separately determined and falls within a relatively limited range of speed. A flat-plate anemometer of this type, but using a spring restoring force in lieu of gravity, was employed as an air-speed indicator on early models of the DH Moth aircraft, *circa* 1925. Interest has been revived in this form of anemometer as a result of the availability of modern methods of measuring force without appreciable displacement, the unidirectional flat plate being replaced by a sphere, cylinder or other solid shape generated around a vertical axis. Strain gauges or magnetic devices provide a means of measuring the wind force, and various schemes are being explored currently to overcome or reduce the effect of non-linearity of response arising from the power laws relating wind velocity to force upon solid shapes.

The classic example of an anemometer which is operated by the direct wind pressure upon an open-ended tube, of the pitot type, is the Dines anemograph, first described in 1892. It employs both the pressure increase arising from directing an open tube into wind by means of a wind vane, and the pressure drop from openings around the vertical and cylindrical supporting mast. Although not the first to be based on these general principles, it is certainly one of the most advanced designs of its time, particularly in regard to the construction of the float which is designed to provide a linear response throughout the range of wind speeds to be measured.

The third possibility is to convert the dynamic energy of air movement into a rotation by means of a windmill or by a set of cups. In the former case the rotation is about the horizontal axis, which must be brought into line with the wind. For this reason there are certain disadvantages in that, as with many such systems, the overall time response to a change of wind will be dependent both upon that of the speed-measuring component and upon that of the device controlling the orientation. The cup type of anemometer, in which rotation is produced by the difference of pressure between the concave and convex sides of the cups, rotates around a vertical axis and is omnidirectional in the horizontal plane. A great variety of methods may be employed for measuring the speed of rotation of the axis, in common with general engineering practices, and, by careful design both of the cups themselves and of the measuring equipment, almost linear response over a useful range of wind speeds is achieved. The cup anemometer, the first record of which appears to be by Schober in 1752, was developed into a practical instrument by Robinson and described in 1846. Such instruments remain in wide use, the Meteorological Office currently employing a three-cup form, with cups of conical section with a fairly pronounced rim. Many other versions, some with multiple cups forming virtually a 'turbine' arrangement, have been designed.

The requirements for a routine anemometer for general meteorological observations of wind velocity can be stated fairly simply. It must be robust and reliable, demanding a minimum of routine attention, easy to install and to service thereafter. It must maintain its original calibration for response to fixed wind speeds and have a response to changes of the type to which meteorologists have become accustomed, but for which there are no precise rules. It must operate satisfactorily over a range of wind speeds of from a few knots to at least 100 knots, and it must not sustain permanent damage

at higher speeds. Modern requirements dictate that it should provide a reading over a simple cable system of some hundreds of yards in length, and be capable of full telemetry over considerably greater distances. Its output, on dials or recorders, may be in multiple form and its indication may be required as an instantaneous reading or as a mean wind speed and direction, or in the form of component wind velocities. Four examples of modern anemometers which are either already in general use or under development within the Meteorological Office are described below.

The *Meteorological Office Mark 4* anemometer system consists, in fact, of a number of alternative and interchangeable units designed to satisfy individual requirements, while meeting the criteria for a routine instrument. Certain of the requirements are, in fact, in conflict and cannot be met by a single unit. For example, where quick response to wind changes is required, in addition to the measurement of a 10-minute mean wind, at least two indicators are required. The component units available are :

- (i) The Mark 4a anemometer head, a conventional three-cup anemometer operating both an electrical generator and a contact device. The generator provides a linear current output from about 5 kt to 150 kt, and the contact will close twice for each knot of wind speed in an interval of 10 minutes. This head, which is of light weight for field use, is the version generally employed for anemograph records and will additionally provide, with the use of a simple counting device, means of wind speed over 10 minutes or similar intervals of time. It will operate a number of dial indicators and two or more graphical recorders.
- (ii) The Mark 4b anemometer head is of similar design but is fitted with the contact device only. It is thus suitable only for use where mean wind speeds are required.
- (iii) Wind Vane Mark 4a is a freely rotating wind vane operating a Desynn transmitter. Distant indication of wind direction may thus be obtained by low-voltage (battery) supplies, but graphical presentation is not currently possible from this source of power, as no suitable low-voltage recorder is available.
- (iv) Wind Vane Mark 4b is similar, but operates a Magslip transmitter, requiring a power supply of 50 volts a.c. It will provide both a recorded and dial-indicated output.
- (v) Wind Vanes Mark 4c, d and e are damped wind vanes for association with a mean wind speed available from the Mark 4 anemometer. Windmills or paddles are set on either side of the axis of rotation, to which they are coupled by high reduction gearing. When the plane of these windmills is set in line with the wind direction they do not rotate but, should the direction change, the windmills will revolve and, by means of the gearing, slowly realign themselves with the new direction. The three optional versions provide a distant indication of the setting of the vane by a contact system, Desynn and Magslip transmitters respectively.

In the above, either anemometer head may be mounted directly upon a mast or upon one or other of the wind vanes which, in turn may be mounted upon the mast. Probably the main disadvantage not so far overcome in this system is the magnetic drag of the electric generator which makes it necessary

to have a wind speed as high as 4 kt in order to start the rotation of the cup assembly. A new form of output device, currently under development, is expected to reduce this starting speed to 1 kt or less.

The *Porton sensitive portable anemometer* originally introduced in 1937 is not novel in principle, and employs the three cups to convert wind velocity to a rotational speed, as in the Mark 4 generator anemometer. Its merits arise from the sensitivity of the method employed to determine the rate of revolution of the cup system and the low moment of inertia of the latter. Since its first introduction it has recently undergone further development\* with the principal object of improving performance in responding to and registering *fluctuations* of wind speed. These improvements have been achieved by replacing the contact system by a photoelectric system, in which the beam from a miniature lamp is interrupted 60 times per revolution of the cup rotor. Also, the inertia of the cup rotor has been reduced by using expanded polystyrene cups and balsa-wood arms. The response time was thereby reduced to 0.1 seconds, about one fifth of that for the aluminium cup rotor. The equivalent frequency for 50 per cent response is about  $1\frac{1}{2}$  c/s, which means that the instrument is capable of measuring an important part of the high-frequency spectrum of atmospheric turbulence.

