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EVAPORATION MEMO NO. 17.

THE ACCURACY OF WIND DATA USED IN ESTIMATING EVAPORATION BY THE PENMAN FORMULA

By A G Seaton

(comments and appendices B G Wales-Smith)

Introduction

The reliability of the two metre wind run was assessed in two ways:

(I) at three stations with anemometers at both 2 metres and a greater height, comparisons were made of the wind run at the two levels (a) on a monthly basis for 24 months and (b) on a daily and pentad basis for two sample months;

(II) comparisons were made of the two-metre wind runs from neighbouring stations.

Station details are given at Appendix 1.

Key

W_2 = wind run at two metres
W_Z = wind run at 'Z' metres (effective height)
$W_{2'}$ = W_Z reduced to 2 metres where $W_{2'} = (2/Z)^{0.17}$ WZ.

$\delta = W_{2'} - W_2$
P $= W_2/W_Z$

C - Cardington	Z = 41	$W_{2'}/W_Z = 0.599$
K - Kew	Z = 15	$W_{2'}/W_Z = 0.710$
R - Rothamsted	Z = 10	$W_{2'}/W_Z = 0.761$

$\bar{\delta}$ = mean of 24 δ's for a given station

Approx error in PE due to error in wind run

= +0.0018 mms/mile in Winter (0.050 mm/day/kt)
= +0.0015 mms/mile in Summer (0.041 mms/day/kt)

Table 4 (based on monthly values of daily mean wind runs for 2 years)

	δ			P		
	C	K	R	C	K	R
Mean of 24	- 8	29	-10	.63	.57	.82
Theoretical mean	0	0	0	.60	.71	.76
Highest monthly mean	23	50	2	.71	.67	.95
Lowest monthly mean	-37	6	-29	.52	.45	.74
Range	60	44	31	.19	.21	.21
Standard deviation	16	15	8	.05	.05	.05

I : THE 2 ANEMOMETERS AT CARDINGTON, KEW, ROTHAMSTED

Monthly Comparison

Graph 1 shows the variation through two years of δ, the difference between the wind run measured at a high level and reduced to two metres and that actually measured at two metres. A seasonal cycle can be seen at Kew and perhaps at Cardington, but the cycles are out of phase with each other. Graphs 2A, B and C display the monthly values of W_2 and $W_{2'}$ for the same station-months as were used in Graph 1. In all cases the correlation can be seen to be good. For Cardington and Rothamsted the regression lines would be quite close to x=y but for Kew the regression line would have an appreciable intercept on the W_2 (y) - axis and a considerably different slope from x=y. Graphs 3 and 4 illustrate the variations in the ratio of the two wind measurements; the scatter of values is considerable and may or may not be about the values $(2/Z)^{0.17}$.

Table 4 summarises the figures given in tables 1 and 2;* the mean daily errors would accumulate over a year to given an error in the calculated potential evaporation of roughly -5, +17, and -6 mms for Cardington, Kew, and Rothamsted respectively. The error in the total PE at each station for the month with the greatest $/\delta/$ (during the two year period studied) would be -2, $+2\frac{1}{2}$, and $-1\frac{1}{2}$ mms respectively; that likely to occur once in a hundred months can be shown (using the standard deviations and the normal distribution function) not to be much larger than this.

These errors are quite acceptable. Although the errors (δ) in the wind runs are considerable their impact on the evaporation value is reduced by the nature of the Penman formula. On studying table 3* no relationship between δ and a given month's weather could be found.

Daily and Pentad Comparison

Table 7 (see also graphs 5, 6, 7, and 8 and tables 5* and 6*)

	Jan 1970			Jul 1970		
	C*	K	R	C	K	R
Mean daily δ	-20	+37	+ 3	-16	+13	- 8
Highest δ for a day	+ 8	+100	+23	+13	+85	+ 7
Lowest δ for a day	-43	0	-27	-54	-15	-25
Standard dev'n of daily δ's	12.8	21.2	12.6	18.6	24.8	8.1
Mean pentad δ	-	+189	+11	- 93	+74	-37
Highest δ for a pentad	-	+325	+84	+ 4	+226	+ 4
Lowest δ for a pentad	-	+ 78	-54	-209	-21	-84
Estimated s.d.	-	57	32	49	57	20

* based on 21 days figures.

Graph 5 shows daily values of δ for 3 stations for July 1970. The horizontal lines marked with station names are positions of 0 on the δ axis adjusted by an amount δ for July 1970 in each case. Values of S referred to the "station zeros" would be considerably smaller than those referred to the common zero of the diagram, suggesting a conversion of the form.

$$W_2 = W_{2'} = (2/Z)^{0.17} W_z + a$$

* available but not reproduced here.

Graph 6 shows daily values of W_2 and $W_{2'}$ for January and July 1970 at Kew Observatory. The regression line for most July values would be close to the x=y line whilst that for January values would have a considerably steeper slope. Correlations are quite good.

Graph 7 shows the variation of δ with $W_{2'}$ for Kew in January 1970. The scatter of points is considerable but a clear trend appears.

Graph 8 shows the variation of P with W_2 for Kew in July 1970. The values are not evenly distributed about the value given by $W_2 = (2/Z)^{.17} W_Z$.

The scatter of points is rather too large for any deductions about trend.

Frequency tables of 1-day and 5-day mean values of δ for 7 station - months are given in Appendix 2. The "boxed" headings show frequencies of numerical ranges of δ (+ and - taken together).

