Evaporation Memorandum No. 20a.

Values of 7-day average, low-level wind speed for use in calculations of potential evapotranspiration by Penman's formula.

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Abstract. The importance of reliable wind speed data for areal or point estimates of p.e. is demonstrated. It is suggested that reasonable estimates of V_2 (n-day average wind speed at 2 metres above ground) may be obtained for Great Britain from routine anemometer measurements and from radar-wind measurements at 900 metres above sea level.

Monthly average wind speed patterns at 900m., for a year chosen at random, are presented and it is shown that reasonable analyses can be produced by simple interpolation. The relevance to the present problem of unpublished work by N C Helliwell, J J W Blackburn and O L Palfrey is explained and reference is made to similar work by A G Davenport. Comparisons between 2 metre wind measurements and estimates of wind at 2 metres (from measurements made at other heights) made by A G Seaton are quoted and the data he used are processed to provide some simple results. Comparisons are made between measurements of wind speed at 2 metres at adjacent stations and stations in the same general area and it is shown that good estimates of monthly, average wind speeds at 2 m. may be obtained from 900 m. speeds. Finally a system is proposed to produce good estimates of 2m., 7-day average wind speed for grid squares (40 X 40 km) covering Britain.

Introduction.

The rate of potential evapotranspiration (p.e.) may be required for a very small area, such as an experimental site, or for a sizeable area of, say, 400 km^2 or more.

For "point" estimates of p.e. we want the true, average wind speed at the point, even though this may be much less than the average speed over the surrounding countryside, due to local friction and obstructions to air flow near the measuring point.

For the area-representative estimate of p.e., on the other hand, we want a speed appropriate to the whole area and this may be a compromise between speeds over sites having varying degrees of shelter and terrain roughness.

The purpose of the present work has been to find a way of obtaining area-representative, 7-day average values of wind speed at 2 metres above the ground immediately after the end of each 7-day period and using data available in the computer synoptic data bank and data sets.

1.1. THE SIGNIFICANCE OF WIND FLOW IN THE PENMAN METHOD OF ESTIMATING POTENTIAL EVAPORATION FROM METEOROLOGICAL DATA

In the general formula $E = \frac{\Delta H + \gamma E_a}{\Delta + \gamma}$

the wind flow affects the estimate of evaporation (E) only through the aerodynamic term $\frac{\gamma}{\Delta+\gamma} E_a$, where

$$E_a = 0.35 (e_a - e_d) \left(1 + \frac{U_2}{100}\right);$$

where $(e_a - e_d)$ is the saturation deficit (measured in a Stevenson Screen) and U_2 is a measurement (or estimate) of the run-of-wind at 2 metres above the ground.

It can be seen that if there is no horizontal air movement the expression reduces to

$E_a = 0.35 (e_a - e_d)$ which, **becomes zero if the input of heat is not sufficient to prevent e_d from becoming equal to e_a**

It can be seen, also, that if the air is very moist, so that $(e_a - e_d)$ is small, U_2 is not very important (of course, if the air is very moist there will not be much evaporation anyhow as there will probably be a thick layer of cloud excluding incoming solar radiation).

Seaton has shown that for a saturation deficit of 1.6 mb (in summer - June) the estimate of PE changes by .0015 mm/day for a change of 1 mile/day in wind flow.

Thus, for example, if the mean wind speed is 15 mph (wind run 360 miles /day) and it is measured as only 7.5 mph (180 miles), the under-estimate of evaporation (potential) would be 0.27 mm/day and if the rate of PE is, say 3.3 mm/day this would represent an 8% error.

Note: H L Penman used 2 metre wind speeds because these data were readily available for many agro-meteorological stations; they are also representative of flow over crops in the immediate vicinity.

H is the net radiant energy available at the (earth and vegetation) surface

Δ is the slope of the saturation vapour pressure curve at the air temperature.

γ is the hygrometric constant (taken as 0.49 where temperature is expressed in °C and vapour pressure in millimetres of mercury).

1.2 AN EXAMPLE OF THE EFFECT ON MONTHLY P.E. OF ALTERING THE WIND SPEED DATA.

A careful examination of monthly patterns of average wind speed over Northern Ireland in 1971 suggested that the values of run-of-wind at 2 metres above ground obtained at Lisnafillan were too small to be representative of a sizeable area and were, probably, applicable only to the observing site.

Estimates of wind speed were made and monthly totals of (Penman) P.E. were re-calculated, using the same computer programme as had been employed for the original set of P.E. values.

Fig.1. shows the two sets of monthly P.E. estimates in tabular form and as cumulative curves, the two sets of monthly average wind speeds and the monthly and accumulated totals of difference between the two sets of P.E. estimates.

The differences are significant throughout the year, totalling 65.7 mm. Even if only the summer half-year (April to September) is considered, when evaporation may be expected to exceed rainfall, there is still a difference of 34.8 mm.

1.3. THE NEED TO PRODUCE RELIABLE N-DAY ESTIMATES OF AREA-REPRESENTATIVE AVERAGE WIND SPEED FOR NATIONAL EVAPORATION AND SOIL MOISTURE ADVISORY SERVICES.

The example given in 1.2. and other comparisons of data which appear at later stages in this report* are held to be sufficient evidence of the need to devise and implement a system for processing wind data for the purposes of estimating potential evaporation.

1.4. WIND MEASUREMENTS, SITES AND EFFECTIVE HEIGHT.

Copies of advisory notes on these topics are attached as Appendix I.

* see Figs. 7, 8 and 9

2.1. DATA AVAILABLE.

Wind speeds at 10 m. or thereabouts above ground, obtained from anemograph traces are reported to Bracknell at hourly or less frequent intervals, via telecommunications channels, from some 70 stations in the United Kingdom (3 are in Northern Ireland). Speeds read from fixed anemometers are reported, in the same way, by some 49 stations.

Upper-level winds are measured at 6-hourly intervals, from 8 stations in the U.K. (one being in Northern Ireland) and from one station in the Irish Republic, by means of radar and balloon reflectors.

Daily values of run-of-wind at 2 metres above ground are obtained at some 110 stations and there are also some 45 additional, anemograph and fixed anemometer stations but these 155(approx) stations do not make daily reports. These figures are set out, with some additional information, in Appendix 2.

3.1. EFFECTS OF EXPOSURE ON WIND SPEED MEASUREMENTS.

The fact that wind speed measurements are strongly site-dependent has long been well known. Measurements made at levels as low as 2 metres are influenced by the varying height of grass and crops and by the leaf-cycle of deciduous trees, for example. Buildings, hedges, trees (whether in leaf or not) and topographical features are very important even when the measurements of wind speed are made at heights of 10 metres, or more, above ground.

Out of some 119 anemograph and anemometer stations sending daily reports (see Appendix 2) 60 are coastal sites, some being airfields, 31 are inland airfields and only some 28 (approximately 23%) are inland sites which are not airfields. Bearing in mind that airfields are flat, level areas we would expect their average wind speeds to be considerably greater than those of many other places in their vicinities.

3.2. SURFACE WIND SPEEDS AND TOPOGRAPHY.

Average speeds near coasts are normally higher than average speeds at corresponding heights (above sea level) inland, because of the low frictional resistance to wind flow offered by the sea surface and because of the well-known sea breezes produced through the differential heating of land and water masses.

The content of this paragraph is very well summarised in Fig.3.2.

4.1. BROAD-SCALE WIND FLOW AT LOWER LEVELS IN THE FREE ATMOSPHERE.

The term "free atmosphere" is taken to mean those layers high enough (above the earth's surface) to be uninfluenced by small-scale irregularities and other minor, place-to-place variations at ground level.

Such layers are, of course, influenced by large-scale surface features even at great heights. Figs. 2.1. to 2.12. show subjective isotach (equal speed line) analyses of monthly average wind speeds at 900 metres above sea level. The plotted data are averages of speeds measured from Lerwick, Stornoway, Shanwell, Long Kesh, Aughton, Hemsby, Crawley and Valentia at 06 and 18 hr. GMT, daily, in 1969. The guiding principle of analysis was simple interpolation.

In general, we would expect higher speeds near windward coasts than near leeward coasts or inland so, for the British Isles, lying in the path of prevailing westerlies, stronger in high latitudes, we would expect to find the annual distribution actually shown by Fig. 3.1.

Monthly, average wind speed fields at about 900 m. (a.s.l.) can be adequately represented by simple interpolation between a few points and that these patterns, whilst influenced by large-scale topographical features, are dominated by the varying patterns of atmospheric pressure. In other words, once clear of the frictional and sheltering effects of local topographical and other minor features, average wind speeds form smooth, coherent patterns controlled by the broad-scale distribution of atmospheric pressure.

4.2. THE 900 METRE LEVEL WIND AS A STANDARD.

One way of obtaining n-day estimates of area-representative average wind speed at 2 metres might be to obtain a relationship between averages at 900m and, say, 10 m above open, level terrain and then to produce estimates at 2 m by the use of a "roughness" factor.

The existence of a convenient "reference level" also suggests a possible means of quality-controlling average wind speeds measured at a given height above open, level terrain or corrected to represent such a measurement. Examination of instruments and sites from which "suspect" data had been obtained might reveal mechanical or observational errors and/or hitherto unsuspected site controls on wind flow.

4.3. RELATIONSHIPS BETWEEN 900 M. AND ANEMOMETER WIND SPEEDS. AT 10 M.

In Table I hourly average wind speeds are given for 8 stations which are either upper wind sounding stations or places very close to them. The anemometer winds are expressed as decimal fractions of the corresponding 900 m winds. for each month of 1969. The averages in the far right-hand column are averages of the 12 monthly fractions. Table II is an extension of Table I; the 900 m. speeds being taken from the isotachs. The monthly decimal fractions V_{10}/V_{900} have been averaged over the year and are shown in Fig. 4. As would be expected, the coastal values are high and the inland ones are mostly lower.

The 900 metre pattern, already suggested as a reference for quality-control, might be used to provide factors by means of which the effects of areally-unrepresentative friction and shelter could be removed from measured wind speeds.
Once a reasonable, country-wide pattern of V_{10}/V_{900} has been produced it will be possible to estimate V_{10} for areas where data are sparse.

5.1. USE OF TERRAIN ROUGHNESS INDEX.

Theoretically speaking, if we know the extent to which the terrain in the vicinity of an anemometer interferes with the wind flow we can produce a good estimate of the speed which would have been recorded, at a given time and place, had the interference been reduced by a known amount. To produce an area-representative n-day average wind speed at z metres (above ground) we would first remove the effects of local interference to a defined extent and then apply the effects of average, areal interference.
In Appendix 3 is set out relevant work by Helliwell, Blackburn and Palfrey.* A roughness index is allotted to a site or area by reference to a descriptive table. This provides a possible means of obtaining the area-representative speeds as suggested in the last paragraph.
In general, it seems that this method should be effective but a study of the V_s values given in the right-hand column of Table 4 of Appendix 3 suggests that a

* a paper by A G Davenport "Rationale for determining design wind velocities" 1960 Proc Amer Soc Civ Eng Vol 86 ST5 is also relevant.

few are too low even after roughness has been allowed for. The opinion has been expressed that this may be due to basin effects resulting in a frequency of calms and light winds too high to be representative of the general area.

To obtain a country-wide set of roughness estimates the cooperation of official and cooperating observing stations has been obtained and the Index values are given in Fig 11. in the form of a reduced version of the resulting areal roughness index map.

6.1 ESTIMATING 2M WIND SPEEDS FROM SPEEDS MEASURED BY ANEMOMETER HEADS AT GREATER HEIGHTS.

In Meteorological Office (Met.O.8) Evaporation Memorandum No.17 (June 1971) A.G.Seaton analysed measurements of wind speed at 2 metres and at greater heights at Kew, Cardington and Rothamsted. Fig.5 shows the relative positions of these three stations and of others mentioned in the report. Fig.6 compares monthly average speeds measured at 2 m. and estimated from measurements made at greater heights using the reduction factor $(2/Z)^{0.17}$ where Z is the "effective height" (see Appendix 1) of the station anemometer. The data are for the 24 months of 1969 and 1970 except that 2m data were not available from Cardington until June 1969. The equations, in which suffix "a" means measured at 2m and "b" means estimated or "reduced" from measurements at a greater height, were produced by using the averages of 24 or 19 monthly values and estimates respectively. The relationship between measured and estimated 2m winds at Cardington and Rothamsted are much the same but that at Kew is quite different from the other two.

The measured average at 2m is not necessarily the true average speed even though it may be the average as influenced by some obstruction or other effect. If the run-of-wind anemometer is sheltered from winds from certain directions the measured average may only represent one spot and not the whole site. The measured wind, with excessive shelter, will be much too low. On the other hand, the modified, higher-level wind speed may be over-damped or under-damped by the arbitrary reduction formula.

It can be seen from Figs.2.1 to 2.12. that there was very little difference between the monthly average wind speeds at 900 metres in 1969 over the stations in the cluster enclosed in the dotted line on Fig.5. It would be reasonable therefore to expect that differences in average wind speeds at any given level at pairs of stations would depend only on site characteristics. Fig.7.1 compares Cardington and Kew. The correlation is not good for reduced, high-level anemometer winds but is good for measured 2m winds. It must be remembered that the effective heights of the anemometers are Cardington 41 metres and Kew 15 metres. It is clear that the 2m anemometer at Cardington is far more exposed to the wind than that at Kew.

Fig.7.2. compares Kew and Rothamsted. The correlation is quite good for both pairs of measurements. The estimated 2m winds suggest that Kew is the more exposed site whereas the measured 2m winds suggest that Rothamsted is the more exposed. It would be surprising if both were true !

Fig.7.3. compares Rothamsted and Cardington. The correlation is quite good for both pairs of measurements and both comparisons suggest that Cardington is the windier location. The slopes of the regression lines through zero are very similar.

7.1. INTER-STATION COMPARISONS OF 2M WIND SPEEDS.

It is important to examine the extent to which an average 2m wind speed is reproduced (or not reproduced!) at an adjacent or not far distant station. Such comparisons are made in Figs.8.1. to 8.4. It is seen that correlations are generally good but in 7 out of the 8 comparisons the difference between 1:1 relationship and the slopes of the regression lines through zero is appreciable. This is, of course, the result of site characteristics and, perhaps, of instrument condition. It is assumed that all the instruments are of the same type and have the same, theoretical starting speed (i.e. speed below which the cups do not rotate).

Table III contains monthly average 2m wind speeds for 9 stations in 1969. These data are plotted in Fig.9 and it can be seen that all stations have, in general, the same pattern through the year.

Monthly 9-station averages are plotted in the upper part of the figure. The annual 9-station average speed is 4.1 kts and this has been divided by 19, the average, annual 900 m speed for the whole area, obtained from Fig.4.1. Monthly 900 m speeds, multiplied by 4.1/19 = 0.2157 are plotted for comparison. It is obvious that a close relationship exists between the monthly average wind speeds at 900 and at 2 metres. The agreement between the two graphs is not so good for January to March as for the rest of the year.

s. It is noticeable (lower part of Fig.9) that there is rather less agreement between station graphs in the 2nd & 3rd months of 1969 than during the rest of the year.

Since the desired end-product is a 7-day estimate of 2m average wind speed it is suggested that the above evidence justifies the use of the 900 m speed pattern as a starting point or datum.

8.1. PREPARATION OF N-DAY , AREA-REPRESENTATIVE ESTIMATES OF AVERAGE WIND SPEED AT 2M ON A GRID-SQUARE BASIS.

The first model, which will almost certainly undergo development in due course, is based on work by A G Davenport and on unpublished work carried out in the Climatological Division of the Meteorological Office.

7-day averages of wind speeds measured by anemometers (at 10 m or more above ground) are adjusted to provide estimates (V_s) of values which would have been attained at 10 metres, in the same geographical location and with the same major topographical features but with few trees or other obstructions. Routine corrections are made to wind speeds measured at effective heights of other than 10 m before they are included in synoptic weather reports. In the model, these corrections are reversed so as to leave averages of speeds actually read from the anemometers. The correction for non-standard height in the model is combined with a correction for the frictional characteristics of the locality.

A field of V_s is produced and values are stored representing the centre points of the 40 x 40 km squares used in the model. A field of 7-day averages 900 m wind (V_{900}) is produced and values are stored for the same points. For each point there is stored a standard value of V_s/V_{900} and these values are applied, as multiplying factors, to the point values of V_{900} to produce V_s' (a version of V_s estimated from V_{900}). $\frac{1}{2}(V_s + V_s')$ is now worked for each point. The final step is to adjust $\frac{1}{2}(V_s + V_s')$ to obtain V_2' (estimated 40 x 40 km square 7-day average 2 m wind speed) by introducing the frictional effect of the average roughness of the terrain in the square.

Details of the calculations are as follows:-

(1) Obtain 7-day average wind speed V_h at anemometer effective height h for each station. (See Note)

(2) Adjust V_h to V_s by the use of a power law formula including a roughness exponent a and an empirical roughness divisor q. (See Table)

$$V_s = 1/q\ (V_h)\ (10/h)^a$$

(3) Produce a field of V_s

(4) Store a value of V_s for each square (centre)

(5) Obtain 7-day average 900 m wind speed (V_{900}) at each upper wind station.