The basic output is a square wave voltage with a frequency proportional to the rate of rotation of the rotor. This can be used directly, but in the present model it is passed to a ratemeter, housed with the photo-transistor and lamp, and converted to a d.c. voltage. The latter output is closely linear with wind speed, amounting to 1 V per m/s with an external supply of 12 V. With the special light-weight rotor the instrument is most suitable for light or moderate winds, but with the more conventional metal rotor it may be used (with good linearity) up to 20 m/s. An all-weather version for use in winds up to 60 m/s is in course of development.

An *experimental strain-gauge anemometer* is currently being developed by the Meteorological Office (see Figure 1). Working basically on the 'flat-plate' principle, the system uses a perforated cylinder with vertical axis to ensure uniform response to all wind directions. The force on the cylinder is measured by strain gauges firmly attached in pairs to each of the four arms of a cruciform spring. Horizontal pressure upon the sensing head produces flexing distortions in the spring and hence a change of resistance in the strain gauges. The wind measurement is thus made by means of its components in the directions of the arms of the cruciform spring. An earlier anemometer developed by the Electrical Research Association operated along broadly the same lines, but employed a perforated sphere as a sensor. Current work is directed largely towards determining empirically the optimum aspect ratio of a cylinder or other shape employed, together with the size and spacing of the perforations and the variations in the spring restoring force, in an attempt to obtain a linear, or at least an acceptable form of response, over a wider range of wind speeds. The temperature coefficient of the strain gauges themselves has no effect because pairs of matched gauges are placed in opposite arms of a bridge circuit but changes due to strain unbalance the bridge. To reduce response to high-speed fluctuations, the system is damped by oil.

---

\* JONES, J. I. P.; A portable sensitive anemometer with proportional d.c. output and a matching wind velocity-component resolver. *Jnl scient. Instrum.*, London, 42, 1965, p. 414.

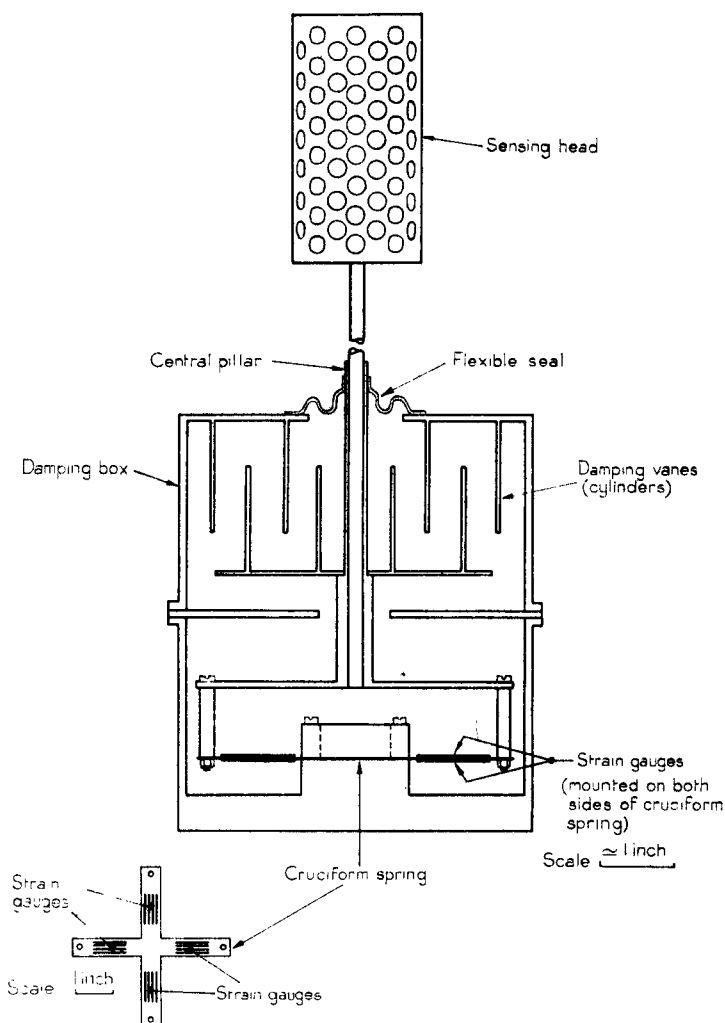


FIGURE 1—STRAIN-GAUGE ANEMOMETER

Work is also proceeding with an *ultra-sonic anemometer* (Figure 2). Sound, at a frequency of 40 kc/s is produced by the transmitter  $T$  and received by receivers  $R_1$ ,  $R_2$  and two further receivers in the same plane. With no horizontal air movement, the path length between the transmitter and each of the receivers is  $\frac{1}{2} (L \operatorname{cosec} \alpha)$  and the sound received by  $R_1$ ,  $R_2$ , etc. is in phase. With a wind of velocity  $V$  in the horizontal plane, the component adding to or subtracted from the velocity of sound is  $\pm V \sin \alpha$ .