The comment made at the end of the monthly comparison also applies here: the error in the wind run is considerable but (except in mid-Winter) its impact on the PE calculated is sufficiently small to be acceptable. For example the highest pentad error in July 1970 at Kew was +226 miles; this gives an error in the evaporation for the five days of about +0.34 mms which is about 2% of the total in a Summer pentad.

II: COMPARISON OF NEIGHBOURING ANEMOMETERS

Graphs 9-11 and tables 9-11* illustrate the variations in wind runs measured at neighbouring stations. The graphs tell their own story. The stations were chosen to be in similar topographical situations.

Table 8 — Distances

	Miles
Moreton Morrell - Luddington	8
Reading - Hurley	9
Reading - Shinfield	4
Hurley - Shinfield	10
Church Fenton - Bramham	7
Church Fenton - Cawood	3
Bramham - Cawood	8

The above has not attempted to give reasons for the discrepancies - there are many possible reasons other than bad exposure of the two-metre anemometer - but its intention has been to make the user of the data aware of the size and nature of the errors inherent in it.

Comments

The following are some of the factors likely to cause differences between wind run values at the same height above ground at neighbouring sites.

(i) mechanical condition of instruments and state of lubrication.

(ii) differences in instrument type and in "stopping speeds".

(iii) topographical wind-break differences.

(iv) differences in the wind-break characteristics of the sites themselves.

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* available but not reproduced here.

(v) seasonal wind-break variations on sites - ie growth of plants, foliage etc.

(vi) Area-to-area variation in albedo, resulting in variations in convectively induced turbulence.

An example of the significance of wind flow in calculations of PE is given at Appendix 3.

It has been shown that although the wind run at one point and level above ground is not always well reproduced by that at an adjacent point at the same level or by that at the same point but at another level the differences found from the station data analysed would not have resulted in large errors in the calculated estimates of (Penman) potential evaporation.

If a desired end-product of accurate and areally - representative wind run (or speed) measurement is a realistic estimate of potential evaporation the chance of an error of, say, 8% in PE (as shown in Appendix 3) is sufficient reason for doing everything reasonably possible to obtain the desired quality and representativeness in the wind data. Future developments in the technique of estimating evaporation might some what increase the importance of the aerodynamic term. Wind data have many valuable practical applications and should, therefore, be as representative (of a general or of a special area) as possible. This end requires careful attention to instrument maintenance, calibration and checking and exposure.

24 June 1971

Meteorological Office
Met O 8c
Bracknell

AJT

Appendix 1

Details of wind measuring stations used in the analysis

Station Name	Nat Grid Ref	Ht asl m	Anemograph head height m (Above ground)	Anemograph head height m (Effective height)
Kew observatory	51-171757	5 m	23	15
Cardington	52-083464	28 m	41	41
Rothamsted	52-132134	128 m	13	10
Church Fenton	44-528380	8 m	10	10
Moreton Morrell	42-306553	85 m		
Luddington	42-167528	56 m		
Reading	41-736713	69 m		*
Hurley	41-822823	43 m		
Shinfield	41-734686	61 m		
Bramham	44-431412	54 m		
Cawood	44-561366	6 m		

All Stations measure run-of-wind at 2 m above ground.

* run-of-wind also measured at 16 m above ground.

Appendix 2.

FREQUENCY TABLES OF δ (= $W_{21} - W_2$) FOR JANUARY (3 STATIONS) AND JULY (4 STATIONS) 1970 FOR 1-DAY AND 5-DAY MEAN RUN OF WIND.

JANUARY 1970 — KEW — 1-DAY

	(PLUS)									
0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
1	2	2	10	4	3	5	3	0	0	1
1	3	5	15	19	22	27	30	30	30	31

CARDINGTON — 1-DAY

				(MINUS)		(PLUS)
50-41	40-31	30-21	20-11	10-1	0	1-10
1	2	7	7	2	0	2

0	±1-10	-11-20	-21-30	-31-40	-41-50
0	4	7	7	2	1
0	4	11	18	20	21

(10 DAYS MISSING)

ROTHAMSTED — 1-DAY

		(MINUS)		(PLUS)		
30-21	20-11	10-1	0	1-10	11-20	21-30
2	3	6	0	9	9	2

0	±1-10	±11-20	±21-30
0	15	12	4
0	15	27	31

JULY 1970 — KEW — 1-DAY.

	(MINUS)		(PLUS)							
20-11	10-1	0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
1	8	3	6	5	3	2				2

0	±1-10	±11-20	+21-30	+31-40	+41-50	+51-60	+61-70	+71-80	+81-90
3	14	6	3	2	0	0	0	2	1
3	17	23	26	28	28	28	28	30	31

CARDINGTON — 1-DAY

					(MINUS)		(PLUS)	
60-51	50-41	40-31	30-21	20-11	10-1	0	1-10	11-20
2	2	3	5	8	3	0	7	1

0	± 1-10	± 11-20	-21-30	-31-40	-41-50	-51-60
0	10	9	5	3	2	2
0	10	19	24	27	29	31

ROTHAMSTED — 1-DAY.

		(MINUS)		(PLUS)
30-21	20-11	10-1	0	1-10
1	10	15	1	4

0	± 1-10	- 11-20	-21-30
1	19	10	1
1	20	30	31

JANUARY 1970 — KEW — 5-DAY.

	(PLUS)						
0	1-10	11-20	21-30	31-40	41-50	51-60	61-70
0	0	1	8	10	6	5	1
0	0	1	9	19	25	30	31

CARDINGTON — 5-DAY

		(MINUS)	
30-21	20-11	10-1	0
8	7	0	0

(16 days missing)

0	-1-10	-11-20	-21-30
0	0	7	8
0	0	7	15

ROTHAMSTED — 5-DAY.