(6) Produce a field of V_{900}

(7) Store a value of V_{900} for each square centre

(8) Multiply each V_{900} value by the corresponding value of $\overline{V_s/V_{900}}$ (Fig 10) to get V_s'

(9) Calculate $\frac{1}{2}(V_s + V_s')$ for each point

(10) The formula in (2) relates V_s and V_h, putting h = 2 we have $V_s = 1/q(V_2)(5)^a$ or $V_2 = qV_s/5^a$

So we evaluate $\frac{1}{2}(V_s + V_s')q/5^a$ using values of a, and q appropriate to the average roughness index for the square (Table and Fig. 11)

Note: The routine corrections applied to winds measured at non-standard heights are removed as follows:

Effective height	Change	
10 to 13 m	none	to obtain V_h from V_r
14 to 22 m	X 10/9	where V_r = reported speed
23 to 42 m	X 5/4	
43 to 93 m	X10/7	

Terrain Roughness - Table

Index.	Description
1	Very smooth terrain Open water Mud flats
2.	Open, level, smooth country with few hedges or trees
3.	Open, level country with many hedges but few trees
4.	Level, sparsely wooded country. Outskirts of small towns.
5.	Rolling country with tree-hedges and small villages
6.	Rolling country with small towns. Outer suburbs of cities.
7.	Inner suburbs.
8.	City centres.

Index c	Exponent a	Divisor q	$q/5^a$
1	0.14	1.05	0.84
2	0.17	1.00	0.76
3	0.20	0.95	0.69
4	0.23	0.90	0.62
5	0.26	0.85	0.56
6	0.28	0.82	0.53
7	0.30	0.79	0.49
8	0.32	0.75	0.45

The staffs of official and auxiliary meteorological stations and of cooperating climatological stations assessed their stations and surrounding areas ($\frac{1}{2}$ mile and 5 miles around observing point) according to the upper part of the Table. Station values ($\frac{1}{2}$ mile) are used to obtain V_s from V_h. The 5 mile average index values were plotted and averaged for 40 x 40 km squares (Fig.[1).

Acknowledgement: Thanks are due to Mr H C Shellard who read the first draft of this memorandum and made many helpful comments.

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(revised version
of Memo. No.20)

	P.E. mm E_1	P.E. mm E_2	D mm
JAN	0	2.9	2.9
FEB	10.7	16.4	5.7
MAR	23.8	29.6	5.8
APR	39.2	42.0	2.8
MAY	65.8	73.1	7.3
JUN	77.0	86.1	9.1
JUL	79.4	85.8	6.4
AUG	55.6	61.7	6.1
SEP	30.3	33.4	3.1
OCT	12.6	18.1	5.5
NOV	4.5	10.1	5.6
DEC	0	5.4	5.4
	398.9	464.6	65.7

46.1 (MAR–OCT) 34.8 (APR–SEP)

$D = E_2 - E_1$

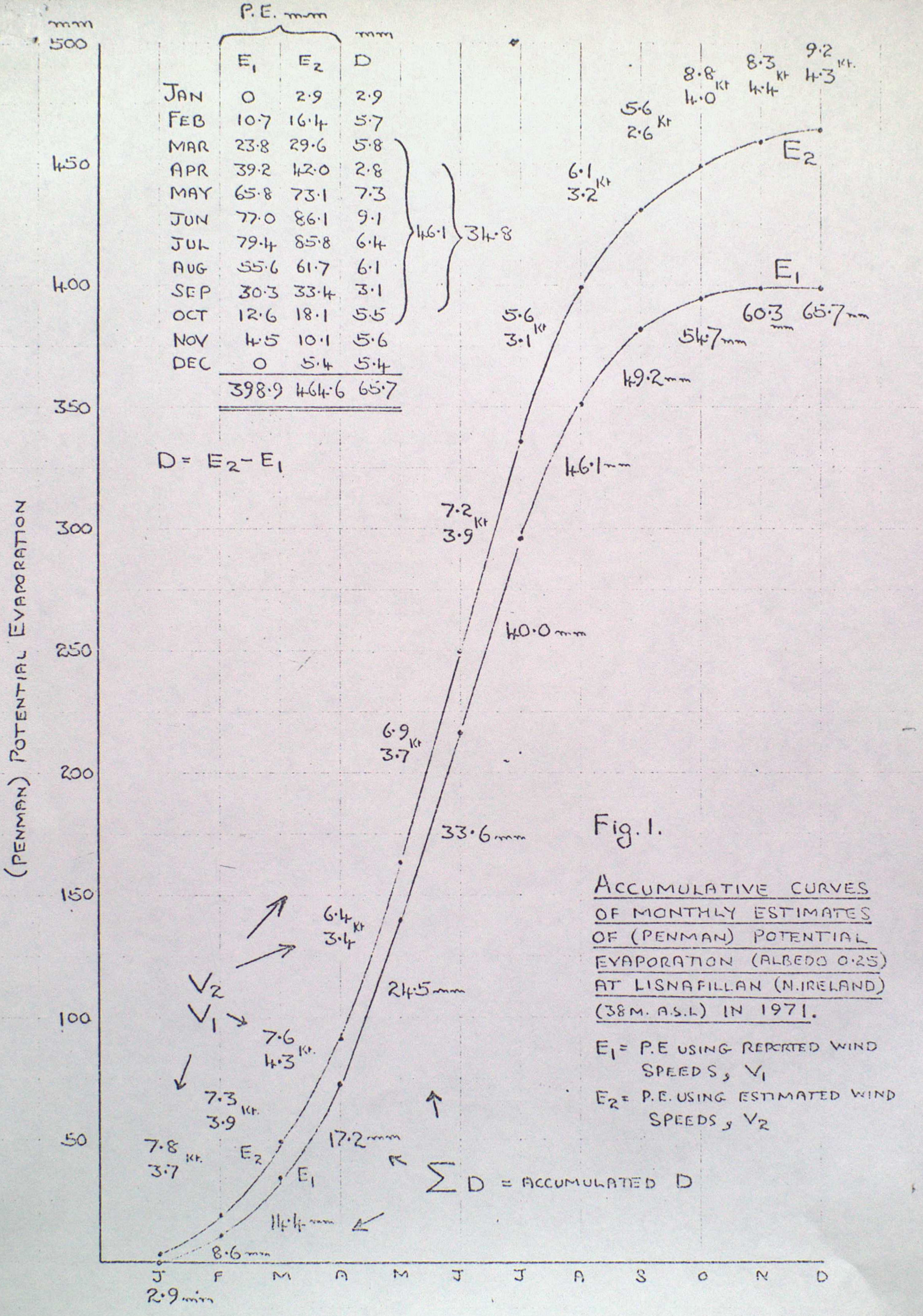


Fig. 1.

ACCUMULATIVE CURVES OF MONTHLY ESTIMATES OF (PENMAN) POTENTIAL EVAPORATION (ALBEDO 0.25) AT LISNAFILLAN (N. IRELAND) (38 M. A.S.L) IN 1971.

E_1 = P.E USING REPORTED WIND SPEEDS, V_1

E_2 = P.E. USING ESTIMATED WIND SPEEDS, V_2

Monthly Averages of Wind Speeds (knots) measured at 900 m. above ground from radiosonde stations in the British Isles - 1969. 06 and 18 hr. GMT.

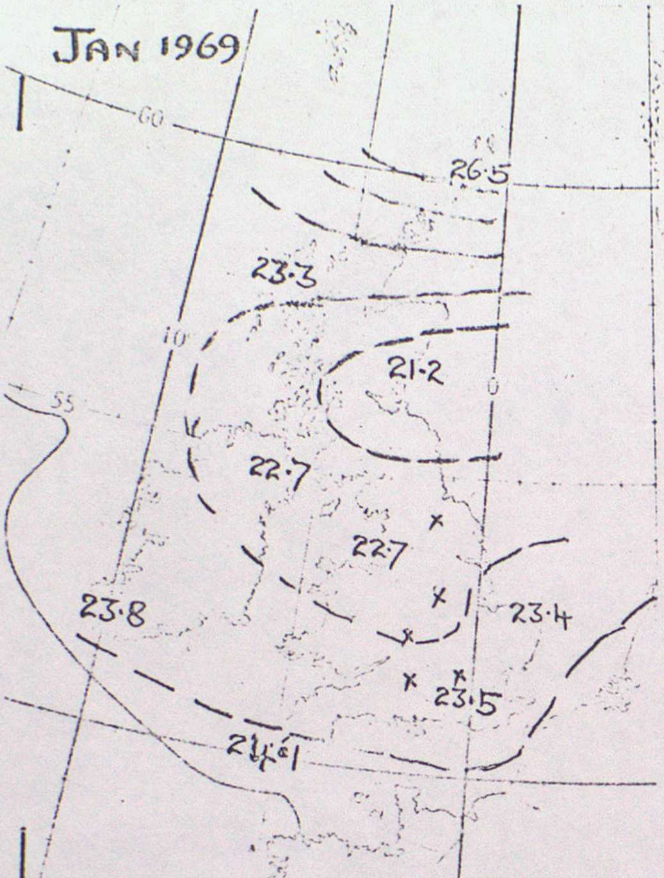


Fig. 2.1.

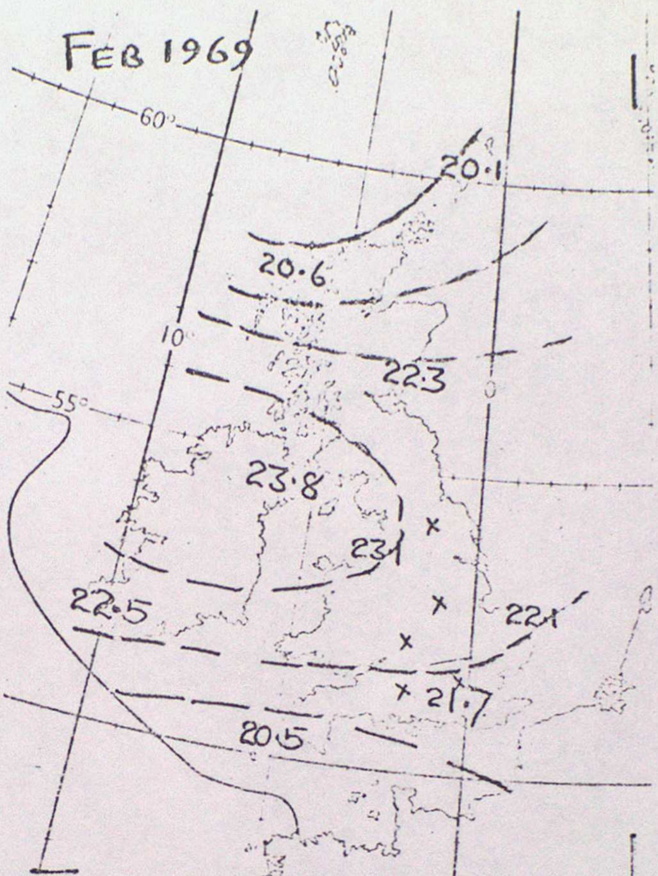


Fig 2.2.

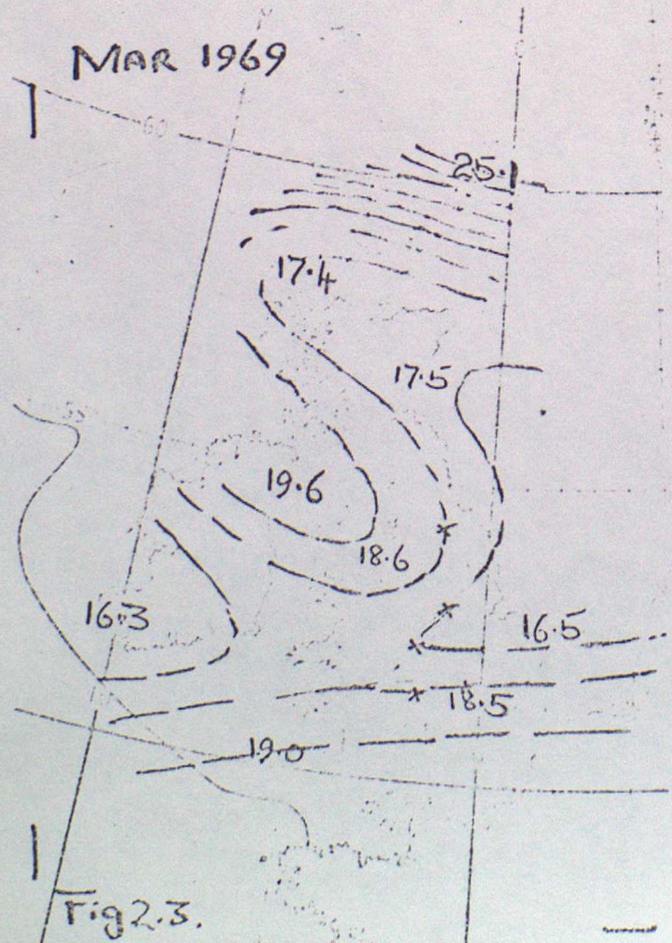


Fig 2.3.

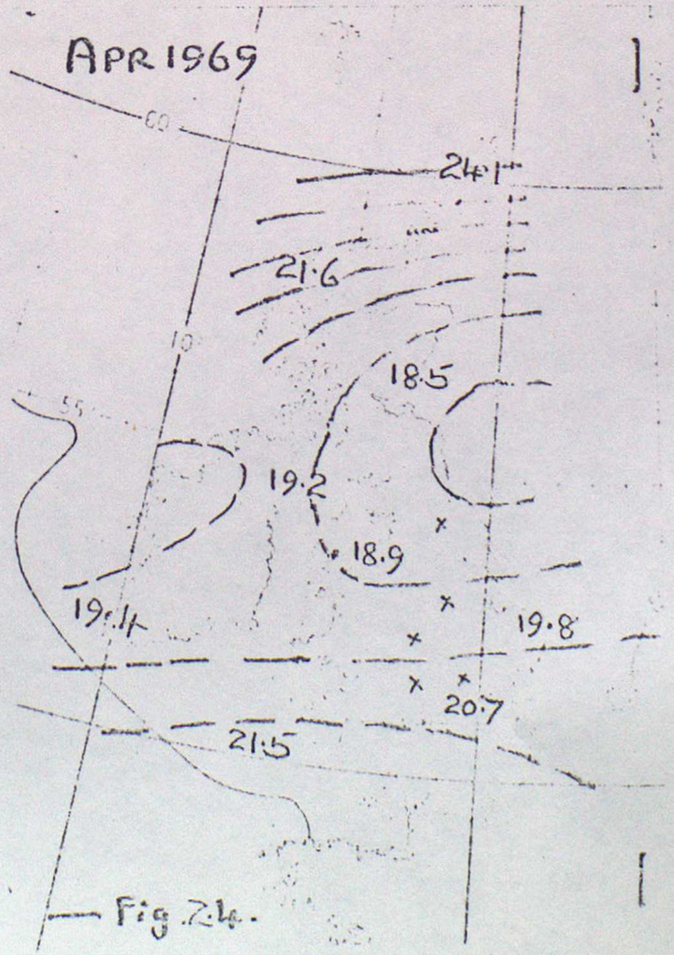


Fig 2.4.

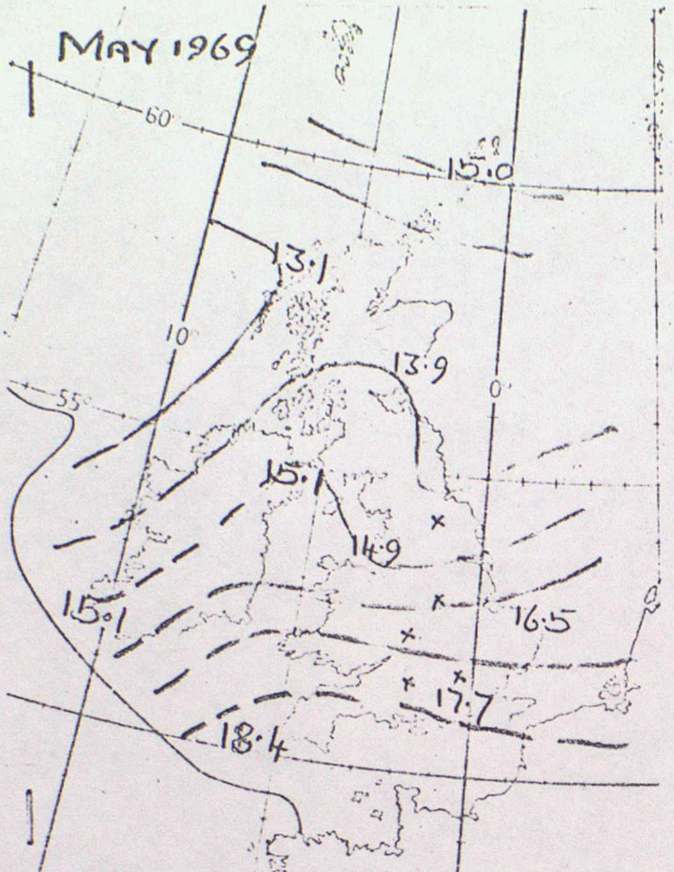


Fig 2.5.