There are thus  $n_1$  and  $n_2$  cycles of sound in the paths  $T-R_1$  and  $T-R_2$  respectively where

$$n_1 = \frac{f}{v - V \sin \alpha} \left( \frac{L \operatorname{cosec} \alpha}{2} \right)$$

$$n_2 = \frac{f}{v + V \sin \alpha} \left( \frac{L \operatorname{cosec} \alpha}{2} \right)$$

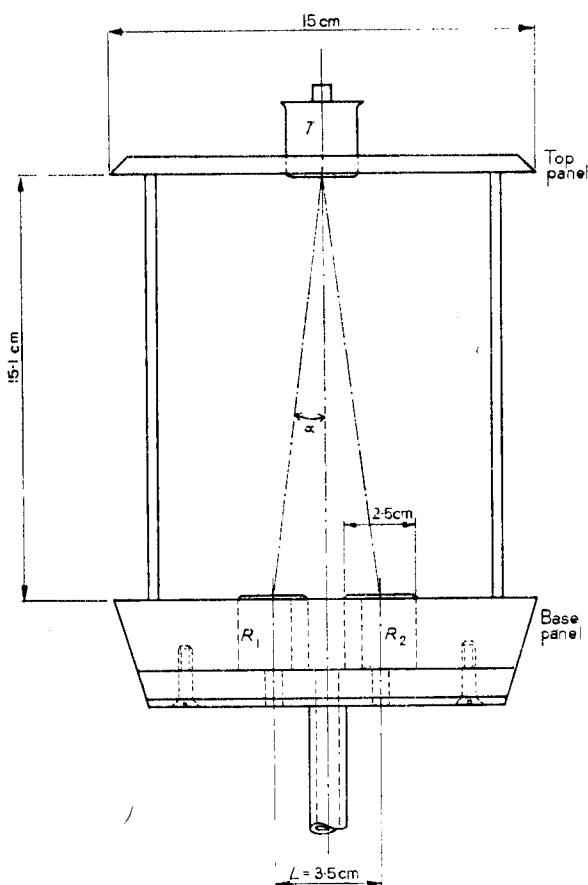


FIGURE 2—ULTRA-SONIC ANEMOMETER—GENERAL ARRANGEMENT

where  $f$  = frequency of sound

and  $v$  = velocity of sound.

Hence the phase difference between  $R_1$  and  $R_2$ , neglecting a term  $(V \sin \alpha)^2$ , is

$$n_1 - n_2 = \frac{L f V}{v^2}.$$

Figure 3 shows the relationship between phase shift and wind speed achieved by a prototype model of the anemometer.

In this system two problems remain to be solved. The velocity of sound in air varies with temperature and steps must be taken to correct for this. Whilst such corrections could be achieved electronically by use of an independent thermometer, it is hoped to avoid the resultant complications. Secondly, the frequency produced by the transmitter may itself vary with the temperature of the transmitter and, as this will be exposed to both the air and to

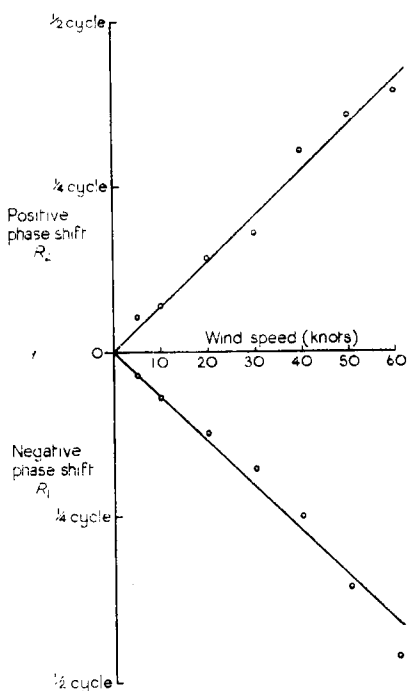


FIGURE 3—THE RELATIONSHIP BETWEEN PHASE SHIFT AND WIND SPEED ACHIEVED BY THE ULTRA-SONIC ANEMOMETER

radiation, its control may prove difficult. The effects of temperature variations are being investigated currently, while, at the same time, thought is being given to alternative systems of measurement. Should it prove possible to produce, receive and time a sharp pulse of sound along two opposite paths, the actual velocity of sound would be eliminated, and a direct measurement of wind velocity, independent of the frequency of the sound employed, would be achieved.

551.586:632.1:636.089

## AIRBORNE TRACERS IN AGRICULTURAL METEOROLOGY

By C. V. SMITH

**Summary.**—The motion of the air around us interests the agricultural meteorologist since the spread of pest and disease may commonly be by an airborne route. Both back-tracking by means of trajectories and the downwind diffusion from known sources have been employed in investigation on the synoptic scale. Artificial tracers which label a parcel of air or the path it has taken, or which visualize its motion, have found their use in studies of ventilation rates and of the air movement in and around farm buildings.

**Introduction.**—We can all read the signs of the sky, but the clouds are not the only natural tracers of the motions of the atmosphere. The agricultural meteorologist has an interest in such things as airborne spores and insects, in windborne and disease-carrying particles and in droplets and aerosols. Among

the reasons for this is the importance to be attached to the dispersal phase in the life cycle of many organisms. For it is likely that sporulation or dispersion, with its implied object of the colonization of new areas, of the inoculation of new hosts, will be a particularly weather-sensitive phenomenon. An understanding of the weather events leading up to dispersal, or of the weather necessary for the maintenance of viability during flight and on subsequent deposition, opens up the possibility of control of the further spread of the pest or disease. Synoptic observations will obviously have a part to play in this kind of study. However, experimentation cannot always wait upon natural events and artificial tracers find their use also.

**Natural tracers.**—The plant pathologist or veterinarian may ask the meteorologist for help in identifying the source of a pest or disease, for help in determining its method of transmission, or for help in developing weather (or related) criteria which correlate with the initiation of the various phases of the pathogen or with the extent or severity of the outbreaks.