	(MINUS)		(PLUS)	
20-11	10-1	0	1-10	11-20
1	12	0	13	5

0	± 1-10	± 11-20
0	25	6
0	25	31

JULY 1970 — KEW — 5-DAY.

(MINUS)		(PLUS)				
10-1	0	1-10	11-20	21-30	31-40	41-50
4	0	11	4	8	3	1

0	± 1-10	+ 11-20	+ 21-30	+ 31-40	+ 41-50
0	15	4	8	3	1
0	15	19	27	30	31

CARDINGTON — 5-DAY.

				(MINUS)		(PLUS)
50-41	40-31	30-21	20-11	10-1	0	1-10
2	3	7	15	3	0	1

0	± 1-10	- 11-20	- 21-30	- 31-40	- 41-50
0	4	15	7	3	2
0	4	19	26	29	31

ROTHAMSTED — 5-DAY.

20-11	10-1	0	1-10
10	20	0	1

0	± 1-10	- 11-20
0	21	10
0	21	31

JULY 1970 READING 1-DAY

10-1	0	1-10	11-20	21-30
1		9	18	3

0	±1-10	+11-20	+21-30
0	10	18	3
0	11	28	31

READING 5-DAY

0	1-10	11-20	21-30
0	9	21	1
0	9	30	31

Appendix 3.

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, in effect, partly* allows for

(i) the air to become saturated and

(ii) moisture to be carried aloft by convection (if any) and to be evaporated by unsaturated air above screen level.

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.

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).

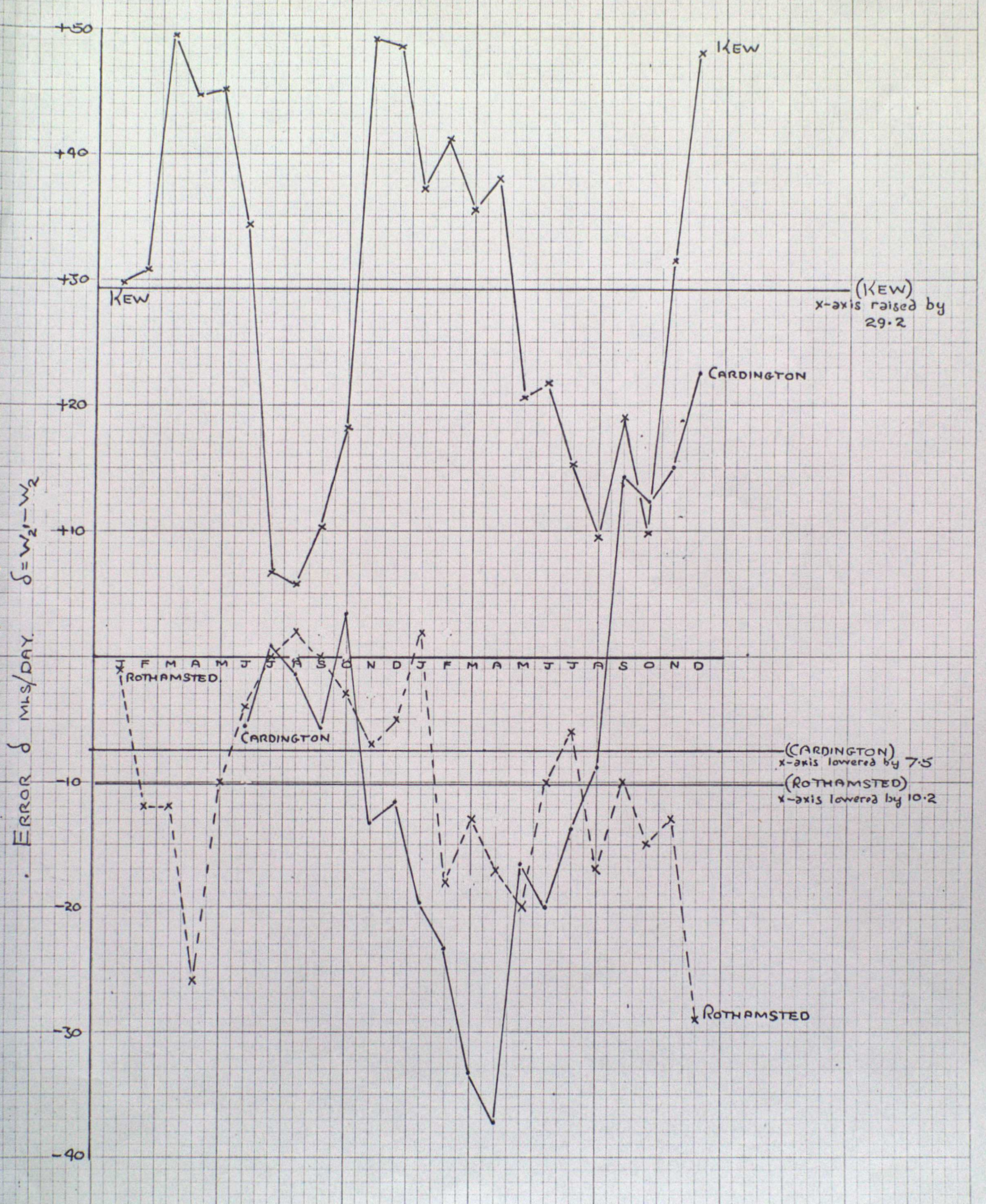
* E is always +ve provided that the radiation balance is +ve.