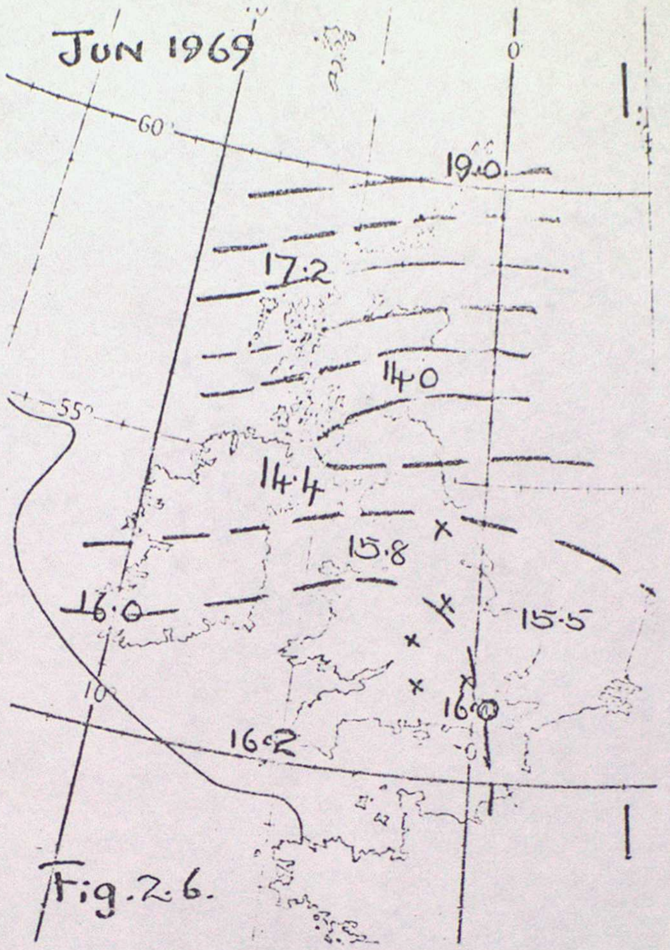


Fig. 2.6.

Fig. 2.7.

Fig. 2.8.

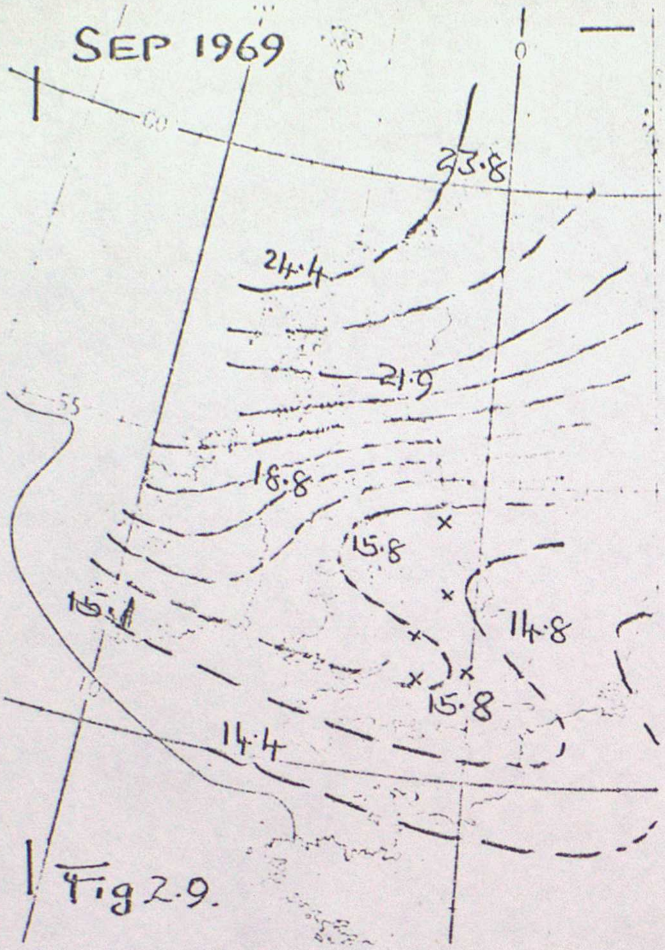


Fig 2.9.

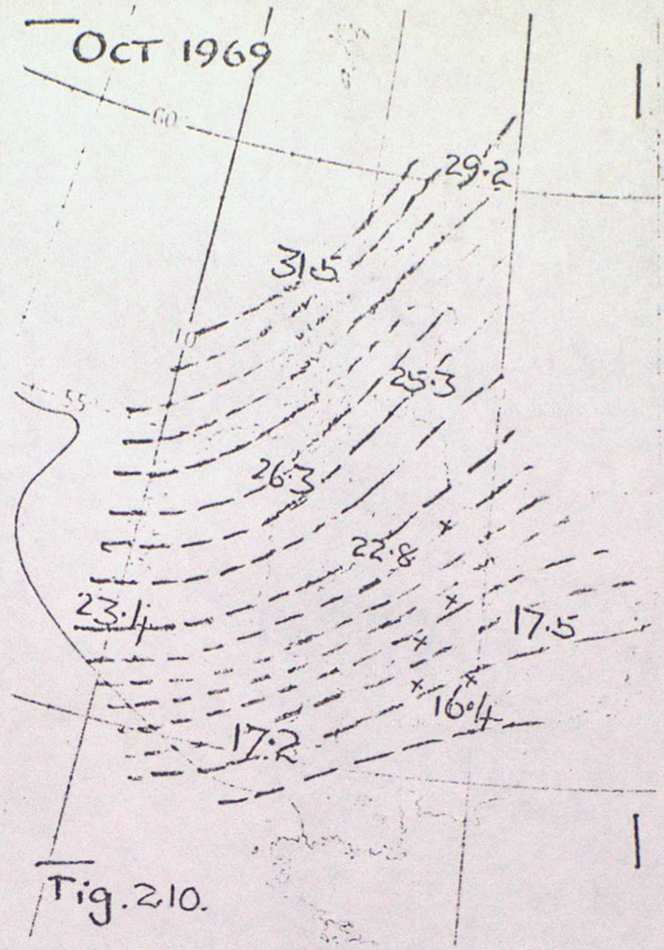


Fig. 2.10.

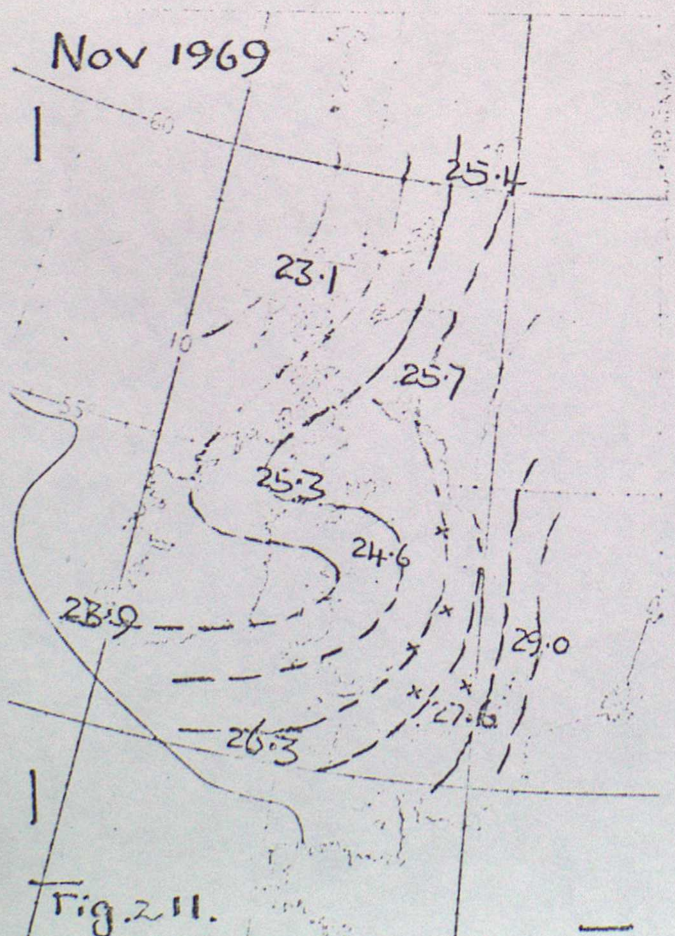


Fig. 2.11.

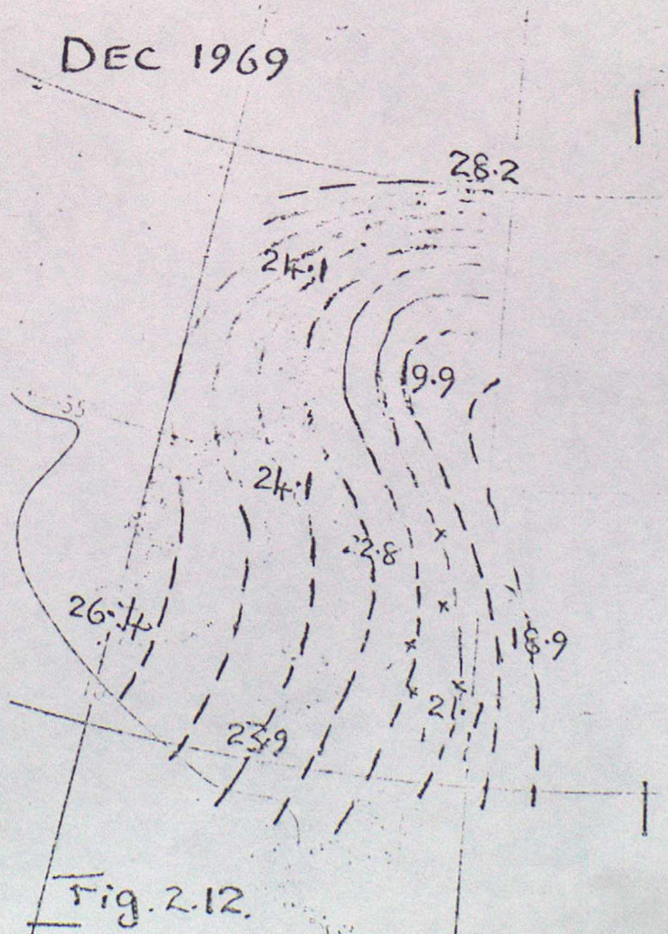


Fig. 2.12.

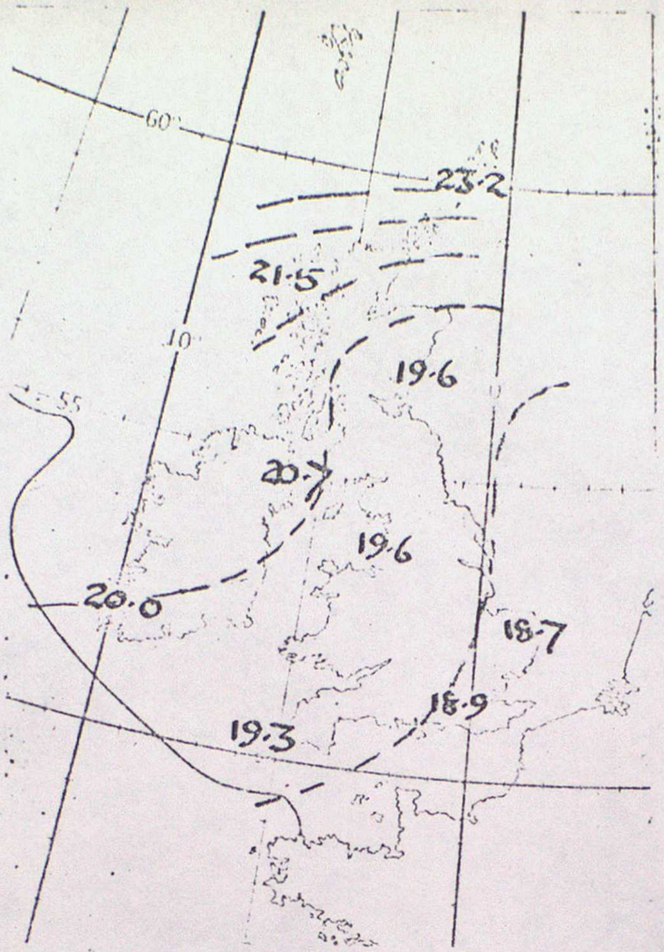


Fig. 3.1. Average wind speed (kts.) at 900 metres (above sea level) 1969.

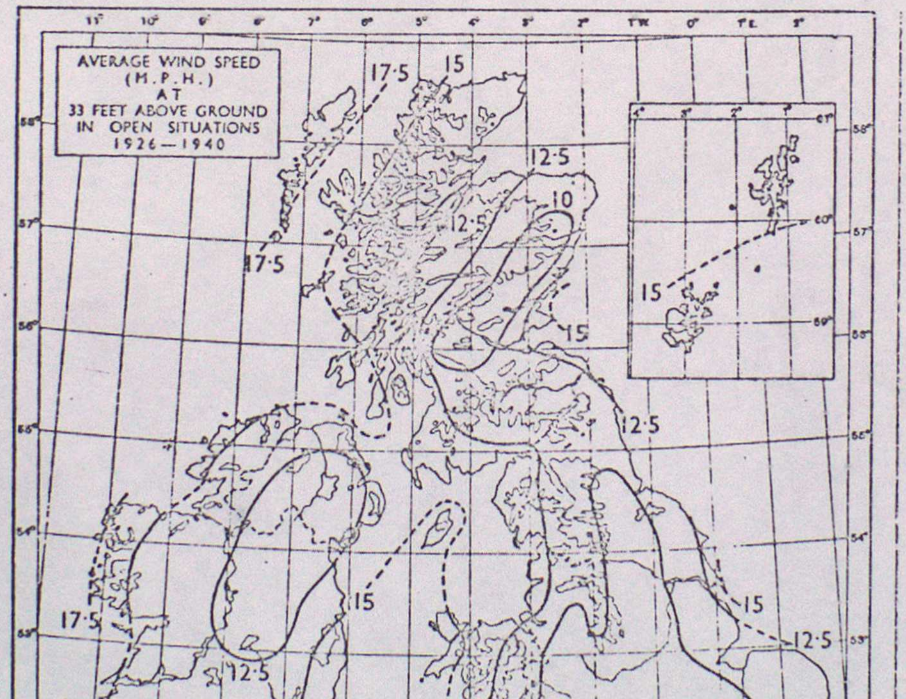


Fig. 3.2. Average wind speed (m.p.h.) at 33 ft. (10 m.) above ground in open situations 1926 - 1940 (M.O. Climatological Atlas).