Back-tracking with the aid of trajectories, after catches of spores and insects by routine trapping or air sampling, is a well-tried procedure to indicate sources. Hogg<sup>1</sup> has shown Europe and North Africa to be source regions for certain cereal rust spores collected in Britain. Even negative evidence can be useful, as shown by Hurst.<sup>2</sup> The recently introduced wheat, Rothwell Perdix, was known to be resistant to the three common races of yellow rust found in Britain, yet went down badly to rust in 1966. A new form of the rust, rather than the spread of an existing form from outside, was finally accepted as the reason for depressed yields.

Newcastle disease (fowl-pest) was of particular interest a few years ago, when control by compulsory slaughter was about to change over to a preventive control by vaccine. At the time, the spread of the disease was attributed variously to personnel, vehicles, or to wild birds and animals, passing between farm and farm. Given the location and timing of the occurrences of the disease in a particular outbreak, Smith<sup>3</sup> showed it unnecessary to invoke anything other than a windborne spread of the disease, with obvious implications for flock hygiene. The technique employed was an application of the procedures developed by Pasquill.<sup>4</sup> Each broiler house with its large through-put of air was treated as a point source for the emission of a cloud of infectious dust particles and interest centred on the location of the downwind dust plume, rather than on the use of trajectories.

The progress of potato blight in the east of England has been followed by the crop markings shown on successive infra-red photographs taken from aircraft. The windborne dispersal of the spores is at times shown by the plume-like spread of the markings from the first sightings.

Fireblight is a disease of pear trees for which the only effective control is likely to be grubbing. In spring and early summer, bacteria are carried by insects, or by splashing, from diseased branches to the blossom. Here they multiply and are spread to other healthy blossom by pollinating insects. The infected blossom does not set fruit. An interesting case occurred in 1966 of the disease on mature fruit, a fact which ruled out the normal route for the spread of infection. A satisfactory explanation was suggested by the occurrence of a warm, wet, windy spell of weather, able to disperse the bacteria in water droplets over considerable distances. A reasonable incubation period fitted

in with the first sighting on the fruits, which were downwind of a known source of the disease.

Hurst<sup>5</sup> has carried out several interesting case studies of the enforced, airborne migration of insects into Britain, again from the Continent and Africa. Whilst this passive movement with the wind may appear an advantageous means of dispersal, it is counterbalanced by the need to find a suitable host at the end of the journey. Nevertheless, as has been pointed out, it is possible for a successful species to achieve the best of both worlds. The movement of swarms of locusts in the wind in the semi-arid areas is likely to mean movement towards a convergence zone and towards a region of recent rainfall and vegetation growth.

The deposition of insects and airborne particles is not something that has exercised the agrometeorologists too greatly until now. If such problems become pressing, then true to our practice of bringing several disciplines together, we should draw on the work of the atomic scientists who have given much thought to the subject of 'fallout'.

**Artificial tracers.**—The growth of the intensive housing of farm animals has brought problems in its train. Standards of housing and hygiene, and levels of management, acceptable when small numbers of stock are kept, have to be greatly modified and controlled when large numbers are brought together under one roof.

The young animal will normally be provided with accommodation heated in some way or other, for draughts can be killing—the cold piglet will become comatose; cold chicks will huddle and smother. The result is an interest in the measurement of low air velocities, in the patterns of airflow in and around buildings and in the overall air-change rate of buildings. These factors are still of the greatest importance for adult animals, for the natural ventilation of an intensively stocked building will seldom be adequate. Productivity can be related to animal comfort and the forced ventilation of the buildings must be such as to carry off the waste heat and moisture necessarily generated by the animals, as discussed by Smith.<sup>6</sup> As with humans, coughs and colds are more prevalent in the winter, so with farm animals, respiratory troubles are likely to be at a peak at this time. It is not unusual to find minimum rates of air renewal specified in an attempt to combat these respiratory diseases. In a large house with a complicated control system for the fans, it may be difficult, without actual measurement, to determine what is happening at any one time.

The quantities we wish to measure inside the house evidently require that we should be able to label the air in some way and to visualize its motions. The same is true if we move outside the house and attempt to follow the subsequent motion of the air on leaving the house, or the wind effects around collections of buildings. In many respects, the agrometeorologist has moved into the field of the heating and ventilating engineer. Understandably, the solutions to the many problems thrown up by animal housing have an application to the storage of farm products kept in bulk and normally conditioned by ventilation.

The standard tracer used for the measurement of ventilation rate is the radioactive gas, krypton 85. In principle the method is simple. After obtaining

an initially uniform dispersion of the tracer through the house, its subsequent rate of change of concentration, as indicated by a Geiger counter and rate-meter, gives a measure of the rate of dilution, i.e. of the rate of air renewal in the house. The agricultural section of the Meteorological Office initiated this kind of measurement in animal housing in Britain and has progressed from borrowed equipment to its own field equipment and the possibility of a routine service.

The krypton technique gives only a 'spot' value of the ventilation rate and the continuous monitoring of ventilation rate, even in houses where experiments are in progress, remains an outstanding problem in this field. Though the radioactive tracer technique could obviously be extended to meet this requirement, the nature of the tracer (and its cost) rule out its use for continuous work. In fact, the range of permissible gaseous or volatile tracers becomes limited by the requirements that neither the animals nor man should suffer from prolonged exposure to the tracer and that it should not be a gas, or react with a gas evolved naturally within the house by the animals or their litter. These requirements suggest the use of a volatile organic compound as a tracer, perhaps one of the higher alcohols. Such a tracer would enable us to make use of the recent discovery that organic volatiles pass through silicon-rubber tubing at a steady rate and this would offer a simple and practical procedure for generating the tracer continuously throughout the building. This kind of experiment is likely to take place in the coming months.