Met O 8c
Bracknell
June 1971

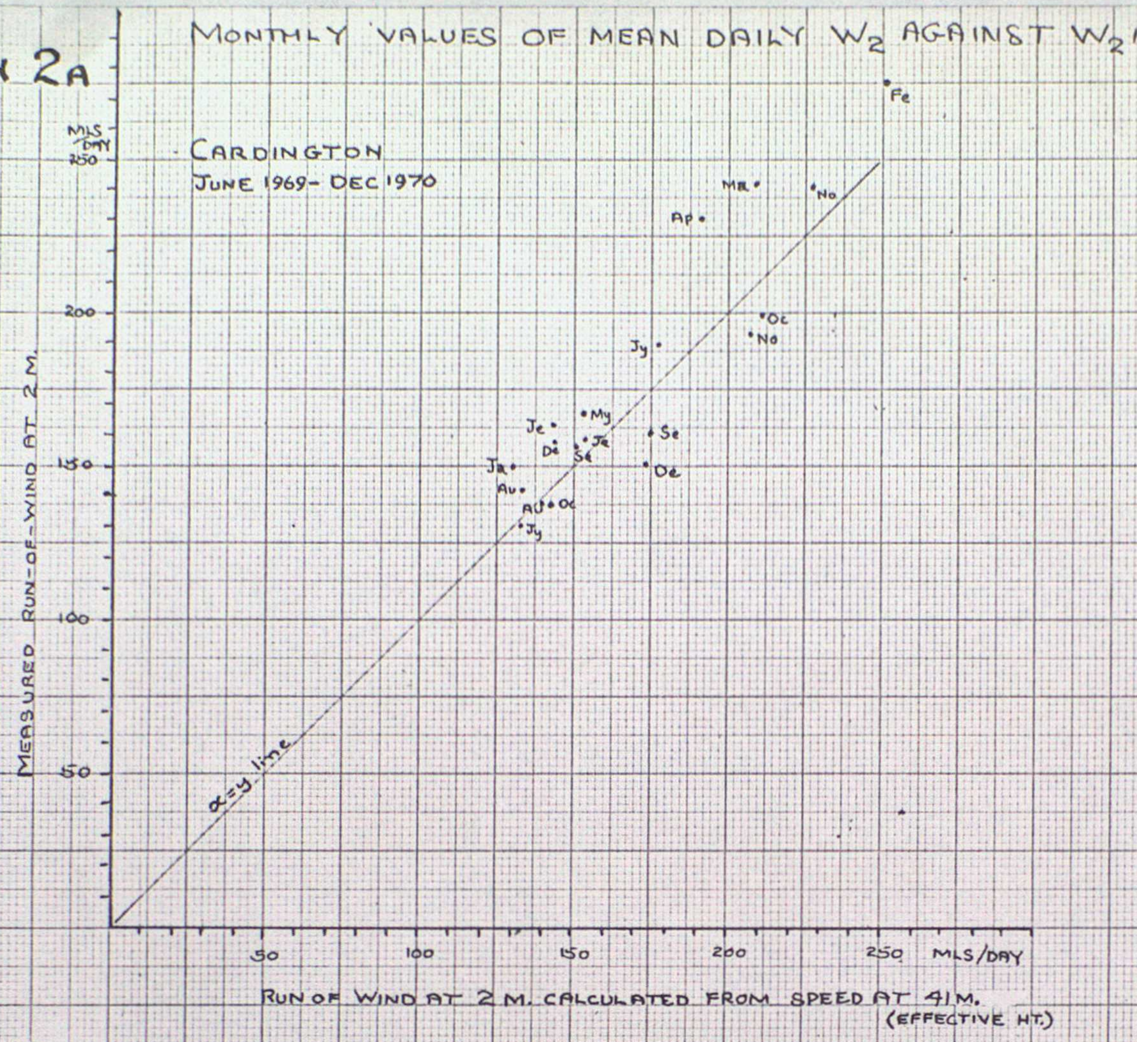
B G WALES-SMITH

G. 13201/MD/6/71/30

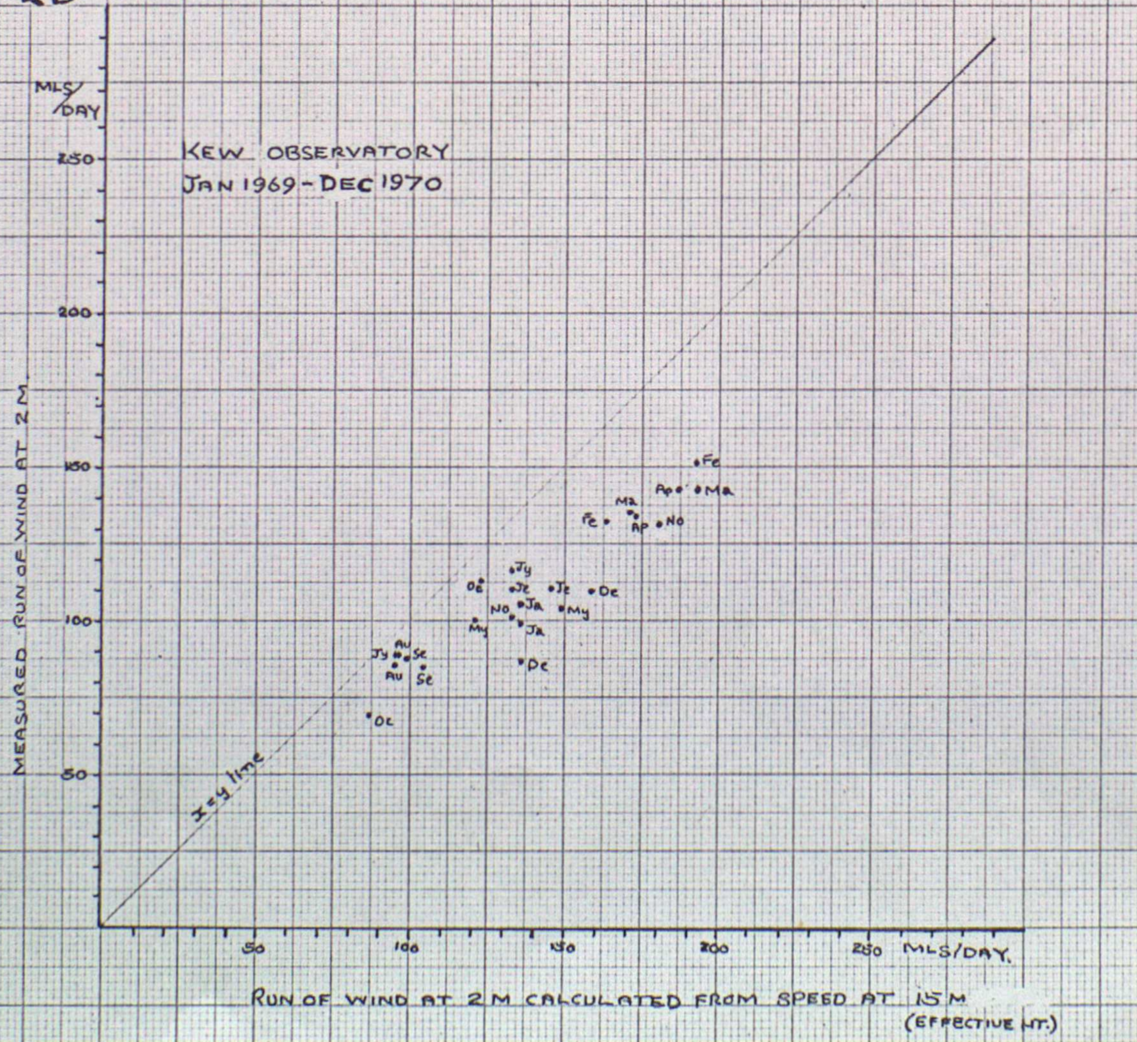
GRAPH 1. MONTHLY VALUES OF $\delta = W_{2'} - W_2$ FOR 67 STATION-MONTHS (3 STATIONS)