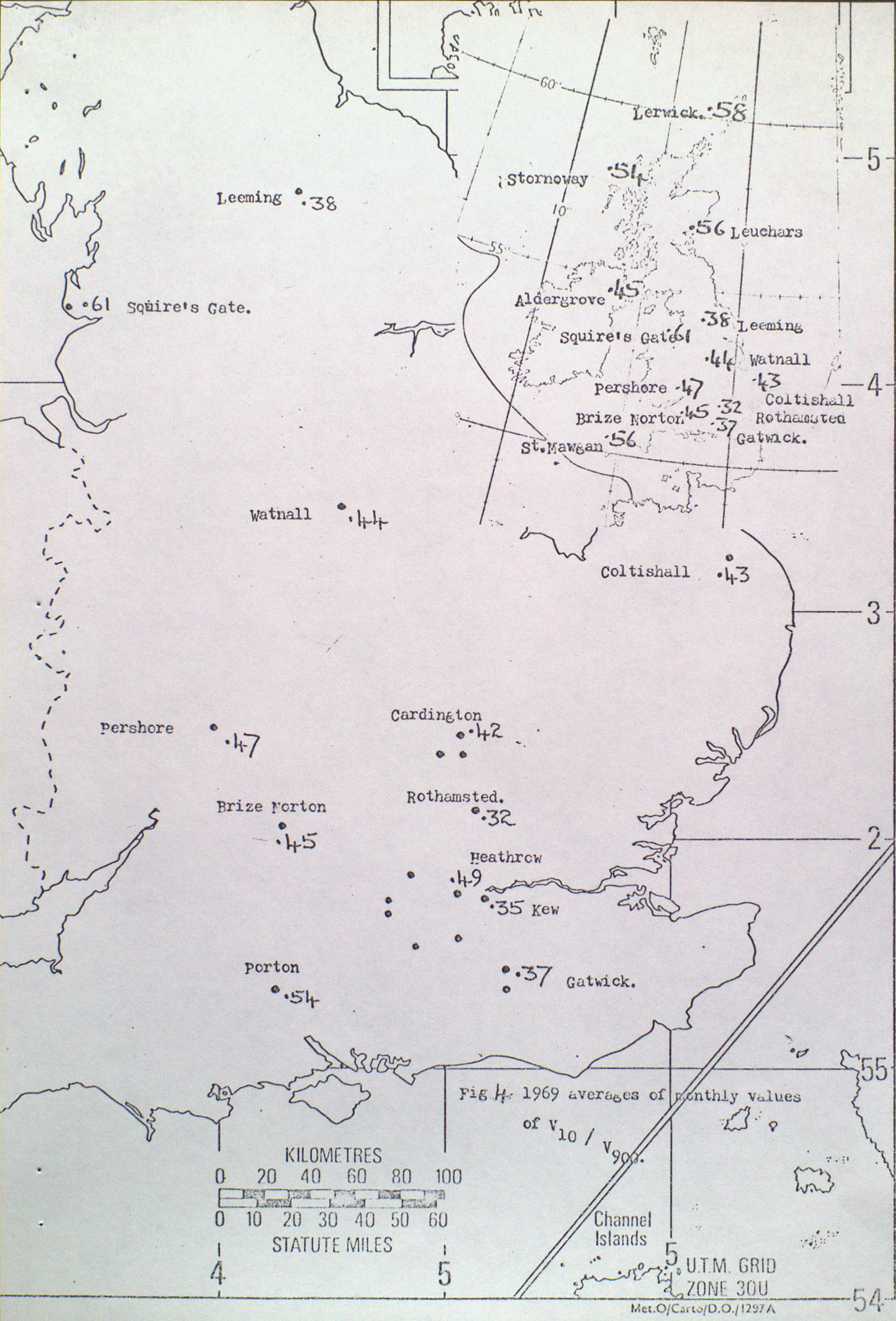
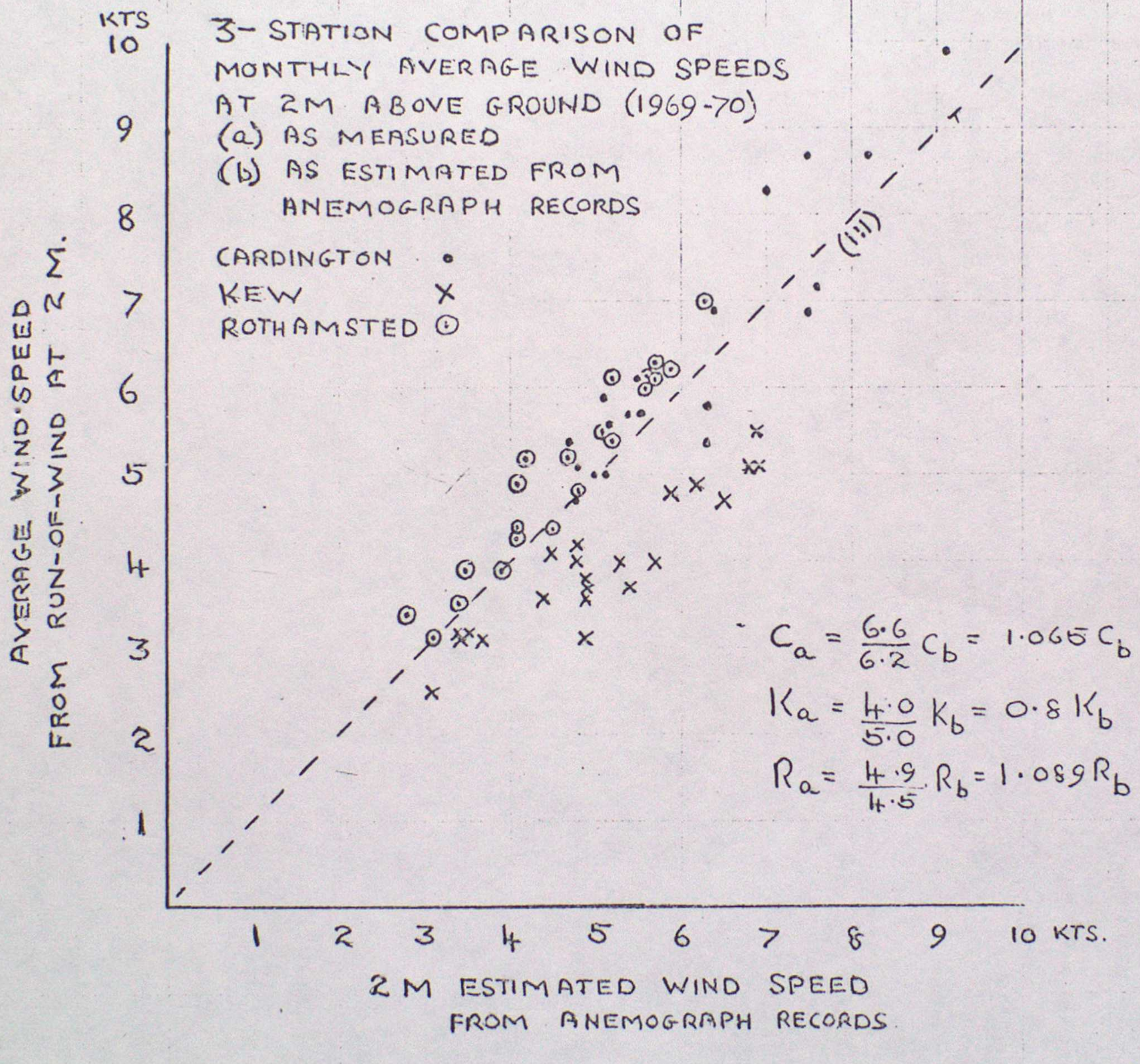


Fig 4. 1969 averages of monthly values of V_{10} / V_{900}.


Leeming
Squire's Gate
Watnall
Pershore
Cardington
Woburn
Silsoe
Rothamsted
Brize Norton
Hurley
Heathrow
Reading
Shinfield
Kew
Wisley
South Farnborough
Gatwick
Crawley
Porton
5
4
3
2
55
54
KILOMETRES
0 20 40 60 80 100
0 10 20 30 40 50 60
STATUTE MILES
4
5
Channel Islands
5
U.T.M. GRID
ZONE 30U
Met.O/Carto/D.O./1297A

Fig. 5

Fig. 6.



KTS
3- STATION COMPARISON OF MONTHLY AVERAGE WIND SPEEDS AT 2M ABOVE GROUND (1969-70)
(a) AS MEASURED
(b) AS ESTIMATED FROM ANEMOGRAPH RECORDS
CARDINGTON •
KEW ×
ROTHAMSTED ⊙
(1:1)
$C_a = \frac{6.6}{6.2} C_b = 1.065 C_b$
$K_a = \frac{4.0}{5.0} K_b = 0.8 K_b$
$R_a = \frac{4.9}{4.5} R_b = 1.089 R_b$
AVERAGE WIND-SPEED FROM RUN-OF-WIND AT 2M.
2M ESTIMATED WIND SPEED FROM ANEMOGRAPH RECORDS
10 KTS.

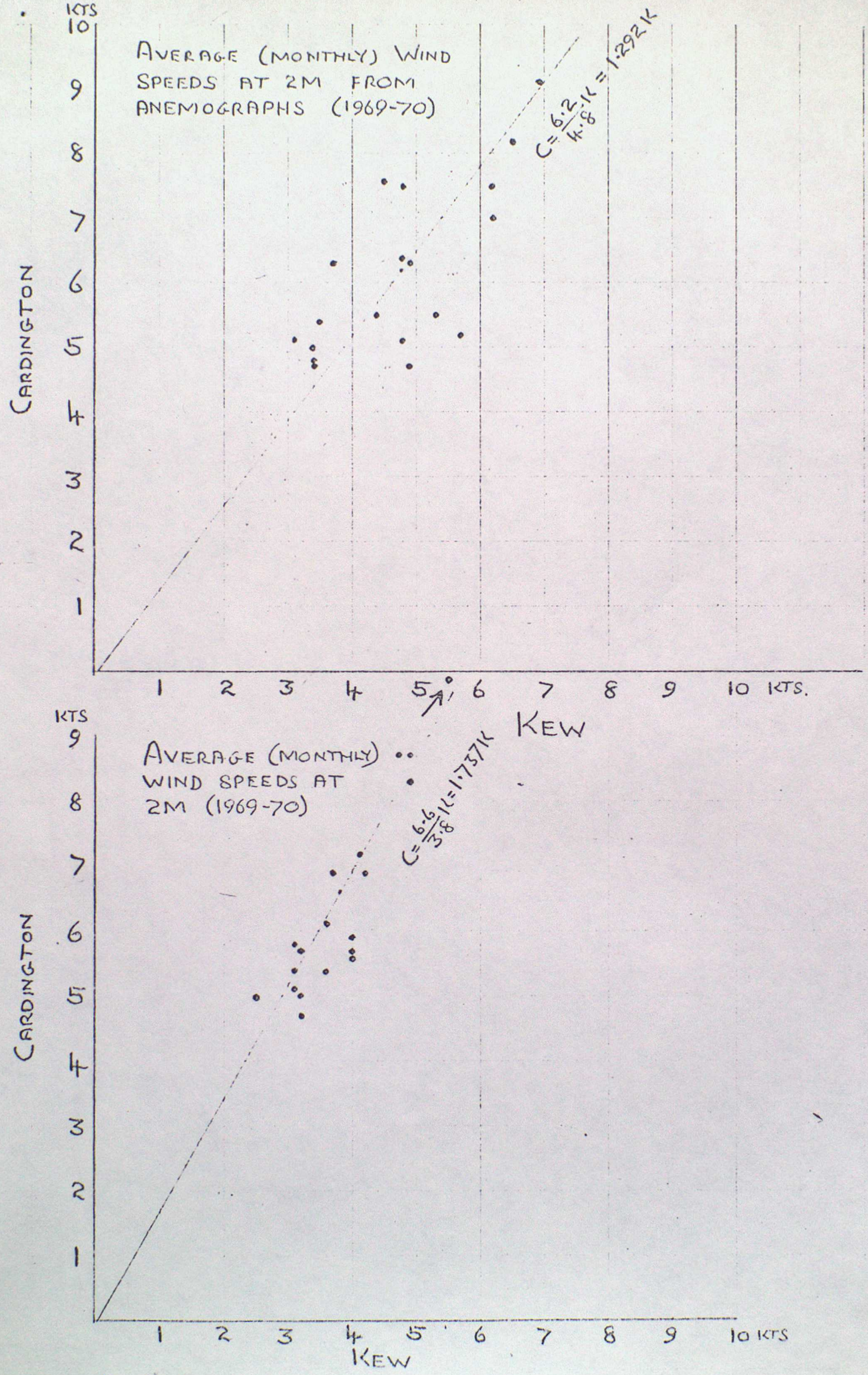
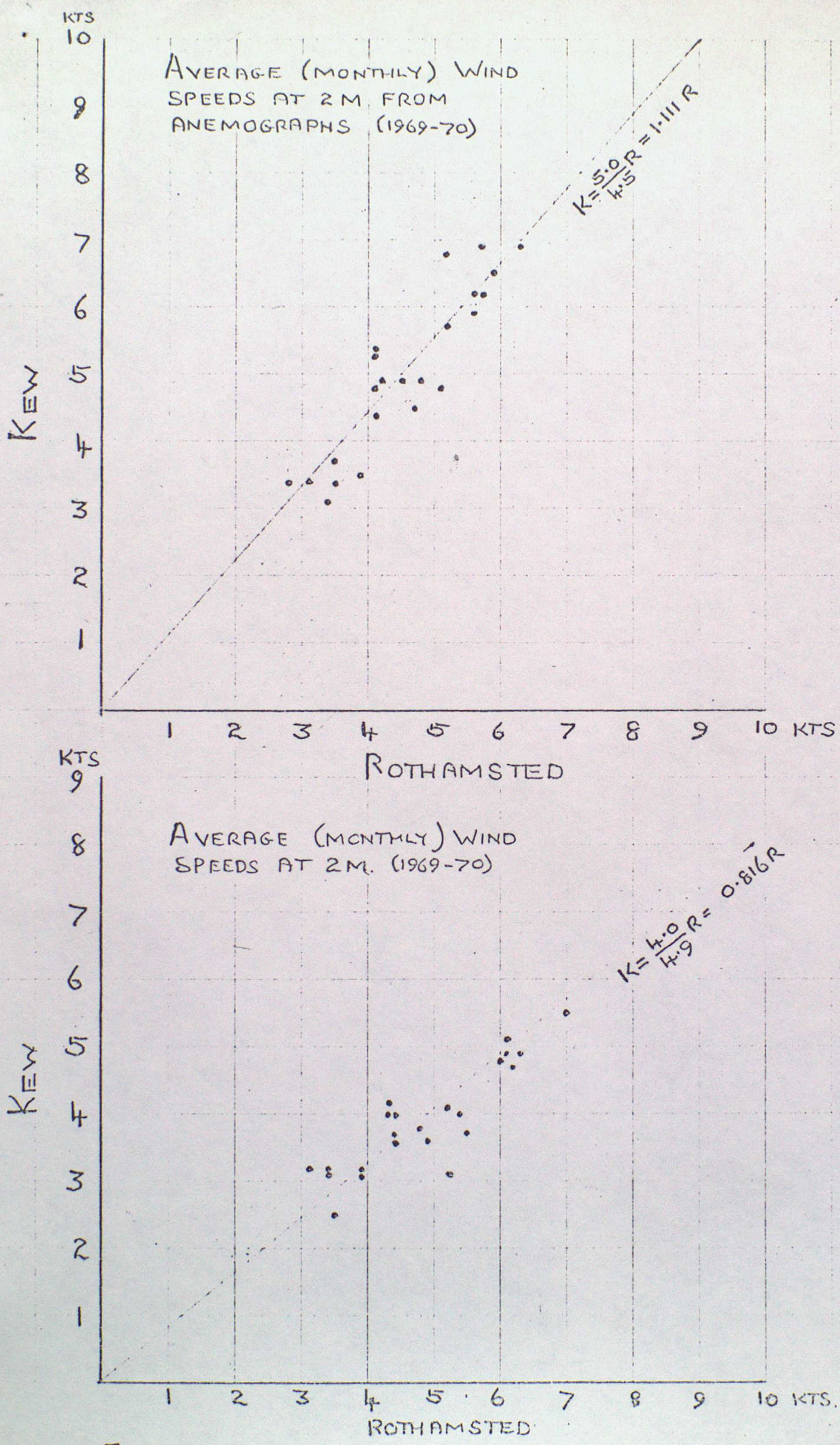
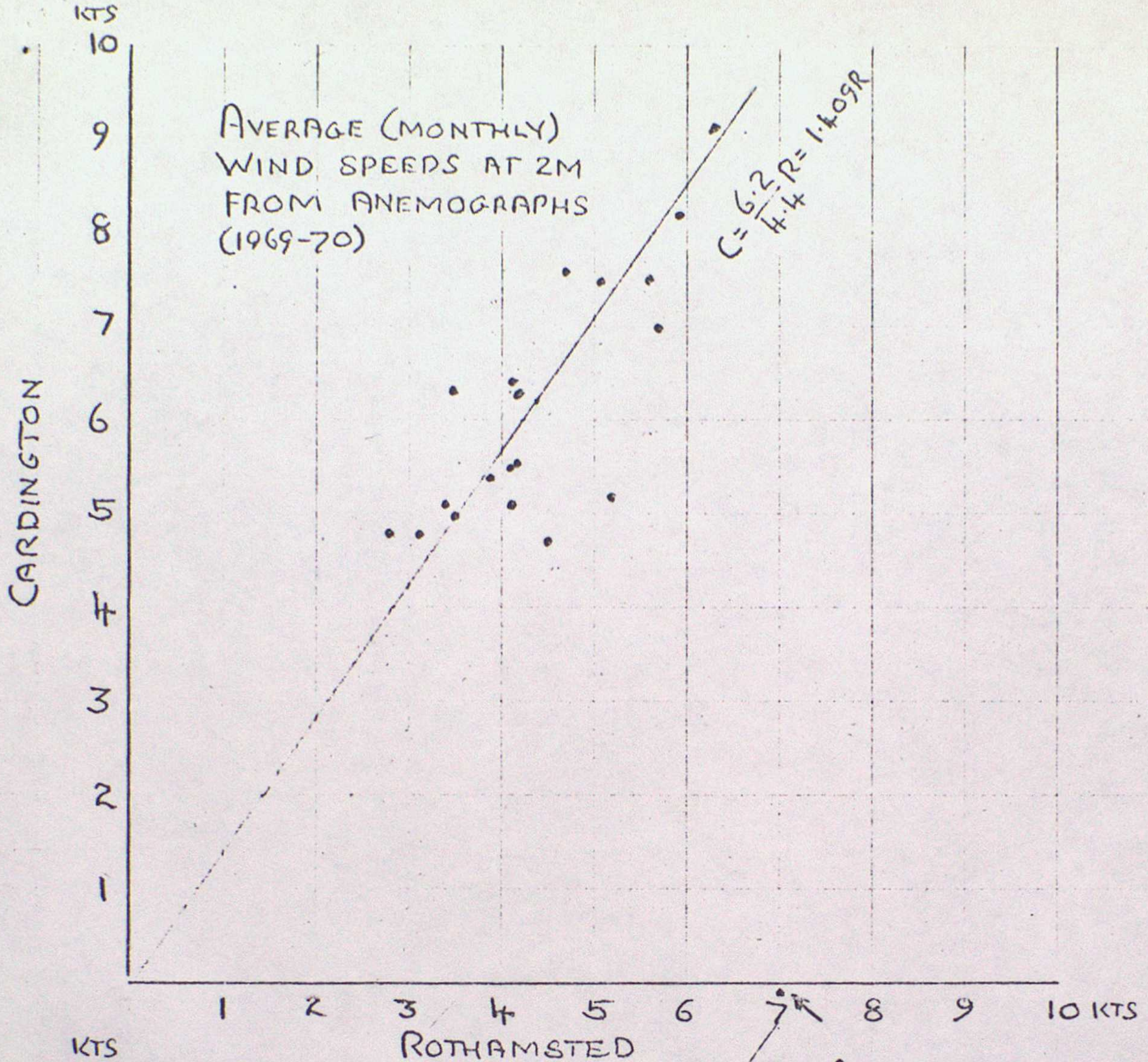

AVERAGE (MONTHLY) WIND SPEEDS AT 2M FROM ANEMOGRAPHS (1969-70)
KTS
CARDINGTON
$C = \frac{6.2}{4.8} K = 1.292K$
KEW
1 2 3 4 5 6 7 8 9 10 KTS.
AVERAGE (MONTHLY) WIND SPEEDS AT 2M (1969-70)
$C = \frac{6.6}{3.8} K = 1.737K$
CARDINGTON
KEW
10 KTS

Fig 7.1.