One function of the agricultural advisory service is to act as 'trouble-shooter'. When called to a problem house or store there is a need to understand what is happening to the air under existing conditions before improvements can be suggested. It is here that smoke proves an invaluable diagnostic tool. Obviously there is a whole range of fuming chemicals or chemically generated smokes which could be used. Most are unpleasant, even noxious, and the most practical cool smoke we have found was developed for use in mines. Though our procedures are simple, this is not to say we are not aware of more sophisticated visualization techniques, such as the use of photographic and stereographic procedures employing fine dust particles or metaldehyde flakes in high-intensity light beams.

To show what the use of smoke alone can do, we can draw on a very recent experience at a large piggery, where there was a costly and continuing loss of pigs, chiefly from dirty pens. The pig is by nature a clean animal and a refusal to make use of the dunging area provided must be taken as a sign of unsatisfactory internal conditions. A telephone conversation before a visit to the site brought out the information that the management had already used smoke as an indicator. Smoke released at a ridge outlet was seen to roll down the roof, and into air inlets at the eaves. This in itself was sufficient to demonstrate there were peculiarities about the site, which in fact was situated close to the brow of a hill. Another factor likely to result in peculiar wind eddies was that there were several houses placed in parallel and close together (less than three times their width apart). Fan engineers had confirmed that the fans were behaving as rated and were providing an overall air-change rate normally regarded as acceptable. A preliminary examination of wind data from a nearby Meteorological Office station showed some relation between increasing wind speed and a reduction in the number of dirty pens.

Understandably, a visit to the farm was made with the preconceived idea that the troubles were due essentially to the siting of the houses and that any improvement would be difficult to achieve. On the farm, the observation of smoke moving from outlet to inlet was soon confirmed, but attention was then turned to the distribution of the incoming air within the individual pens. Smoke immediately revealed that there was not a steady movement of air from the inlet at one end to the extractor fan at the other. In fact there were two distinct circulation cells within the house and stagnant pockets of air at pig level, which the pigs avoided. In places there was air movement at right angles to the line from inlet to fan and even air movement away from the fan at pig level at one end of the house. The fan was providing the right kind of air-change rate, but not at animal level. The correct distribution of the ventilating air was now seen as the real problem, rather than an inadequate air-change rate or the introduction of partly contaminated air. Baffles placed near the inlet were used to modify the pattern of airflow and to produce a steady flow from end to end. The dirty pen problem and pig loss from this cause came to an end.

Smokes or radioactive tracers are non-persistent and where there is a need for a more permanent labelling of the air or of the path it has taken, use has been made of fluorescent particles or bacilli as tracers.

Air-filters are finding an increasing use in poultry and animal housing now that the windborne spread of infectious dust particles is accepted. It is possible to generate fluorescent particles of dimensions comparable with naturally occurring particles and this leads us on to a procedure for testing the efficiency of filters. The method is indicative rather than quantitative, but fluorescent particles released outside a house have been shown to pass readily through filters, both by the sampling of the air inside the house and by looking for deposition on surfaces within the house.

Comments were called for on the ventilation systems and procedures at a poultry station interested in the maintenance of disease-free flocks for investigational purposes. Certain routine precautions were being taken, such as ensuring that the poultryman responsible for one flock did not come into contact with any other flock, i.e. did not enter any other house on the site. Anyone of necessity passing between the houses changed his outer clothing and dipped his boots.

The houses had forced ventilation, with air entering through a central duct in each, that ran along the length of the building at ceiling level. The air found its way out through openings in the side walls, but there was no positive extraction. Wind pressure might be expected on some occasions to exceed the fan-generated internal pressure on the side wall openings, and the entry of air from one house into another through its nominal outlets would appear inevitable from time to time. More to the point however, there was another possibility for the daily exchange of infectious particles between the houses. The poultrymen from each of the houses had a common meeting-place in the communal changing room where overalls were kept. We looked at the result of placing dishes of fluorescent particles and *bacillus globigii* (in talc) in this changing room. Within a very short time, the disturbances and air movements caused by people putting on and taking off outer clothing and by the opening of doors, lead to the particles becoming distributed throughout the block housing the changing room. An examination of the outer rooms

to the individual poultry houses some tens of yards away showed smaller but definite deposits of fluorescent particles, in particular on the floor under hanging coats. From examination of the clothing itself it would appear that the long coats dragged on the changing room floor, picked up particles chiefly on their bottom edges and deposited some of these again when the coats were hung up elsewhere.

Collecting dishes placed in the outer rooms to the poultry houses also gave positive counts of fluorescent particles. Other dishes were examined for the bacilli. The recovery of the bacilli required the assistance of bacteriologists to incubate and identify the tracer. This is evidently a more time-consuming procedure than a search for fluorescent particles with ultra-violet light. However, it has the advantage that it is a very sensitive method, for it is possible to multiply a catch for identification. In addition, to those interested in the possibility of the spread of the disease, the collection of viable bacilli is perhaps more interesting and convincing than the collection of an inert particle. As it happened no bacillus tracer was recovered in this instance. This could have been due to a variety of reasons—the method of dispersal, the plating technique, or the fact that a multiplicity of other organisms present in the atmosphere of the poultry house covered the plates. Certainly the procedure has been shown to be effective in more sterile atmospheres. But in any event the demonstration of the way in which fine particles are likely to be carried about this particular site will be borne in mind for the projected building programme.

The wind drift of mist sprays or even, say, the wind drift of fine droplets of slurry generated when it is spread onto the fields by 'rain gun' are not problems the agricultural section has come up against seriously as yet. But even in a brief survey such as this, attention should be drawn to the work of Staniland<sup>7</sup> and his use of fluorescent markers in studies of the effectiveness of spraying techniques.