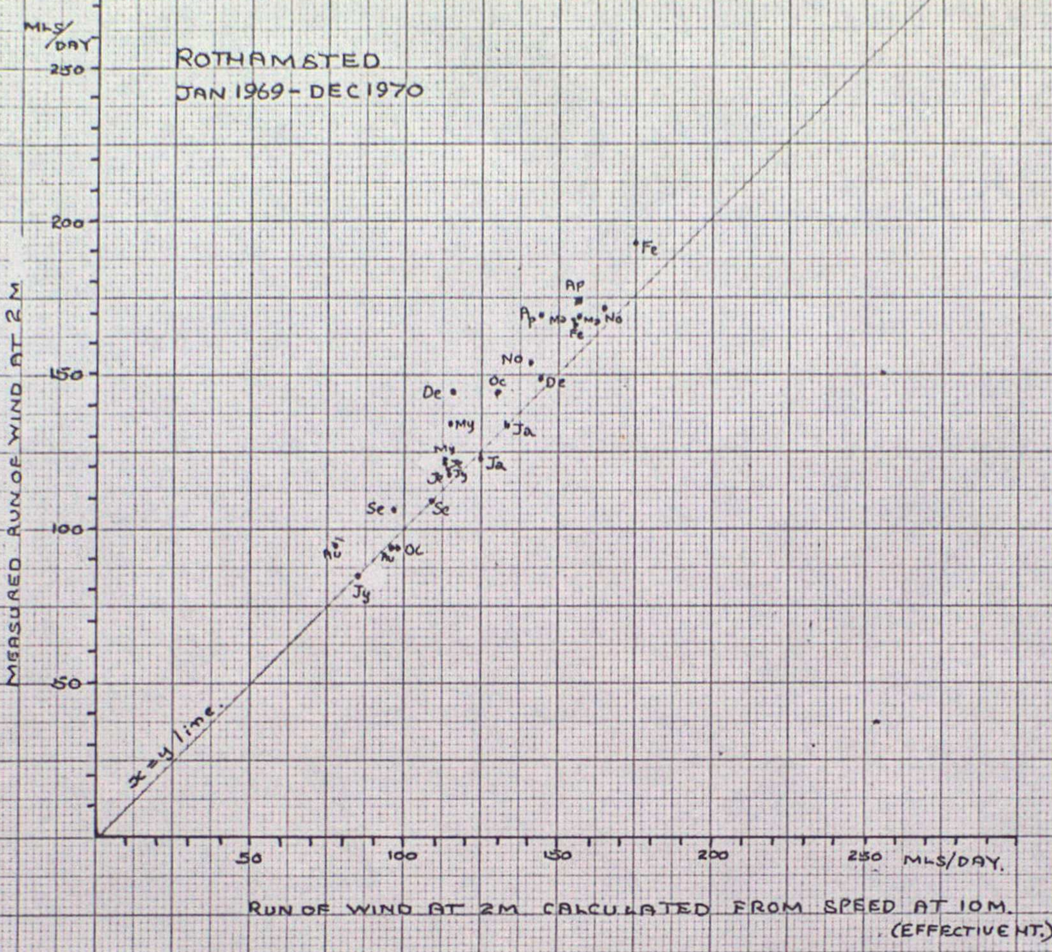
Graph 2A


Monthly values of mean daily W_2 against W_2'
Cardington
June 1969 - Dec 1970
MLS/DAY
Measured run-of-wind at 2 M.
x=y line
MLS/DAY
Run of wind at 2 M. calculated from speed at 41 M. (effective ht.)