AVERAGE (MONTHLY) WIND SPEEDS AT 2M. FROM ANEMOGRAPHS (1969-70)
KTS
10
9
8
7
6
5
4
3
2
1
KEW
$K = \frac{5.0}{4.5} R = 1.111 R$
1
2
3
4
5
6
7
8
9
10 KTS
ROTHAMSTED
AVERAGE (MONTHLY) WIND SPEEDS AT 2M. (1969-70)
KTS
9
8
7
6
5
4
3
2
1
KEW
$K = \frac{4.0}{4.9} R = 0.816 R$
1
2
3
4
5
6
7
8
9
10 KTS.
ROTHAMSTED

Fig. 7.2.


KTS
AVERAGE (MONTHLY)
WIND SPEEDS AT 2M
FROM ANEMOGRAPHS
(1969-70)
C = 6.2/4.4 R = 1.409R
CARDINGTON
ROTHAMSTED
10 KTS

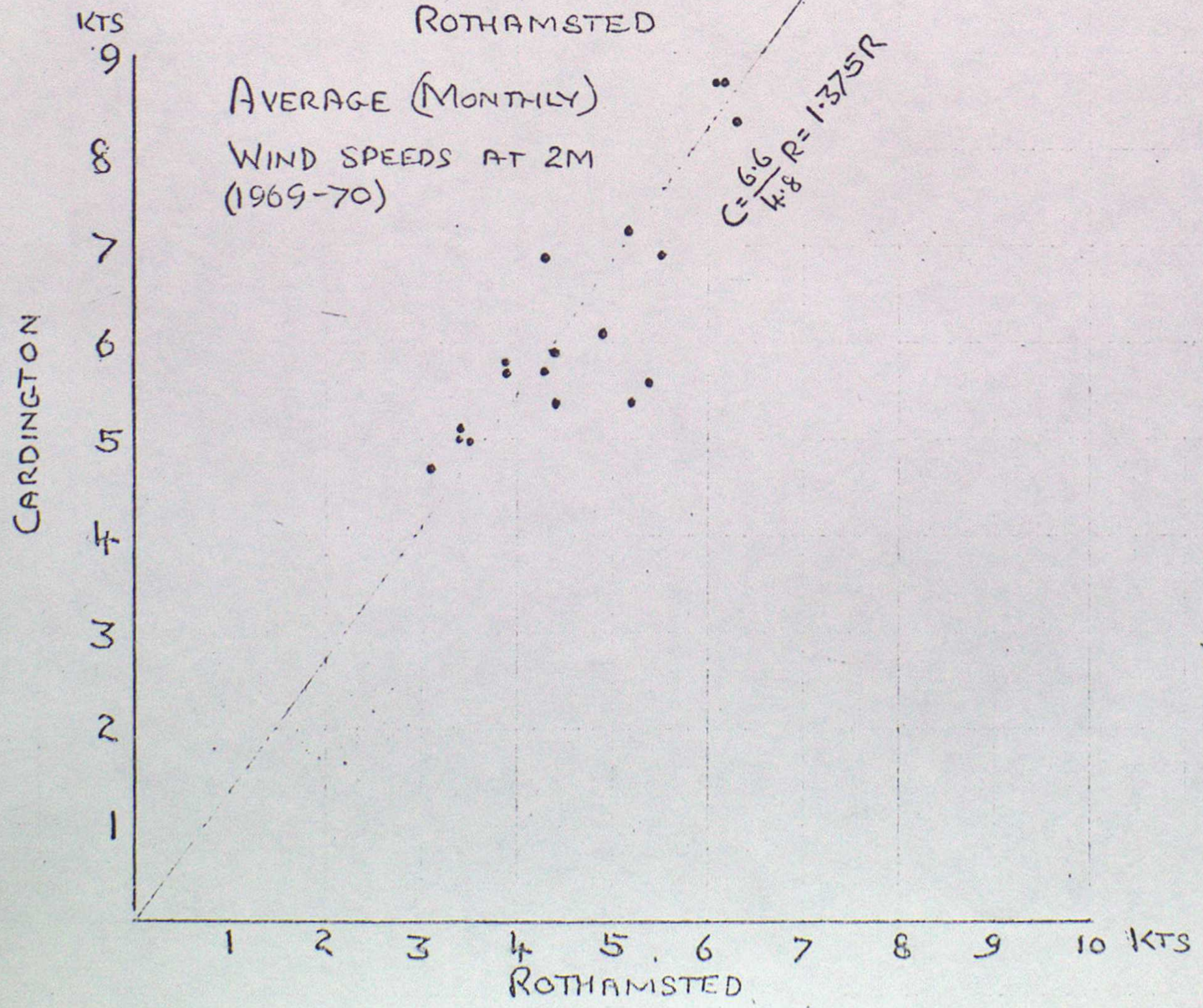

KTS
AVERAGE (MONTHLY)
WIND SPEEDS AT 2M
(1969-70)
C = 6.6/4.8 R = 1.375R
CARDINGTON
ROTHAMSTED
10 KTS

Fig. 7.3.

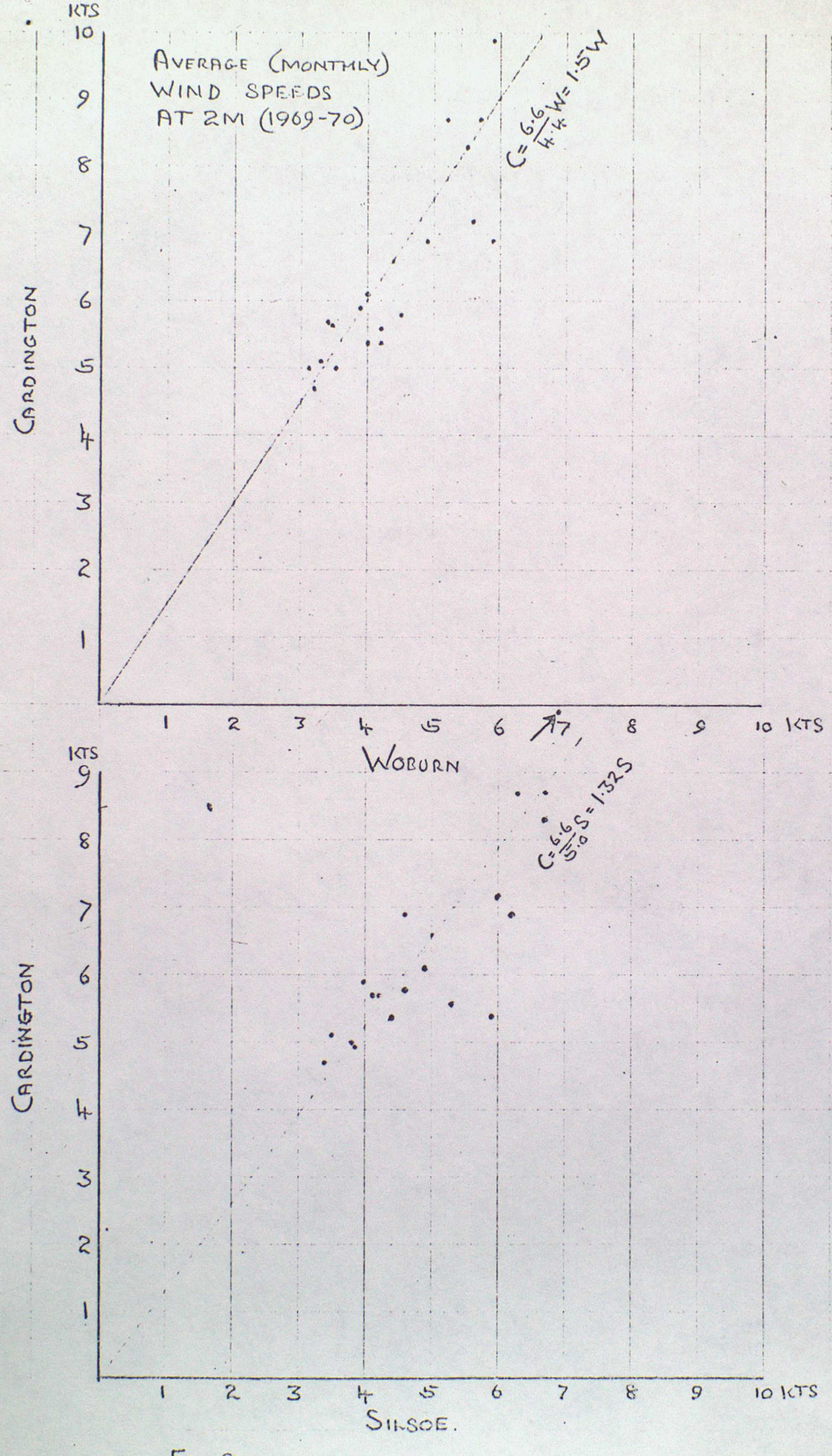
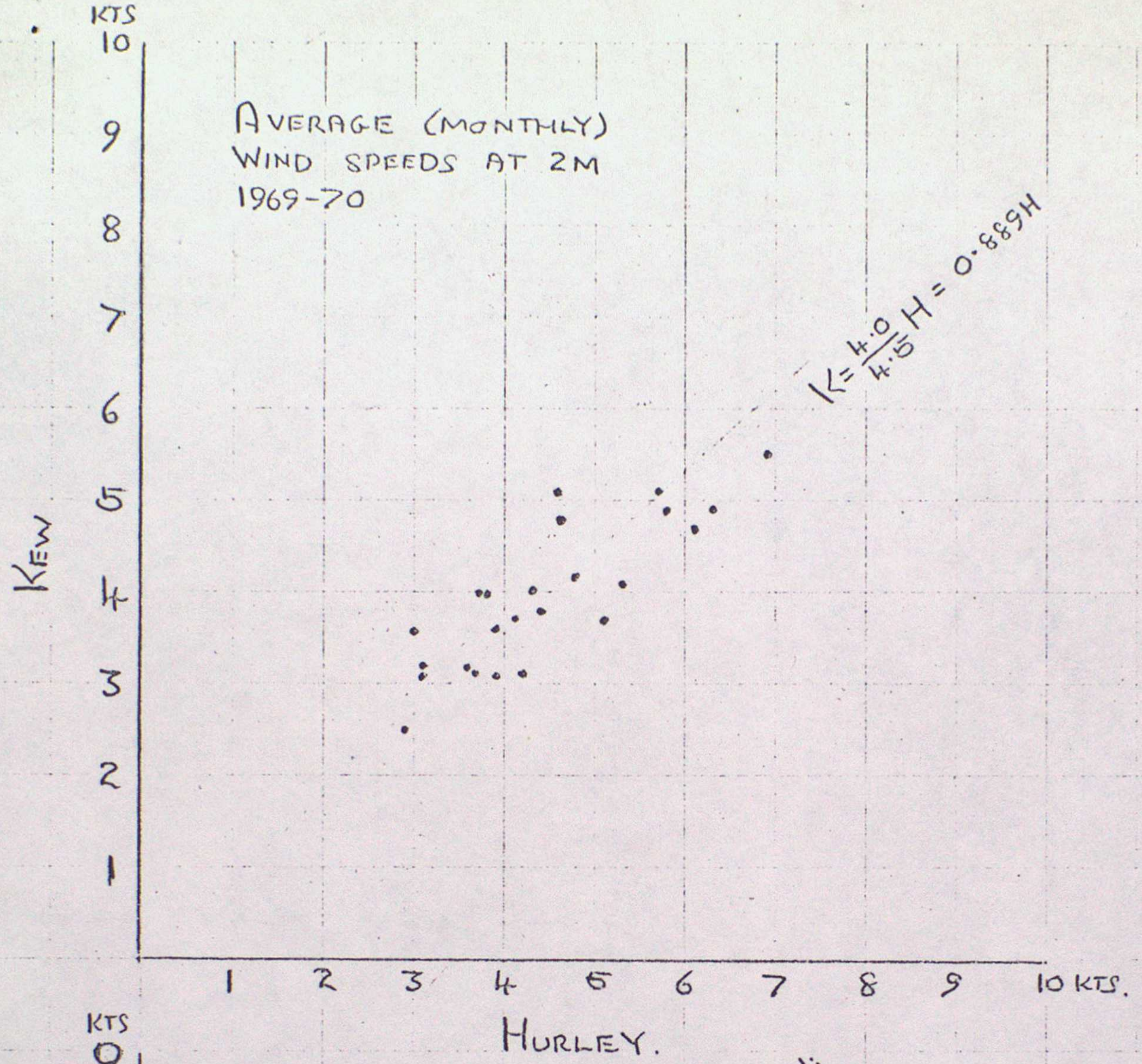
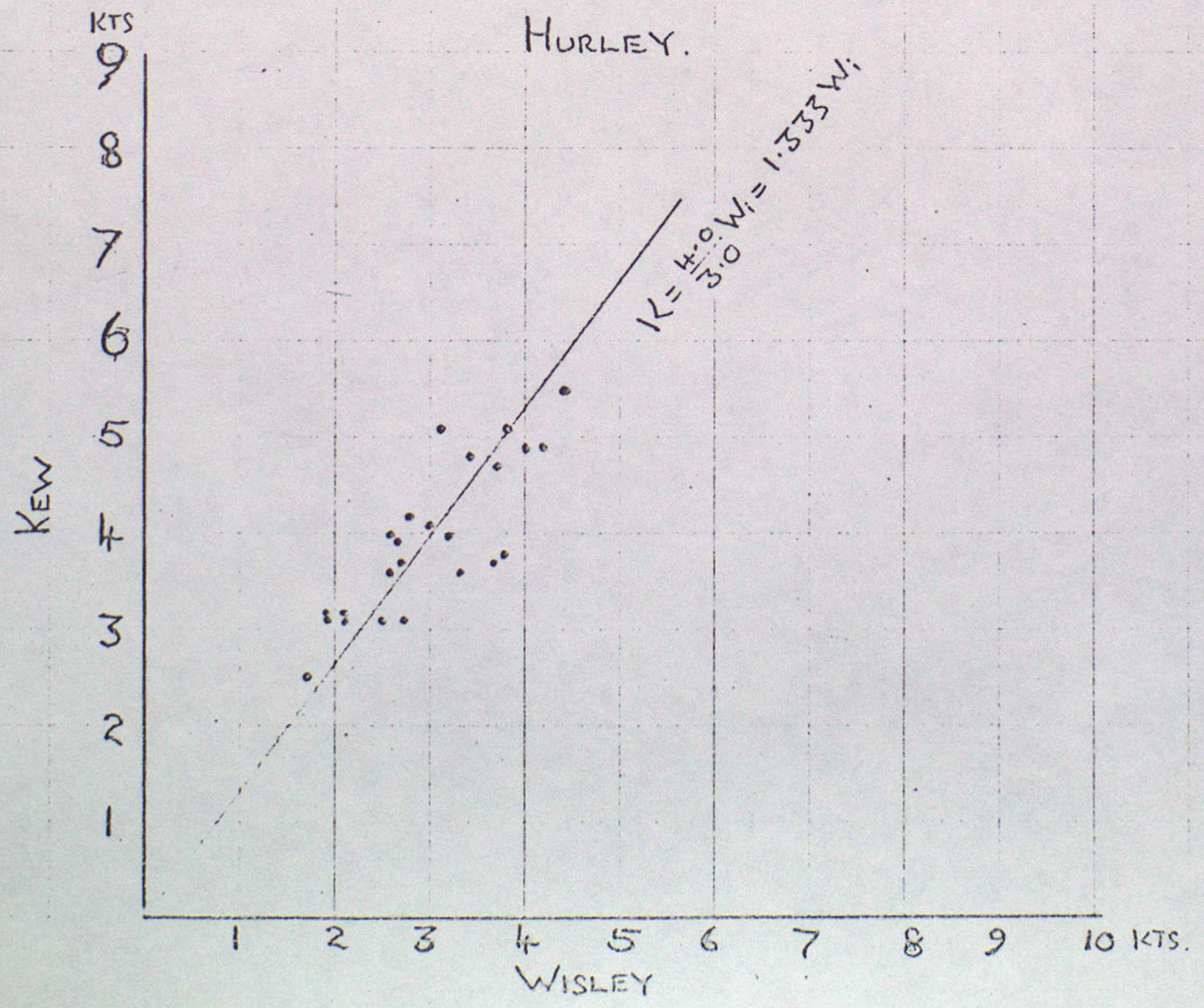

AVERAGE (MONTHLY)
WIND SPEEDS
AT 2M (1969-70)
KTS
CARDINGTON
WOBURN
$C = \frac{6.6}{4.4}W = 1.5W$
KTS
CARDINGTON
SILSOE.
$C = \frac{6.6}{5.0}S = 1.32S$

Fig. 8.1.