#### REFERENCES

1. HOGG, W. H.; The use of upper air data in relation to plant disease. Weather and agriculture. Oxford, Pergamon Press, 1967, p. 101 (in press).
2. HURST, G. W. *et alii*; Origin, development and effects of yellow rust on Rothwell Perdix in 1966 in Great Britain. *Trans. Br. mycol. Soc., London*, 1967, (in press).
3. SMITH, C. V.; Some evidence for the windborne spread of fowl pest. *Met. Mag., London*, **93**, 1964, p. 257.
4. PASQUILL, F.; The estimation of the dispersion of windborne material. *Met. Mag., London*, **90**, 1961, p. 33.
5. HURST, G. W.; *Laphygma Exigua* immigrations into the British Isles, 1947-1963. *Int. Jnl Biomet., Amsterdam*, **9**, 1965, p. 21.
6. SMITH, C. V.; The rating of ventilation systems for animal houses. *Agric. Met., Amsterdam*, **9**, 1964, p. 21.
7. STANILAND, L. N.; Field tests of spraying equipment by means of fluorescent tracer techniques. *Jnl agric. Engng Res., Silsoe*, **5**, 1960, p. 42.

#### REVIEWS

*Meteorology* by W. L. Donn. 6½ in × 9½ in, pp. xv + 484, *illus.*, McGraw-Hill, Shoppenhangers Road, Maidenhead, Berkshire, 1965. Price: 72s.

This book appeared in earlier editions (1946 and 1951) under the title 'Meteorology with marine applications'. Now the third edition (1965) is available, revised and brought up to date in the light of recent advances in science and technology, with more than half of the original text completely rewritten. New chapters include 'Heat energy of the atmosphere', 'The

general circulation of the atmosphere' and 'Weather at sea'. The book is intended to be primarily a general introduction to meteorology, and the author, as a former head of the Meteorology Section of the U.S. Merchant Marine Academy, lays emphasis on the maritime aspects.

Among the chapters of special interest to mariners is one entitled 'The oceans' where sea temperatures, salinity, tides, waves, ice, currents and so on are dealt with. The section 'Weather at sea' discusses the meteorological uses of radar and touches upon the weather routing of ships and trip analysis. It also includes a substantial amount of information about the normal weather conditions for each month in the North Atlantic and North Pacific Oceans.

Not surprisingly in an American book, the text in certain sections is written very much from the American point of view, especially in Chapter 16 which deals with 'Weather analysis and interpretation'. The mariner, or a British reader, trying to familiarize himself with the manner of reporting and plotting observations must bear in mind that the descriptions contain many departures from, for instance, British practice.

The book is well produced with plenty of eye-appeal and contains a large selection of diagrams and illustrations. Particularly interesting are the pictures taken from high-flying aircraft and satellites showing the cloud structure of tropical cyclones and of frontal systems. There is a bibliography running to five pages, and a useful appendix giving climatological data for 149 of the principal ports and islands of the world. To test the reader's progress there is a set of exercises at the end of each of the nineteen chapters.

Some minor errors may be mentioned. Figure 8.13 should not show a ridge of high pressure with a sharp discontinuity of pressure (also mentioned by a reviewer of the 1951 edition). One of the equations on p. 425 should read  $L = 5.1T^2$ , and one on p. 427 should be  $H = 1.5F^{\frac{1}{2}}$ .

Although the book contains a great deal of useful and interesting material the writing sometimes lacks the clarity and precision desirable in a book for the general reader. The subject matter covers such a wide field that almost inevitably the treatment appears to the meteorologist as somewhat superficial and generalized.

G. M. RATTRAY

*Descriptive micrometeorology* by R. E. Munn. 9½ in × 6½ in, pp. xiv + 245, *illus.*, Academic Press Inc. (London) Ltd, Berkeley Square House, London, W1, 1966. Price: 78s.

This survey, issued as 'Supplement 1' in the 'Advances in Geophysics' series, is introduced in the foreword as a natural development of the theme dominating Volume 6 of the same series, which it will be recalled presented the various papers given on atmospheric diffusion and air pollution at an international meeting in Oxford in 1958. Two more symposia of a similar nature having occurred since then (Marseilles 1961 and Kyoto 1966), one is left in no doubt about the continued interest and activity in this field of work, and in that respect at least the demand for a review at the present time is obvious.

Existing reviews and texts on the subject range between the extremes of basic theory in fluid mechanics and qualitative discussion of the practical features of atmospheric flow, and in this latest review Dr Munn gives his readers a glimpse of the whole spectrum. This must have seemed both natural and inevitable in a work which was used as an outline for a university course

for which particular acquaintance with the atmospheric sciences was not an essential qualification. The aim of bringing the latest developments intelligibly to those without formal specialized training is deserving of much encouragement, and one can see the aim being usefully achieved in the more practical aspects. This is not so obvious in respect of the more sophisticated and controversial features. On the other hand, in the latter respect the review provides a comprehensive yet concise résumé which all active workers in the field will be glad to have. The distillation of the enormous amount of material in otherwise rather inaccessible reports of university work in the U.S.A. is also a useful feature.

The survey is divided into 22 short chapters, the first 10 of which deal with the basic physics and theories of the energy balance and turbulent transfer over ideal homogeneous surfaces. Remaining chapters deal in an inevitably more qualitative and descriptive way with the effects of the natural and man-made complexities in the surface conditions (relief, vegetation, buildings, water surfaces), concluding with a brief discussion of the possibilities of modifying local weather conditions.

Binding and printing are of high quality. There are some misprints and errors, most of which have already been rectified in a correction list.

F. PASQUILL

*The climate near the ground*, by R. Geiger, (translated from the German by Scripta Technica). 6½ in × 9½ in, pp. xiv + 611, *illus.*, Harvard University Press, Cambridge, Mass., distributed by Oxford University Press, London, 1965. Price: 92s.

A book giving an authoritative survey of any subject is very welcome both for beginners and specialists. Such a book is doubly welcome when an expert can find the time to bring it up to date periodically. It is very fortunate indeed for the subject of micrometeorology that Dr Geiger, now Director of Meteorology at the University of Munich, has maintained an enthusiastic interest over some 40 years. The first German edition of this work was published in 1927 but it has been revised several times. The fourth edition, published in 1961, discusses material as late as 1959 and is the basis of this third English translation, published in 1965.