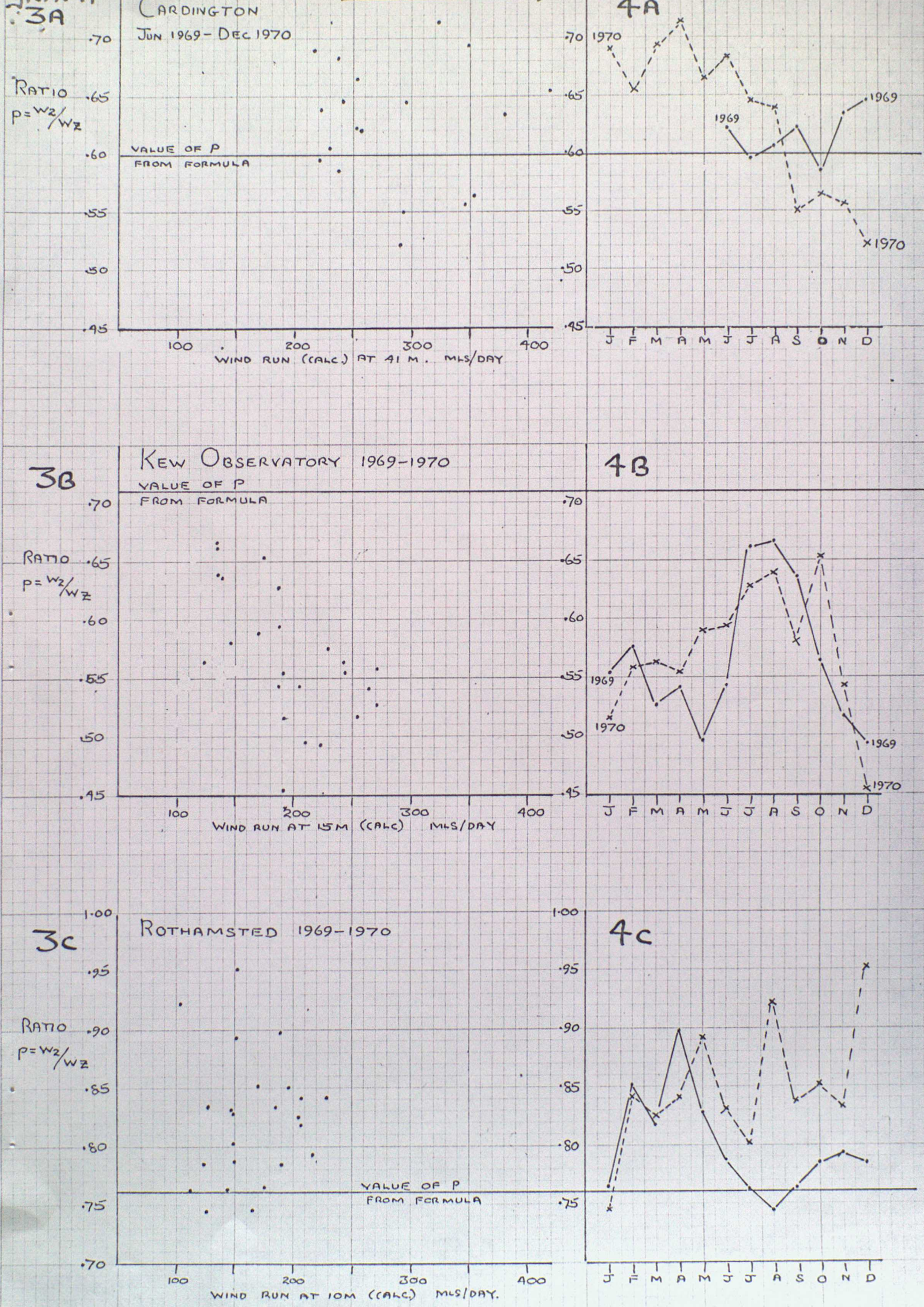
2B

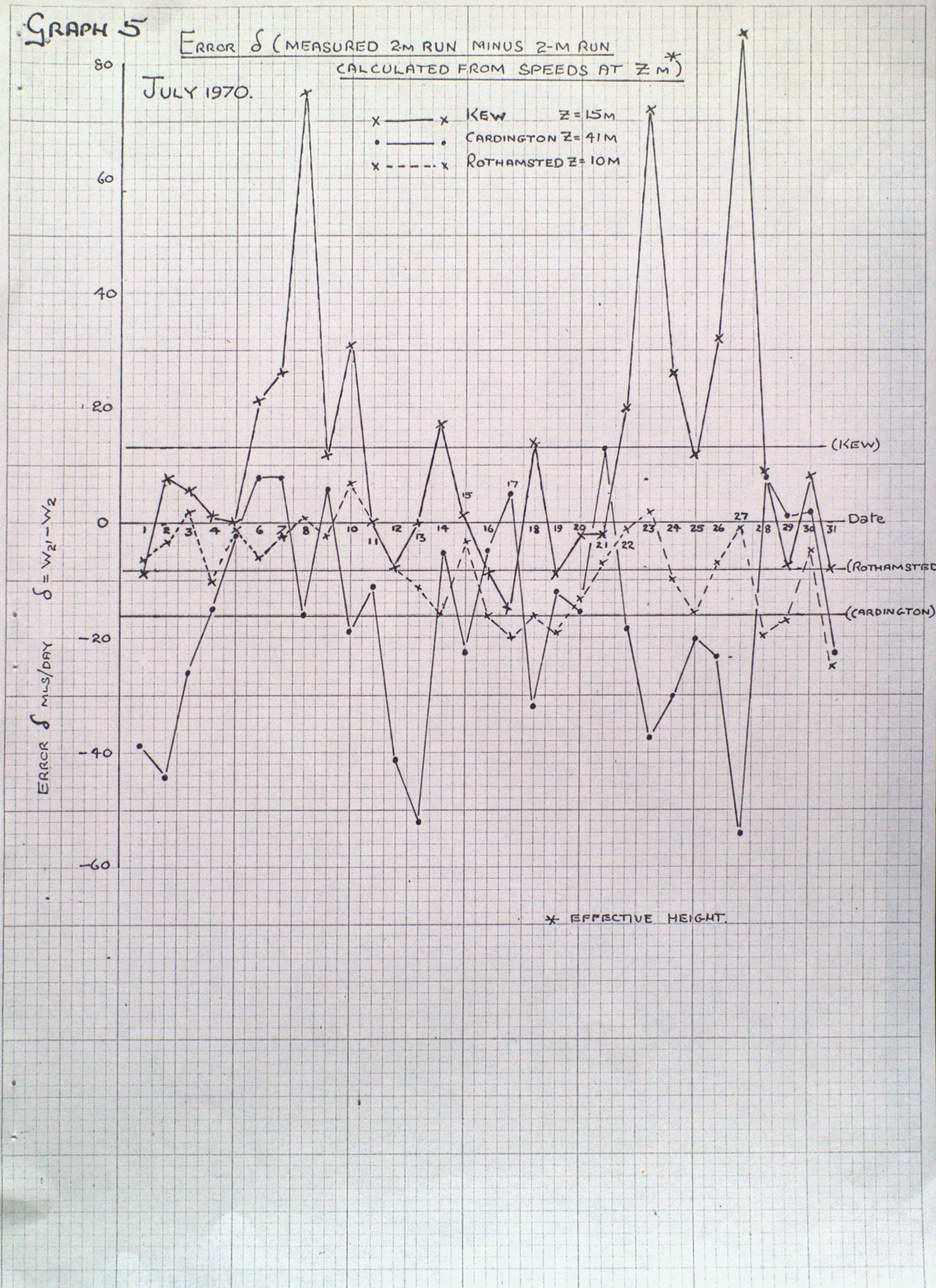

Kew Observatory
Jan 1969 - Dec 1970
MLS/DAY
Measured run of wind at 2 M
x=y line
MLS/DAY.
Run of wind at 2 M calculated from speed at 15 M (effective ht.)