AVERAGE (MONTHLY)
WIND SPEEDS AT 2M
1969-70
KTS
KEW
HURLEY.
10 KTS.
K = 4.0/4.5 H = 0·889H



KTS
KEW
WISLEY
10 KTS.
K = 4.0/3.0 Wi = 1.333 Wi

Fig. 8.2.

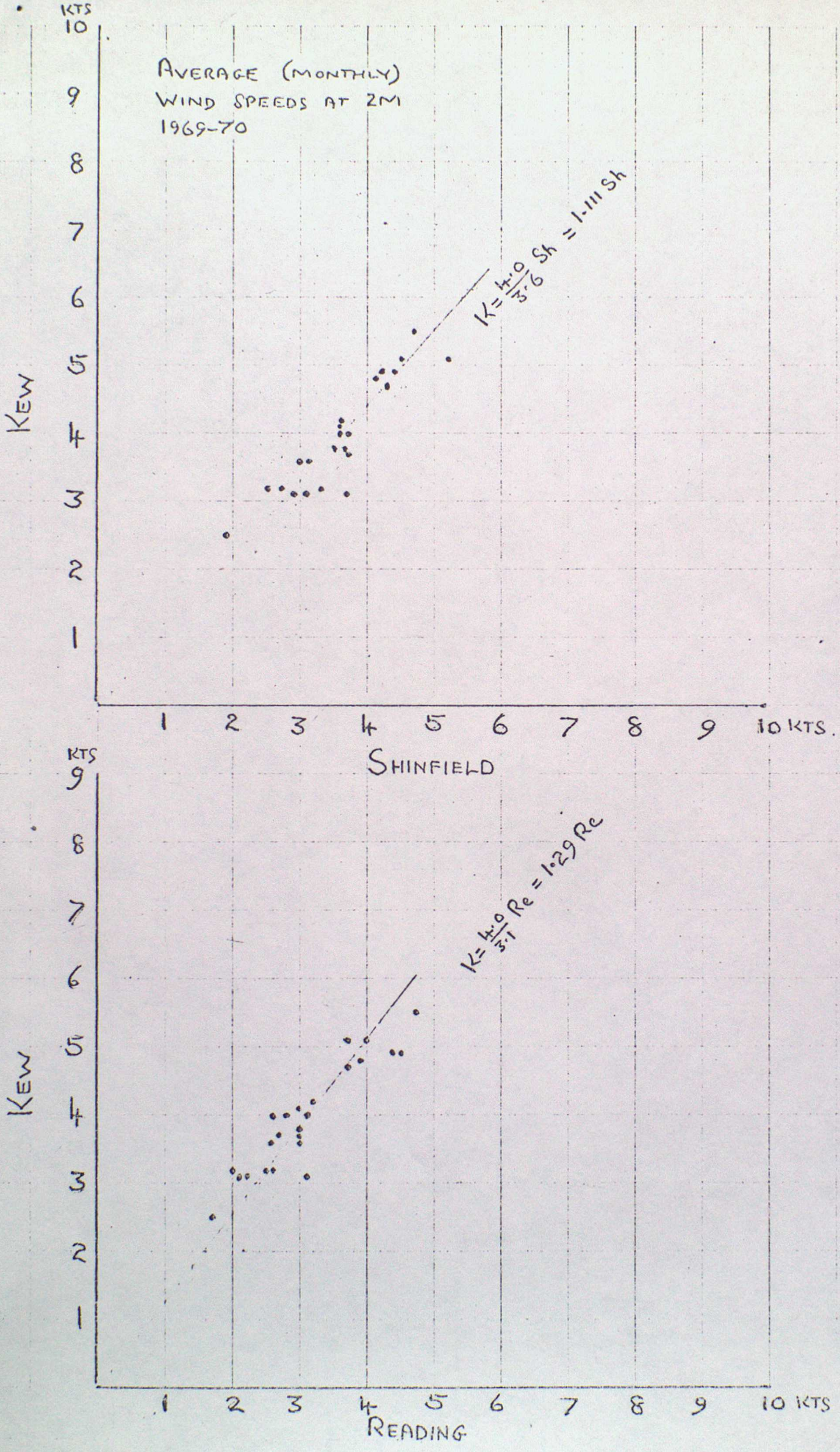
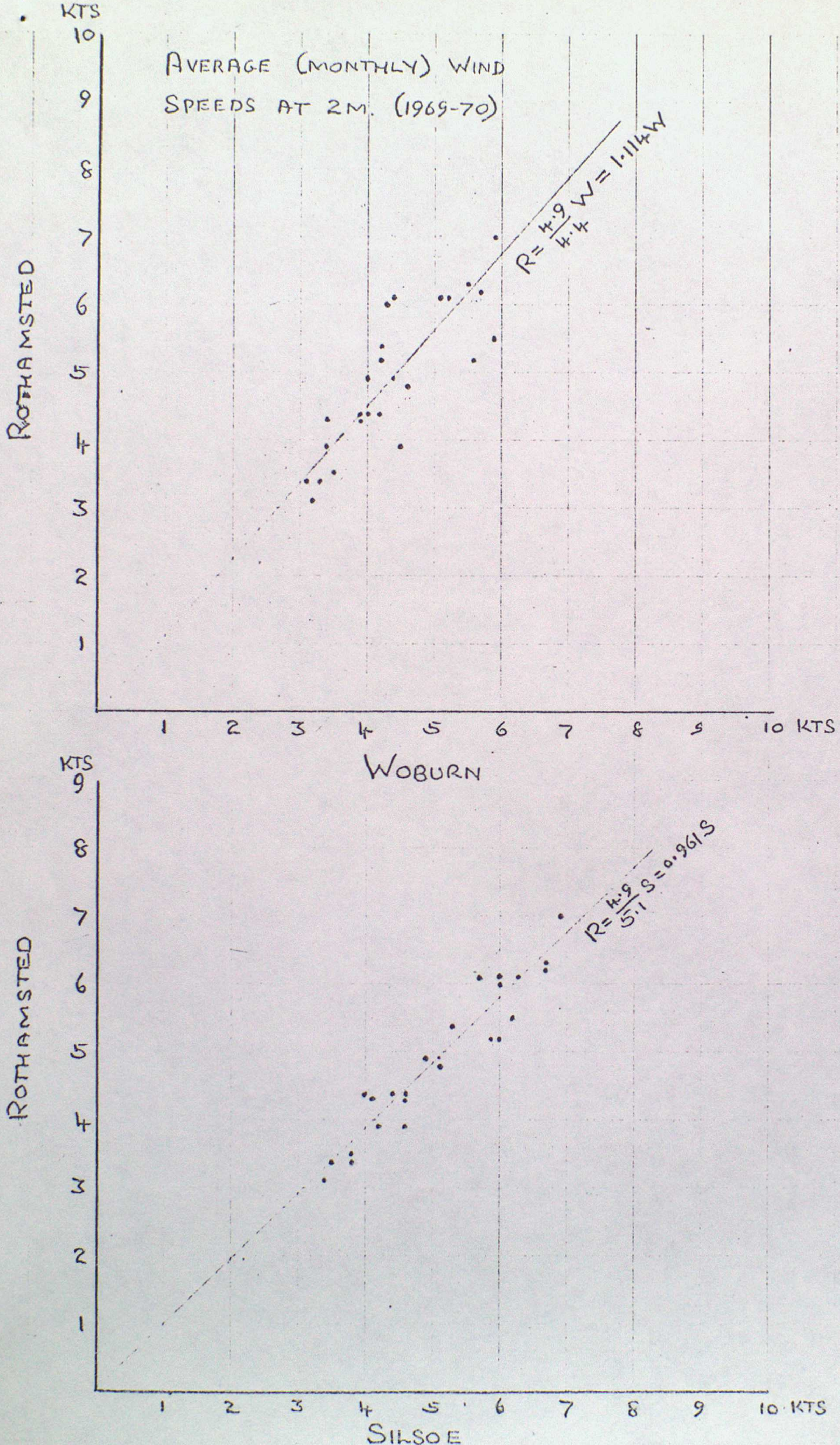

AVERAGE (MONTHLY)
WIND SPEEDS AT 2M
1969-70
KTS
KEW
SHINFIELD
10 KTS.
K = 4.0/3.6 Sh = 1.111 Sh
KEW
READING
10 KTS
K = 4.0/3.1 Re = 1.29 Re

Fig. 8.3.



AVERAGE (MONTHLY) WIND SPEEDS AT 2M. (1969-70)
KTS
ROTHAMSTED
R = 4.9/4.4 W = 1.114W
WOBURN
10 KTS
KTS
ROTHAMSTED
R = 4.9/5.1 S = 0.961S
SILSOE
10 KTS

Fig. 8.4.

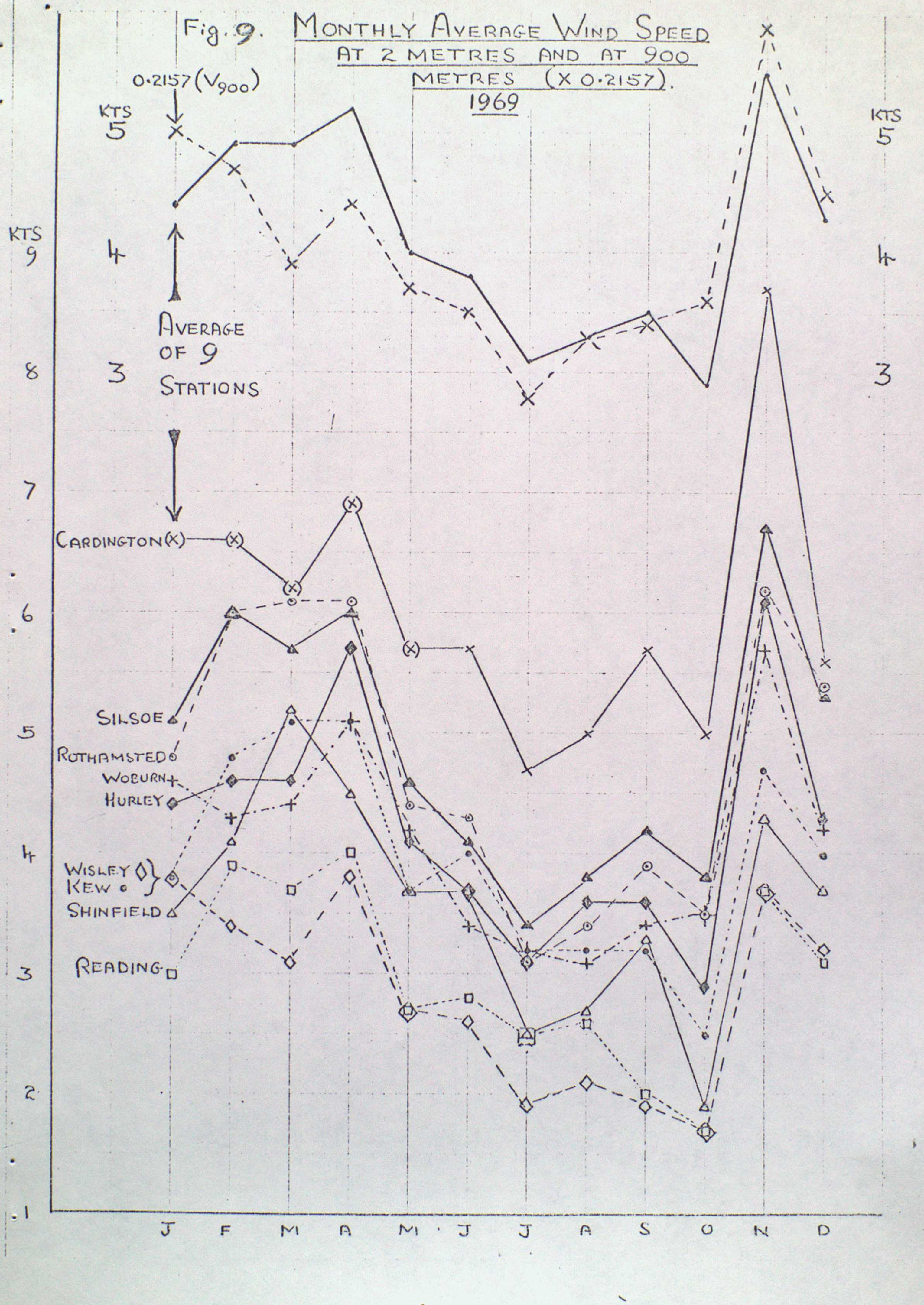


Fig. 9. Monthly Average Wind Speed at 2 Metres and at 900 Metres (X 0·2157). 1969
0·2157 (V_{900})
KTS
5
4
3
Average of 9 Stations
KTS
9
8
7
6
5
4
3
2
1
Cardington (x)
Silsoe
Rothamsted
Woburn
Hurley
Wisley
Kew
Shinfield
Reading
J F M A M J J A S O N D