The book is of undoubted importance in the study of both micrometeorology and microclimatology and the reviews of the last translation edition (1950) presented it in glowing terms (*Met. Mag., London*, 80, 1951, p. 302). Dr Geiger is generally concerned with the lowest two metres—the normal habitat of humans, animals and plants—but greater heights are considered in the discussion of subjects such as forest meteorology and diffusion. The text is divided into 57 titled sections which are grouped in nine chapters. There are ample cross references and an extensive bibliography appears for each section at the end of the book. The first eight chapters deal in turn with the heat budget of the earth's surface, the air layer over bare, level ground, the influence of the underlying surface, quantitative determination of heat balance factors, the air layer near plant-covered ground, problems of forest meteorology, the influence of topography on microclimate, and relations of man and animals to microclimate—which includes an over-optimistic section on the prevention of frost by water spraying. The ninth chapter is concerned with measurement techniques.

Dr Geiger gives graphic descriptions of the various phenomena and incorporates clear vivid diagrams and explanations with the minimum of mathematics. He makes it quite clear that those who are primarily interested in theoretical micrometeorology, which has been called the 'mathematician's paradise' by O. G. Sutton (*Q. Jnl R. met. Soc., London*, **80**, 1954, p. 328) should consult the latter's book on micrometeorology (1953) and similar works. Dr Geiger does not hesitate to retain the material of the earlier editions where this is applicable; thus 40 per cent of the diagrams are the same as in the previous English edition, although the reproductions are better and the captions clearer. The range is wide in space and time; thus there is mention of the optical method of determining surface temperatures over the Greenland ice, of the microclimate of tropical forests and of the blowing of snow in Adelie Land, Antarctica; a whirlwind of the fifth century B.C. is described and there is brief mention of the modern development of automatic weather stations and digital recorders. However, most of the examples are from central Europe in recent years (some three-quarters of the references are to papers in German).

The author states that his intention is to serve 'the ever increasing number of people who hope to learn about the average conditions of life near the ground, without having to use much mathematical physics. These are: the people interested in plant life—the farmers, foresters, gardeners, vine growers and botanists; those interested in animal life—the zoologists, entomologists, farmers, breeders; those interested in the state of the ground—the traffic engineers, road builders, architects, water and soil experts, geographers and country planners, medical men and bioclimatologists, even financial experts, who can no longer fail to take into account whether microclimate is favourable or unfavourable when assessing the just taxation of land'. In describing his work of revision the author remarks 'Then came the feeling of suffocation under the weight of good new literature, and the anxiety that the first chapter would be out of date before the last one could be finished. However, I was able to bear these tensions daily for three years, because without useful signposts no one can find his way any more in the labyrinth of science. If I have been able to point the way to a few, this will be my best reward for all the pains taken'. The present reviewer considers that Dr Geiger has amply fulfilled his task, and English readers will be thankful to Scripta Technica for producing such a fine translation.

L. JACOBS

*Physics of the earth's atmosphere*, edited by C. O. Hines, I. Paghis, T. R. Hartz and J. A. Fejer. 6 in × 9 in, pp. xiv + 434, *illus.*, Prentice-Hall International, Pegasus House, Golden Lane, London EC1, 1965. Price: £5 5s.

The introduction of the techniques of space research together with the inspiration of the International Geophysical Year have led to a veritable explosion of activity in upper atmospheric research. Whereas in the early 1950's it was possible to write a reasonably comprehensive book on the subject in one volume, this is out of the question now. There is therefore a great need for books which review the subject in a well-balanced way while at the same time avoiding too much detail. The volume under review has been written with this aim in mind and it succeeds very well.

Although the book is a compilation of contributions from a number of different authors it is much more homogenous than is usual for books of this kind because the editors have really edited and have planned the choice of chapters very well.

Another valuable feature of the book is that it looks at the subject as it is now and is not too much influenced by historical development. This has helped to maintain a good balance in choice of material.

By and large the subject is divided into two sections, one dealing with the so-called 'normal' or 'undisturbed' atmosphere the other with atmospheric disturbances. After an effective Introduction, Chapter II deals with solar optical radiation and its atmospheric effect. Next there follow three chapters on the ionosphere—the lower regions, the *F*-region and the outer regions. The two next chapters on motions, first of the neutral atmosphere and then of ionization, deal with subjects which are often much less well presented and emphasized. The same applies to Chapter VIII on ionospheric noise and geomagnetic pulsations.

The following chapters deal particularly with disturbance phenomena. Chapter IX discusses solar activity and short-lived terrestrial effects while the remainder deal with solar particle emission and the atmospheric phenomena it produces. Thus these chapters deal successively with solar cosmic rays and the ionosphere, magnetic and ionospheric storms, optical aurora, radio aurora and the theory of geomagnetic and auroral storms. This part of the book is again particularly well balanced and up to date in approach. The book concludes with an Epilogue and two appendices on wave propagation.

This book should be of much value both to students entering the field and to those whose active work in some specialized part of the subject has prevented them from seeing the subject as a whole. It is easy to read and well printed and of a convenient size.

H. S. W. MASSEY

## LETTERS TO THE EDITOR

551.507.362.2:551.509.311:77

### Guidance on chart analysis from satellite cloud pictures

In the interesting article by Potheary and Ratcliffe\* the authors state (last para. p. 335) that 'the satellite picture (Plate I) showed that the organization which should have been present if the occlusion had retained its structure was lacking'.

Now the 0000 and 0600 GMT analyses from Offenbach showed no occlusion extending northwards from the wave tip. Moreover from the 500 mb flow for 0000 GMT it is difficult to imagine that an occlusion process had been or was taking place. In these circumstances it is rather surprising that there is a band of cloud arranged normal to the upper flow, and it is interesting to learn (top of p. 336) that the cloud structure in this band differs from that to the south of the jet-stream axis.