2c

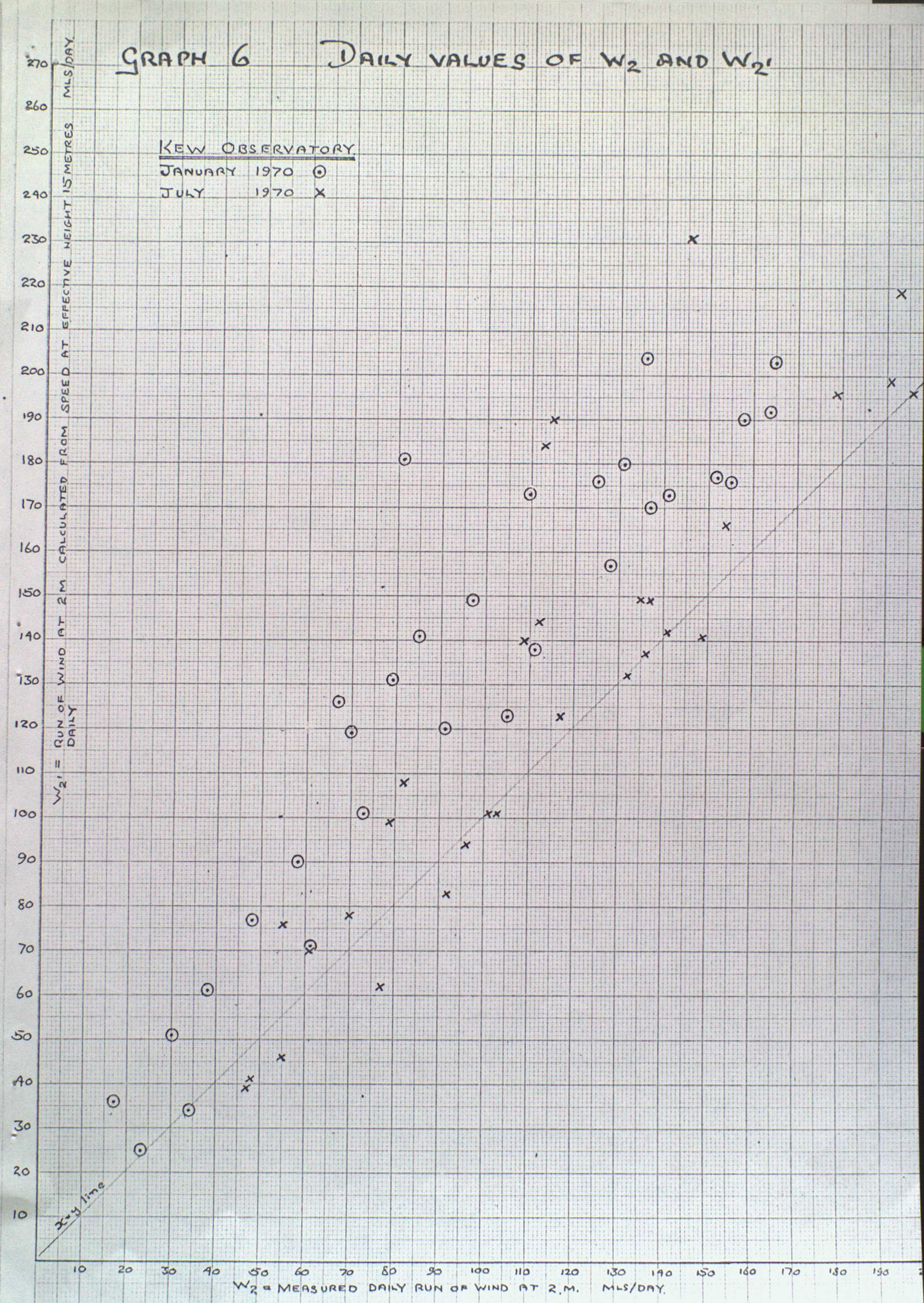

ROTHAMSTED
JAN 1969 - DEC 1970
MLS/DAY
250
200
150
100
50
MEASURED RUN OF WIND AT 2M
Fe
Ap
Ap
Mo
Mo
No
Fe
No
Oc
De
De
My
Ja
My
Ja