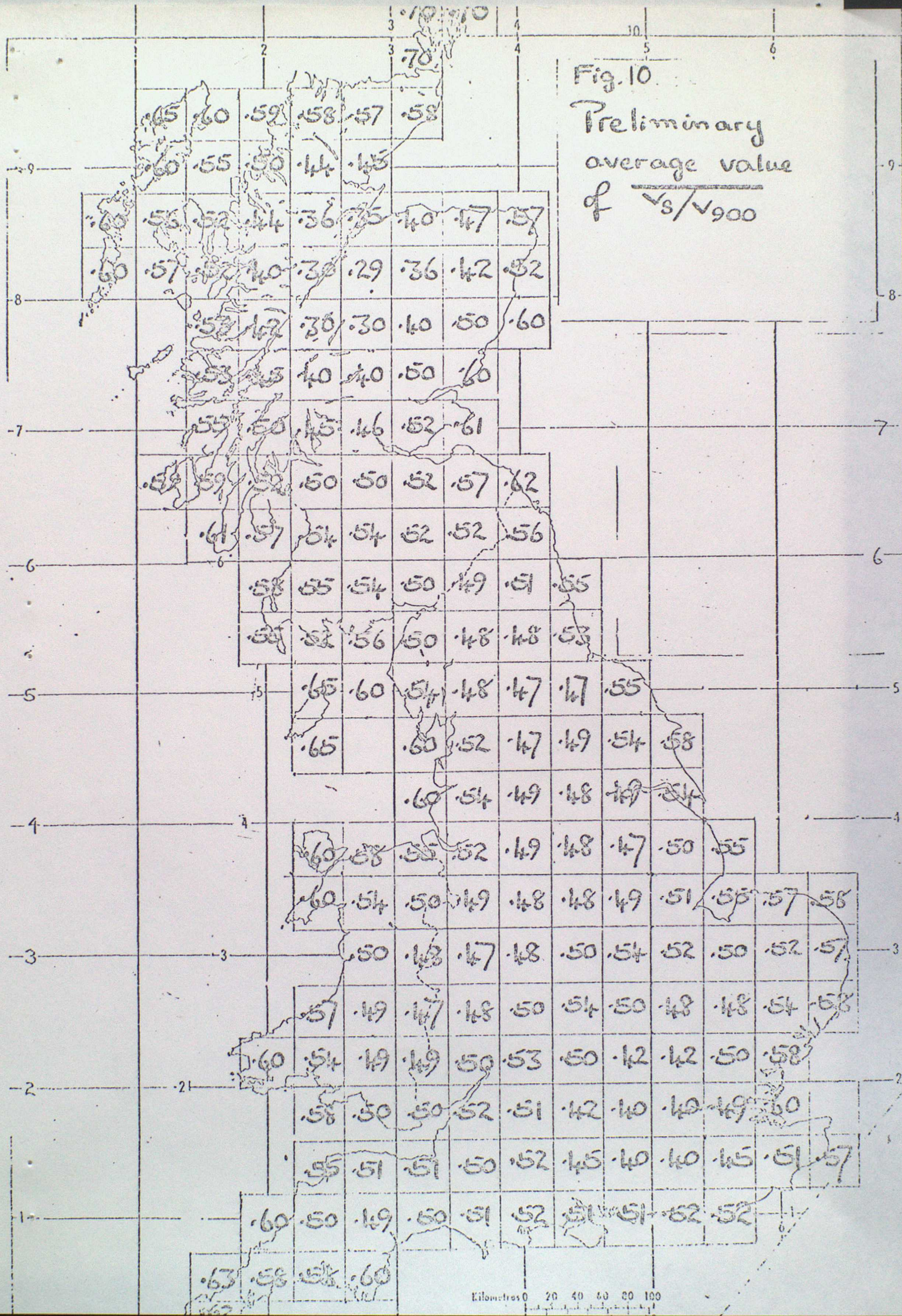


Fig. 10 Preliminary average value of V_s/V_{900}

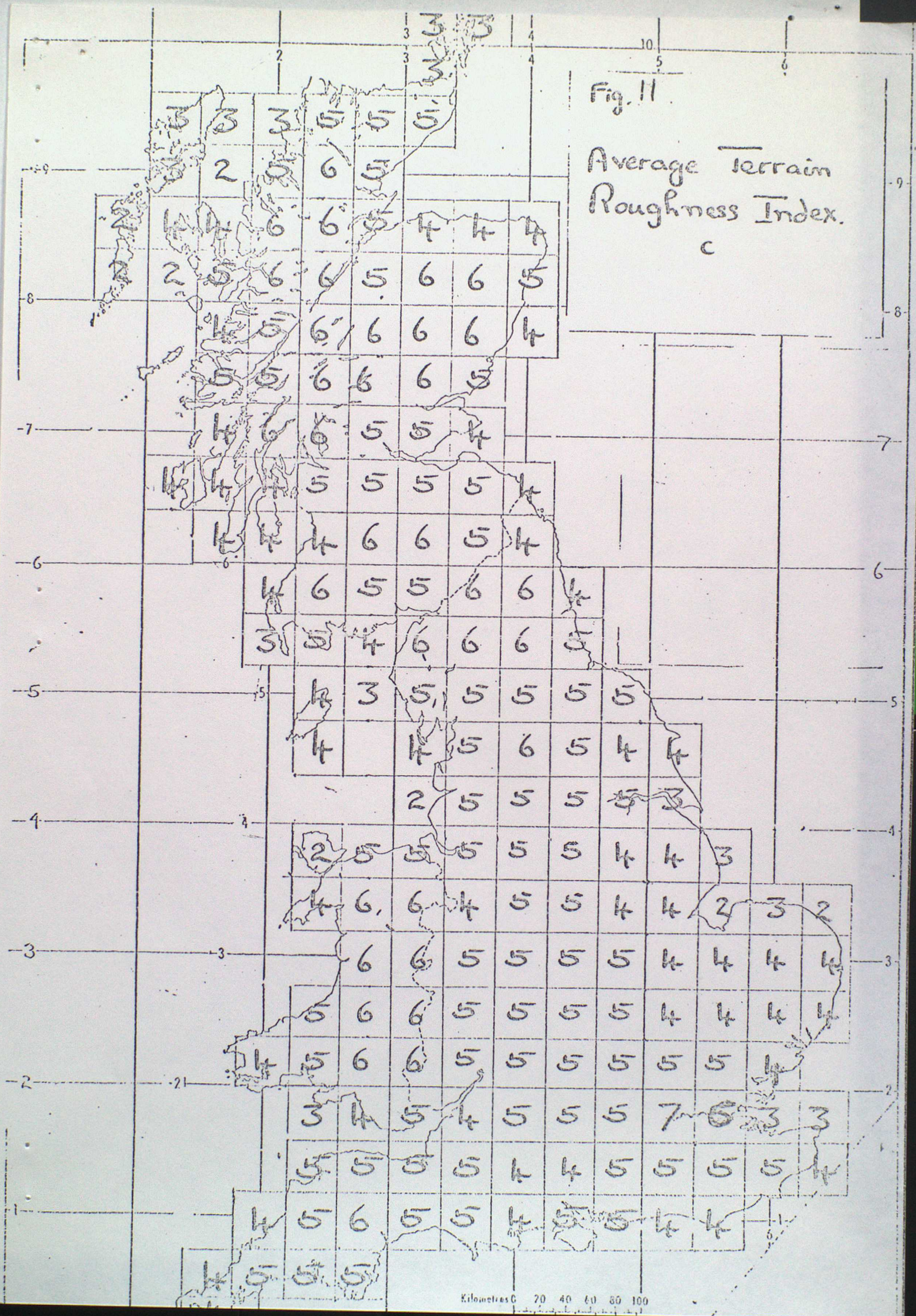


Fig. 11

Average Terrain Roughness Index.

c

Table I.

Hourly average wind speed (kts) at or reduced to 10 m. effective height. Lower figures are V_{10}/V_{900} where V_{10} is 10 m wind speed and V_{900} is 900 m. wind speed. 1969

Station(s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Lerwick	15.7	12.1	16.3	14.4	9.7	10.5	12.5	9.8	15.0	15.9	13.7	16.6	
,,	.59	.60	.65	.60	.65	.55	.60	.46	.63	.55	.54	.59	.58
Stornoway	17.0	14.6	10.8	10.0	7.0	10.0	10.3	8.4	12.0*	12.0*	12.0*	12.0*	
,,	.73	.71	.62	.46	.53	.58	.43	.48	.49	.38	.52	.50	.54
Leuchars	9.8	13.1	11.9	10.7	10.0	9.3	10.8	8.4	12.1	11.0	12.4	9.5	
,,	.46	.59	.68	.58	.72	.66	.54	.54	.55	.43	.48	.48	.56
Aldergrove	9.6	10.0	9.2	9.1	8.1	8.0	9.8	9.4	8.4	10.0	9.4	9.3	
,,	.43	.42	.47	.47	.54	.55	.47	.50	.45	.38	.37	.39	.45
Squire's Gte	10.8	12.2	12.6	11.7	10.4	10.5	11.6	11.5	11.2	13.2	15.1	10.9	
Aughton	.48	.53	.68	.62	.70	.67	.65	.67	.71	.58	.61	.48	.61
St.Mawgan.	12.3	10.7	9.9	12.0	10.7	9.3	8.6	10.5	7.9	10.2	14.5	12.4	
Camborne	.51	.52	.52	.56	.58	.57	.61	.64	.55	.59	.55	.52	.56
Gatwick	7.7	7.1	7.4	8.3	7.2	7.0	5.4	6.0	5.4	4.6	8.7	7.1	
Crawley	.33	.33	.40	.40	.41	.44	.43	.40	.34	.28	.31	.34	.37
Coltishall	8.5	10.5	9.2	8.9	7.4	6.9	5.9	7.2	6.6	6.3	10.6	7.7	
Hemsby	.36	.47	.56	.45	.45	.45	.44	.44	.45	.36	.37	.41	.43

Station	Effective Ht.(m)	Correction to reduce to 10 m.	Stn.Ht. a.s.l.
Lerwick	10	-	82
Stornoway	11	X .984	3
Leuchars	12	X .968	10
Aldergrove	10	-	68
Squire's Gate	11	X .984	10
St.Mawgan	12	X .968	103
Gatwick	10	-	59
Coltishall	10	-	17

* speeds are based on surface wind reports from the Stornoway radar-wind site at 06 and 18 hr GMT daily.

Table II

Hourly average wind speed (kts) at or reduced to 10 m. effective height. Lower figures are V_{10}/V_{900} where V_{900} is interpolated from Figs.2.1 to 2.12. 1969

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Rothamsted	6.3	7.4	7.5	6.9	5.4	5.4	4.0	4.6	5.2	4.5	7.9	6.9	
128 m.	.27	.34	.42	.34	.31	.34	.31	.30	.33	.27	.29	.33	.32
Watnall	8.6	10.0	10.8	9.2	7.4	7.7	7.4	6.5	6.6	6.7	9.6	7.9	
117 m.	.37	.44	.63	.48	.47	.48	.50	.40	.43	.34	.37	.37	.44
Brize Norton	8.1	9.8	10.3	9.9	8.0	8.5	7.0	7.3	7.4	5.9	10.2	8.8	
84 m.	.35	.45	.57	.49	.45	.53	.53	.48	.46	.34	.38	.40	.45
Pershore	9.4	8.9	8.8	9.9	8.9	8.3	7.8	7.5	8.0	7.7	11.6	9.6	
34 m.	.41	.40	.51	.50	.53	.51	.56	.47	.50	.41	.45	.44	.47
Leeming	6.8	8.4	5.9	7.9	6.4	6.7	6.8	6.4	6.6	7.3	9.7	6.9	
32 m.	.30	.37	.33	.43	.44	.44	.40	.38	.42	.33	.37	.33	.38
Kew	6.4	7.7	9.1	6.8	7.1	6.9	4.6	4.5	4.7	4.2	8.6	7.6	
5 m.	.27	.35	.50	.33	.40	.43	.36	.30	.29	.25	.31	.36	.35
Cardington	8.7	8.7	8.1	9.1	7.5	7.3	6.3	6.5	7.2	6.8	10.6	7.6	
28 m.	.37	.39	.45	.45	.44	.46	.49	.43	.46	.40	.39	.36	.42
Heathrow	9.4	9.9	10.2	10.2	9.0	9.7	7.9	8.0	8.3	6.7	10.6	9.1	
25 m.	.40	.45	.56	.49	.51	.61	.62	.53	.52	.40	.39	.43	.49
S.Farnboro'	9.3	8.3	7.7	8.4									
69 m.	.40	.38	.42	.41									
Porton	11.5	10.7	11.2	11.8	10.3	10.3	7.8	7.9	8.6	8.1	12.6	11.1	
111 m.	.49	.50	.61	.57	.57	.64	.61	.53	.55	.48	.47	.51	.54

Station	Effective Ht.(m)	Correction to reduce to 10 m.
Kew	15	X .933
Cardington	41	X .787

all other stations have effective height 10 m.

Table III.

Average (monthly) wind speeds measured at 2 metres above ground, in 1969.
(Cardington values for Jan - May are estimates based on the 41 m. anemograph data.) (Station heights are given in metres).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Kew 5m.	3.8	4.8	5.1	5.1	3.7	4.0	3.2	3.2	3.2	2.5	4.7	4.0	3.9
Cardington 28 m.	6.6	6.6	6.2	6.9	5.7	5.7	4.7	5.0	5.7	5.0	8.7	5.6	6.0
Rothamsted 128 m.	4.8	6.0	6.1	6.1	4.4	4.3	3.1	3.4	3.9	3.5	6.2	5.4	4.8
Shinfield 61 m.	3.5	4.1	5.2	4.5	3.7	3.7	2.5	2.7	3.3	1.9	4.3	3.7	3.6
Reading 69 m.	3.0	3.9	3.7	4.0	2.7	2.8	2.5	2.6	2.0	1.7	3.7	3.1	3.0
Wisley 35 m.	3.8	3.4	3.1	3.8	2.7	2.6	1.9	2.1	1.9	1.7	3.7	3.2	2.8
Woburn 89 m.	4.6	4.3	4.4	5.1	4.2	3.4	3.2	3.1	3.4	3.5	5.7	4.2	4.1
Silsoe 59 m.	5.1	6.0	5.7	6.0	4.6	4.1	3.4	3.8	4.2	3.8	6.7	5.3	4.9
Purley 43 m.	4.4	4.6	4.6	5.7	4.1	3.7	3.1	3.6	3.6	2.9	6.1	4.3	4.2
AVERAGE	4.4	4.9	4.9	5.2	4.0	3.8	3.1	3.3	3.5	2.9	5.5	4.3	4.1

Appendix 1.

Guidance notes on wind measurement compiled in the Meteorological Office.

B. Anemometers

To make good, representative wind measurements anemometers must be sited and their mast heights calculated with great care (See note on run-of-wind).

The object is to obtain wind measurements truly representing the flow over the area.

This means that we must reject positions and heights where topographical features or man-made structures may significantly affect the air flow, so as to make it unrepresentative of the general airflow in the locality.

If we require the "true wind" at a height of 2 metres or 10 metres it is, of course, most convenient if the readings of instruments correctly exposed at those heights can be used.

If we are unable to adopt a site which will allow us to mount the anemometer at a desired height we increase the height until a position can be found where acceptable measurements can be made.

A note in this section deals with suitable sites for "2 metre anemometers". General remarks are as follows:

1. In a site where the obstructions are not especially large say up to 6 metres and they are distributed fairly uniformly around the instrument, to obtain a good 10 metre (33 foot) exposure, we add the approximate height of the obstacles C and expose the instrument at 10 + C metres above the ground.

2. With one or more large obstructions, say 12 metres or more in both height and width, within 200-300 metres of the instrument, Diagram 1 shows the sort of height to which the anemometer will have to be raised to measure fairly undisturbed flow from all directions. If, however, there is only one such obstruction (perhaps consisting of one or two trees fairly close together) and a study of wind records from a nearby anemograph station shows that only a small proportion of the overall flow comes from that direction, the site should be acceptable.

3. When the anemometer has to be mounted on an isolated building, the building itself will disturb the wind flow to an extent depending, among other things, on its size and shape. As a rough guide the mast or tower erected on the roof needs to be ½ to ¾ of the height of the building (assuming the building covers a fairly large area and is not a tower). In this sort of case the "effective height" of the anemometer may be taken as about the height of the mast plus half the height of the building.

These notes give a practical account of the business of wind measurement.

The appraisal of a site is a complicated matter and can only be carried out properly by an expert.

Site selection is best made with the help of a 2½ inch: 1 mile map and professional advice is available from the Meteorological Office, Met O 3 in response to written requests accompanied by such maps.

When the site has been selected from the 6 inch map, final positioning can be decided and the effective height calculated from a plan on a scale of 1:2500 (25 inches to the mile, approx.). Sizes, positions and heights of all objects within 300 metres of the anemometer site should be shown on the plan. If

/Met O 3

Met O 3 advice is requested, it will be important to state whether the wind measurements are required for reduction to 2-metre height for evaporation calculations.

Effective height is defined as the height over open, level terrain in the vicinity which, it is estimated, would have the same mean wind speeds as those actually recorded by the anemometer (as sited).

Without effective height it is impossible to make valid comparisons with other wind measurements made elsewhere and impossible to reduce the measurements to true equivalent speeds at other heights.

Reduction to two metres may be made with Diagram 2.

Detailed instructions for the daily use and management of these instruments are normally provided by the suppliers.

Advice in respect of individual types of instruments can be obtained through the Meteorological Office, Met O 16.

An estimate of charges for professional advice by post for positioning an anemometer and for advising a value to be adopted as its effective height will be given, on request, by Met O 3. Charges for such advice are modest.

A copy of the notes for the observer on cup counter anemometers is attached.

Run-of wind measurements and exposure of instruments

To measure properly run-of-wind at 2 metres the anemometer must be sited so that no object is nearer to the instrument than an absolute minimum of ten (better 20) times the instrument's height. Thus, for a 2 m anemometer the ground for at least 20 metres in all directions must be clear of any significant obstruction.

Outside this "clear circle" there should be no more than a gradual increase in "obstruction" and, in fact, the only really good exposure would be in the middle of a large tract of level, open ground.

The importance of good exposure of anemometers can not be over-emphasised; experiments have shown, conclusively, that the values obtained from badly exposed instruments are useless and misleading.

Even small structures can be most effective wind-breaks as anyone who has sunbathed protected from the wind by a small canvas screen knows.

A 2 metre anemometer sited near buildings, tall trees, etc., may be prevented from measuring the "true" wind over the neighbourhood. The wind flow from some directions may never influence the instrument at all whilst when the wind blows from other directions it may be constrained to "funnel" between wind-breaks, causing the instrument to over-read or rather to over-measure the general force over the neighbourhood.

The most likely overall result is a seriously low total of run-of-wind resulting in a low and therefore useless estimate of evaporation.

OBSERVERS NOTE

WIND MEASUREMENTS

1. General

The instrument normally used at climatological stations set up for evaporation work is the cup counter anemometer. This anemometer is a flow meter and measures "run of wind" as miles of wind flow. If two readings are made at the beginning and end of a 24 hour period and the first subtracted from the second the result, divided by 24 is the mean hourly wind speed.

2. Time of observation

You have probably been asked to take a daily reading and this should be done as close to the normal observation time (usually 1000 hours British Summer Time - 0900 hours Greenwich Mean Time) as possible.

3. Condition of the instrument

Please report at once if you suspect that something is wrong with the instrument or if it has been damaged.