---

\* POTHEARY, I. J. W. and RATCLIFFE, R. A. S.; Satellite pictures of an old occluded depression and their usefulness in analysis and forecasting. *Met. Mag., London*, 95, 1966, p. 332.

There is, of course, a trough extending north-north-west from the wave tip and if there has in fact been no occlusion process then the air at all levels in this trough will be maritime polar with cells of dry and moist air resulting from earlier convection. Lifting of such air may be expected to produce cloud which is less uniform than that resulting from convergence and lifting of maritime tropical air. It is therefore specially interesting to get confirmation of this from a satellite cloud photograph.

I think there is a mistaken tendency to put short occlusions to the north of all wave tips, and I am glad that this new tool provides evidence against the validity of this procedure.

M. K. MILES

*Command Met. Office  
HQ RAF Germany*

551.509.317:551.509.326

### **Instability index**

In a recent letter to the *Meteorological Magazine* (95, 1966, p. 381), Jefferson makes the point that the wet-bulb potential temperature at 850 mb can be used instead of that at 900 mb with little difference to the resulting instability index. I would like to confirm that it is also true for the western end of the Mediterranean and was indeed my standard practice at Gibraltar.

The same reasoning used by Jefferson for devising his modified formula—the extreme dryness, on occasions, of the low-level air and the need to take into account the moisture content at 700 mb—led me to try a modified version of the original Rackliff formula to deal with those cases of high-level convection or middle-level instability, instances of which were often reported in summer by BEA captains over Spain *en route* to Gibraltar.

The formula was

$$\Delta T = \theta_{w700} - T_{400}$$

for which the threshold value appeared to be 40.

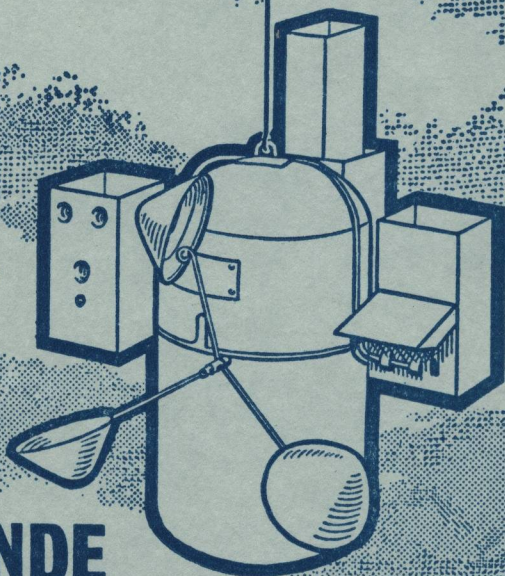
It was still necessary, as Jefferson pointed out, to work out the index for the 850 to 500 mb layer in addition to the 700 to 400 mb but both are quickly done and on occasions the latter index indicated a probability of middle-level instability when the value for the former was below the threshold.

This formula does not have the wider application of Jefferson's final version but as a tool for forecasting thunderstorms over Spain for BEA scheduled flights, which so often seemed to coincide in time with maximum activity, it proved very helpful.

J. D. HASTINGS

*Meteorological Office  
Royal Air Force, Odiham*

For accurate  
upper atmosphere  
recordings—



## RADIO SONDE

### Meteorological Transmitter

The WB Radio Sonde is essential for high altitude weather recording (up to 66,000 ft.), and is available with battery, parachute, radar reflector and battery, or as a single unit, complete with met. elements.

For full specification of the WB Radio Sonde—which is used by the U.K. Meteorological Office, and many overseas Governments—please write or telephone

# WHITELEY

ELECTRICAL RADIO CO. LTD.

MANSFIELD  
NOTTS  
ENGLAND

Tel: Mansfield 24762

## CONTENTS

	<i>Page</i>
<b>Sequences in monthly rainfall over England and Wales.</b>	
R. Murray ... ..	129
<b>Further studies of minimum temperatures in the forest of Thetford Chase.</b>	
G. W. Hurst ... ..	135
<b>The measurement of surface wind.</b>	
A. L. Maidens ... ..	143
<b>Airborne tracers in agricultural meteorology.</b>	
C. V. Smith ... ..	150
<b>Reviews</b>	
Meteorology. W. L. Donn. <i>G. M. Ratray</i> ... ..	155
Descriptive micrometeorology. R. E. Munn. <i>F. Pasquill</i> ...	156
The climate near the ground. R. Geiger. <i>L. Jacobs</i> ... ..	157
Physics of the earth's atmosphere. Edited by C. O. Hines, I. Paghis, T. R. Hartz and J. A. Fejer. <i>H. S. W. Massey</i> ...	158
<b>Letters to the Editor</b> ... ..	159

## NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General Meteorological Office, London Road, Bracknell, Berkshire, and marked "for Meteorological Magazine."

The responsibility for facts and opinions expressed in the signed articles and letter published in this magazine rests with their respective authors.

All inquiries relating to the insertion of advertisements in the Meteorological Magazine should be addressed to the Director of Publications, H.M. Stationery Office, Atlantic House, Holborn Viaduct, London E.C.1. (Telephone: CITY 9876, extn 6098).

The Government accepts no responsibility for any of the statements in the advertisements appearing in this publication, and the inclusion of any particular advertisement is no guarantee that the goods advertised therein have received official approval.

© Crown Copyright 1967

Printed in England by The Bourne Press, Bournemouth, Hants.

and published by

HER MAJESTY'S STATIONERY OFFICE

Three shillings monthly

Dd. 133110 K16 5/67

Annual subscription £2 1s. including postage

S.O. Code No. 40-43-67-5