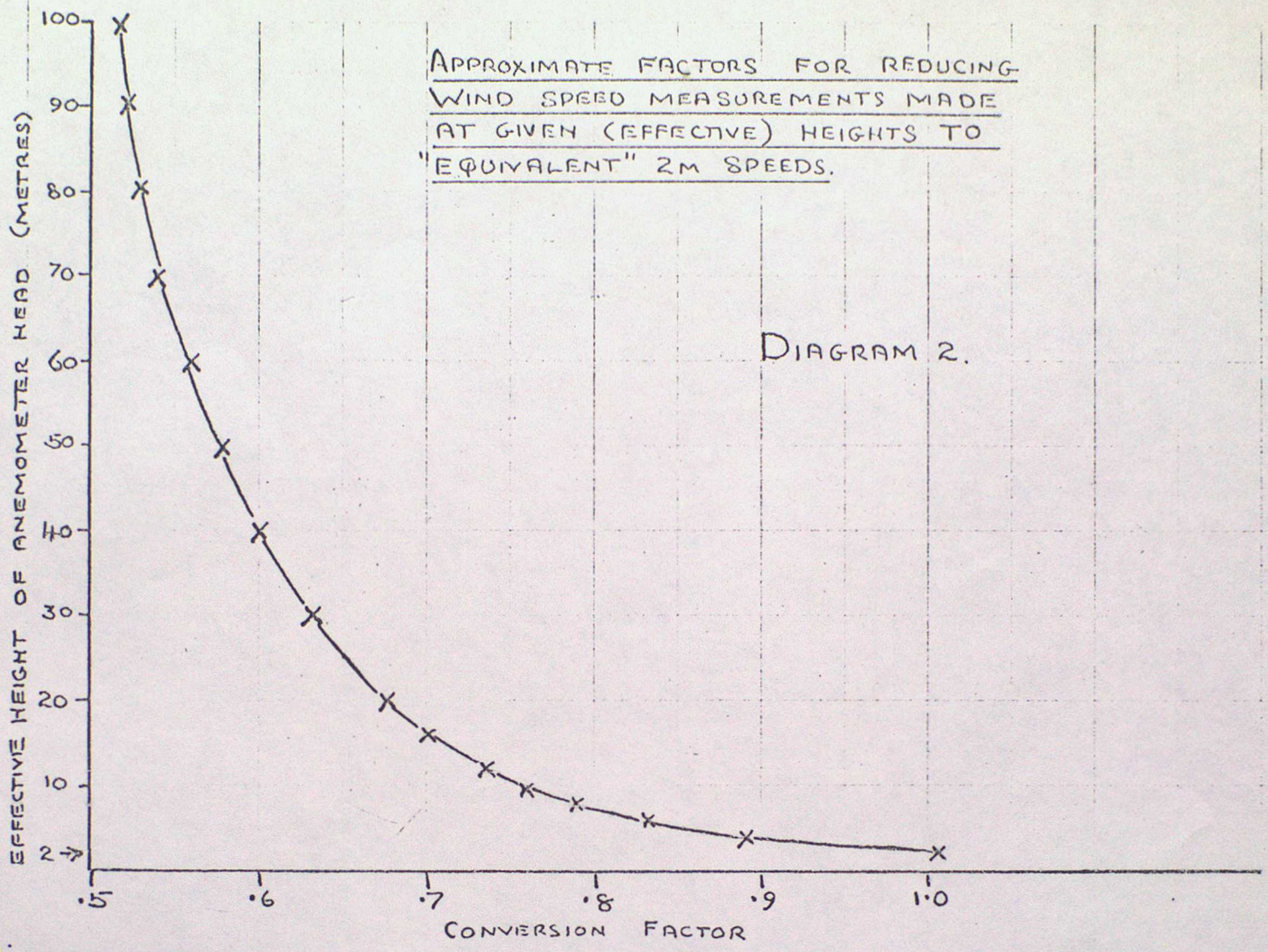
Ideally servicing is carried out every 3 months and is a workshop job. The responsibly authority will either replace the instrument or remove it from use for a day for overhaul. If your instrument has not had any attention for over 4 months you could help to maintain the quality of the measurements by reminding the authority that an inspection is due.

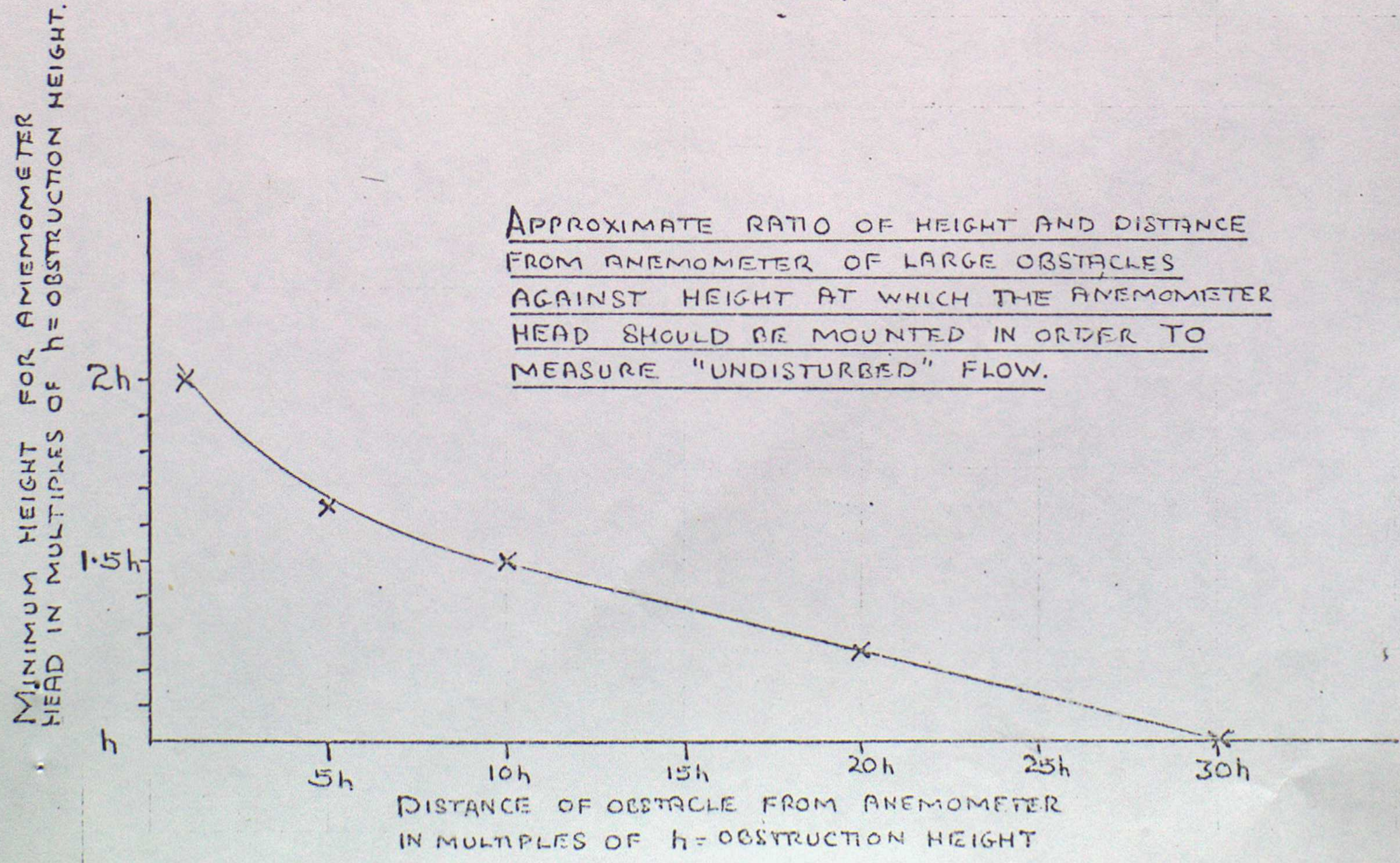
4. The area around the instrument

The ground for a distance of 10 times the height of the anemometer (all around) should be kept clear of all obstructions and be just short grass, bare soil, etc. If the care of the ground is in your hands, please ensure that the "clear circle" is kept clear, if not, please report to the authority when grass cutting, weed clearing etc., is necessary.

5. Other wind measuring instruments

Most of the remarks above apply to other wind instruments but please do not hesitate to get your authority to contact the Meteorological Office at Bracknell if you feel you need any advice.


APPROXIMATE FACTORS FOR REDUCING WIND SPEED MEASUREMENTS MADE AT GIVEN (EFFECTIVE) HEIGHTS TO "EQUIVALENT" 2M SPEEDS.
DIAGRAM 2.
EFFECTIVE HEIGHT OF ANEMOMETER HEAD (METRES)
100
90
80
70
60
50
40
30
20
10
2 →
·5
·6
·7
·8
·9
1·0
CONVERSION FACTOR


APPROXIMATE RATIO OF HEIGHT AND DISTANCE FROM ANEMOMETER OF LARGE OBSTACLES AGAINST HEIGHT AT WHICH THE ANEMOMETER HEAD SHOULD BE MOUNTED IN ORDER TO MEASURE "UNDISTURBED" FLOW.
MINIMUM HEIGHT FOR ANEMOMETER HEAD IN MULTIPLES OF h = OBSTRUCTION HEIGHT.
2h
1·5h
h
5h
10h
15h
20h
25h
30h
DISTANCE OF OBSTACLE FROM ANEMOMETER IN MULTIPLES OF h = OBSTRUCTION HEIGHT

Appendix 2

Anemometers and anemographs in the United Kingdom (Jan 1972).

Anemograph stations (Synoptic)

Airfields	Inland	23	
	Coastal	22	
			Total 70
Others	Inland	11	
	Coastal	14	

Anemograph stations (Non-synoptic)

Airfields	Inland	2	
	Coastal	2	
			Total 39
Others	Inland	21	
	Coastal	14	

Anemometer stations (Synoptic)

Airfields	Inland	8	
	Coastal	0	
			Total 49
Others	Inland	17	
	Coastal	24	

There are about 6, known, non-synoptic anemometer stations — Total 6

Run-of-wind stations.

Synoptic		4	Total 4
non-synoptic	110	Coastal 14	Total 110
		Inland 96	

7

Wind data available by synoptic (communications) channels

60 coastal reports including some airfields

31 inland reports from airfields (1 also measures run-of-wind)

28 inland reports not from airfields (3 also measure run-of-wind)

119

Wind data not available by synoptic (communications) channels

16 coastal reports including some airfields

2 inland reports from airfields

27 inland reports not from airfields.

45

Run-of-wind data not available by synoptic (communications) channels

14 coastal reports

96 inland reports

Appendix 3

Extracts from: the draft version of "Climatological Memorandum No. 71"

"ONE PERCENTILES OF HOURLY MEAN WIND SPEEDS OVER THE UNITED KINGDOM"

N.C.Helliwell, J.J.W.Blackburn and O.L.Palfrey. (unpublished)

1. In their Introduction the authors state that annual, average, hourly mean wind speeds and annual, average wind speeds obtained from hourly synoptic weather reports at the same station are roughly equal.

2. To prepare a map of annual, average wind speed the authors require a method of standardising exposure characteristics. They adopted as standard a wind measured at an effective height of 10 metres above "smooth, open, level country with few trees". They designed a roughness index scale from 1 to 8. Two of the authors, working independently, allotted values on this scale to a selection of stations. They agreed on the index figure for all except three stations for which their separate estimates differed by one point on the scale; these differences were readily resolved in discussion.

3. To each point on the roughness index scale they allotted a power law exponent (by interpolation from published data) and, finding that the power law treatment, alone, did not take account of all the speed loss due to roughness they introduced a divisor to improve the ~~method~~ estimates.

Values of { roughness index c; exponent a; divisor q }

are listed in their Table 3 (attached) together with corresponding terrain descriptions. The modified correction formula, using roughness, becomes

$$V_s = \frac{V_h}{q}(10/h)^a$$

where V_s = speed at standard height

V_h = speed at effective height h (i.e. actual, measured speed)

Roughness indices, altitudes (m), effective heights (m), 1965-1969 annual average hourly mean wind speed (m/s) V_h and corrected speed V_s are listed in their Table 4 (attached) for 77 stations.

Table 3 Roughness Index

Roughness Index c	Exponent a	Divisor q	Description
1	0.14	1.05	Very smooth terrain - open water, mud flats.
2	0.17	1.00	Smooth - open level country with few trees.
3	0.20	0.95	Open level country with many hedges, few trees.
4	0.23	0.90	Level sparsely wooded country, outskirts of small towns.
5	0.26	0.85	Rolling country with tree hedges and small villages.
6	0.28	0.82	Rolling country, small towns, outer suburbs of cities, open forests.
7	0.30	0.79	Inner suburbs, dense forests.
8	0.32	0.75	City centres.

Table [illegible]

STATIONS FOR WHICH ANNUAL AVERAGE HOURLY MEAN WIND SPEED DATA WERE AVAILABLE FOR 1965-69 : STATION CHARACTERISTICS AND WIND SPEEDS

Station Name	Altitude m	Roughness Index	Effective ht m	Annual average hourly mean speed V_h m/s	corrected speed V_s m/s
Lerwick	93	2	10	7.0	7.0
Stornoway Coastguard	37	2	11	7.0	6.9
Dyce	72	3	10	5.1	5.4
Bell Rock	39	1	38	8.2	6.5
Leuchars	25	3	12	5.6	5.7
Tiree	24	1	13	8.0	7.3
Kinloss	18	2	13	5.7	5.4
Lossiemouth	31	2	18	5.1	4.6
Duirinish	38	5	17	5.0	5.2
Benbecula	16	2	10	8.2	8.2
Fort Augustus	58	6	16	3.1	3.3
Kirkwall	41	3	10	7.2	7.5
Dounreay (low-level)	34	2	9	7.5	7.6
Shin	24	6	10	3.6	4.4
Rannoch	307	3	17	5.3	5.0
Tummel	161	6	16	2.8	3.0
Turnhouse	43	3	10	4.7	5.0
West Freugh	25	2	10	5.4	5.4
Prestwick	21	3	10	4.8	5.1
Eskdalemuir	259	3	10	4.0	4.2
South Shields	22	3	13	4.6	4.6
Cranwell	77	4	13	4.6	4.8
Mildenhall	30	4	18	3.8	3.6
Cardington	69	3	40	5.8	4.6
Rothamsted	141	7	10	3.6	4.6
Shoeburyness	36	2	28	6.9	5.8
Elmdon	105	3	10	4.8	5.1
Edgbaston	194	7	22	4.1	4.1
Keele	215	6	10	3.4	4.1
London Weather Centre	93	8	38	5.3	4.6
Heathrow	34	3	10	4.8	5.0
Gatwick	69	3	10	3.7	3.9
Hampton	42	6	30	3.9	3.5
Kew	28	7	15	3.1	4.3

Table 2 (contd)

Station name	Altitude m	Roughness Index	Effective ht m	Annual average hourly mean speed V_h m/s	Corrected Speed V_s m/s
Durham	119	4	10	4.1	4.6
Bedford	94	3	9	5.1	5.5
Garston	94	6	10	3.1	3.8
Pershore	47	3	10	5.0	5.3
Avonmouth	28	2	10	5.2	5.2
Thorney Island	16	4	10	4.8	5.3
Hurn	23	2	10	4.4	4.4
Calshot	15	2	10	5.3	5.3
Larkhill	145	4	10	4.7	5.2
Porton	120	4	10	4.8	5.3
Boscombe Down	130	4	16	5.5	5.5
Abingdon	90	5	12	4.0	4.5
Sellafield (L.L.)	25	4	11	4.6	5.0
Fleetwood	34	2	9	4.6	4.6
Speke	30	4	10	5.1	5.7
Ringway	80	3	10	4.6	4.9
Valley	26	2	12	7.2	6.9
Aberporth	144	3	11	6.5	6.7
Lizard	96	2	18	7.0	6.4
Scilly	70	2	17	6.8	6.2
Paisley	57	7	9	3.3	4.4
Hunterston (L.L.)	13	4	10	4.8	5.3
Jersey	98	4	12	7.0	7.4
Squires Gate	26	2	11	6.6	6.5
Southport	19	2	11	4.2	4.2
Milford Haven	47	4	10	5.8	6.4
Brawdy	130	3	14	6.9	6.9
Port Talbot	28	3	11	5.1	5.3
Rhoose	77	2	10	5.5	5.5
Plymouth Mt Batten	64	6	13	5.6	6.3
Ballykelly	13	2	10	4.8	4.8
Kilkeel	35	2	14	5.9	5.6
Carrigans	129	5	10	4.1	4.8
Castle Archdale	80	5	13	4.6	4.9
Isle of Grain	15	3	10	4.0	4.2
Carlisle	41	3	9	4.7	5.0

Table Ø (contd)

Station name	Altitude m	Roughness Index	Effective ht m	Annual average hourly mean speed V_h m/s	Corrected Speed V_a m/s
Spadeadam	292	6	15	4.9	5.3
Great Dun Fell	857	4	10	9.5	10.6
Moor House	537	3	14	7.3	7.3
South Farnborough	74	4	11	4.6	5.0
Ronaldsway	25	2	10	5.5	5.5
Point of Ayre	20	2	10	7.1	7.1
Aldergrove	80	4	10	4.9	5.5