Jy
Se
Se
Oc
Jy
x = y line.
50
100
150
200
250
MLS/DAY.
RUN OF WIND AT 2M CALCULATED FROM SPEED AT 10M.
(EFFECTIVE HT.)

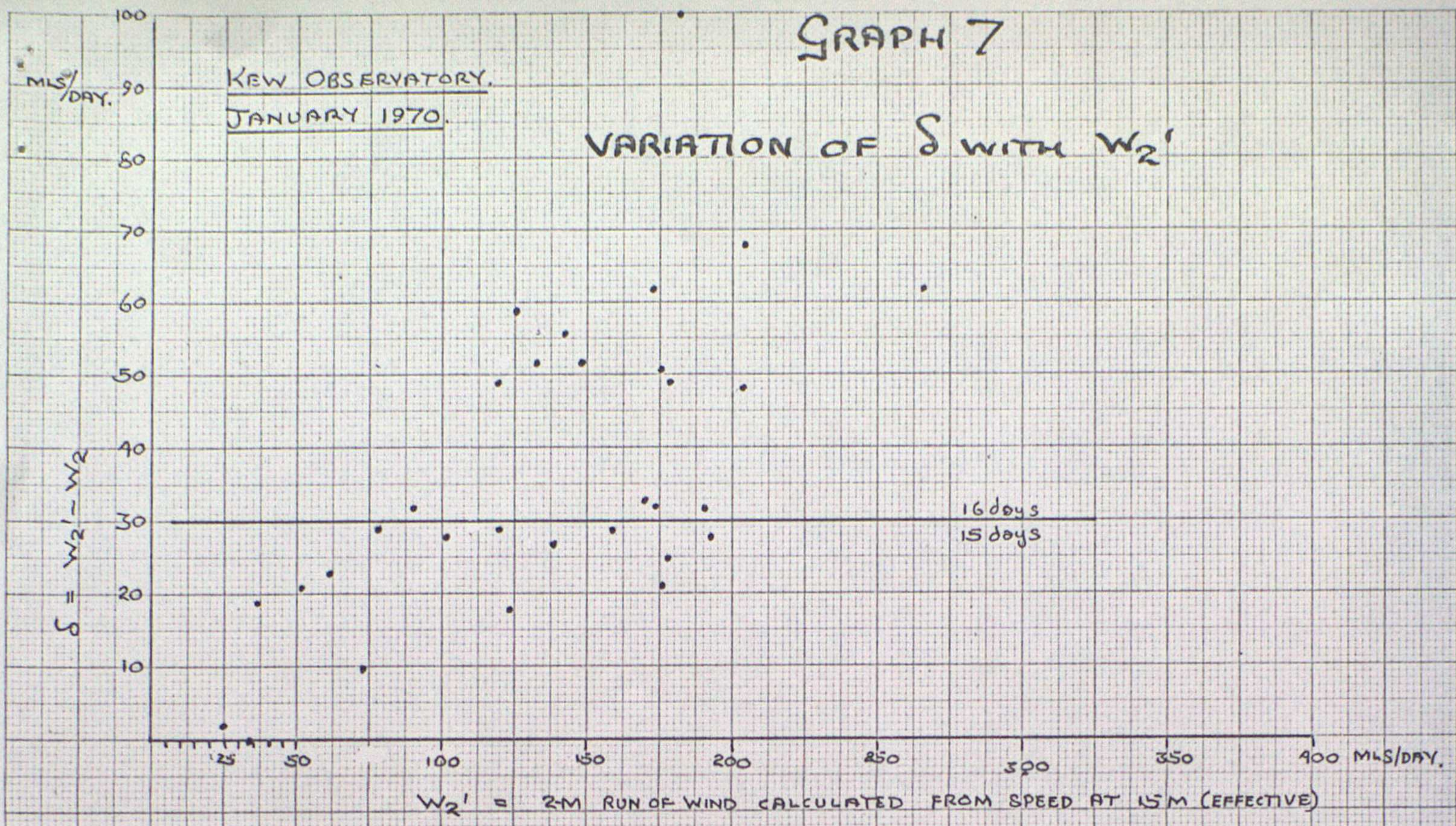
Variation of P

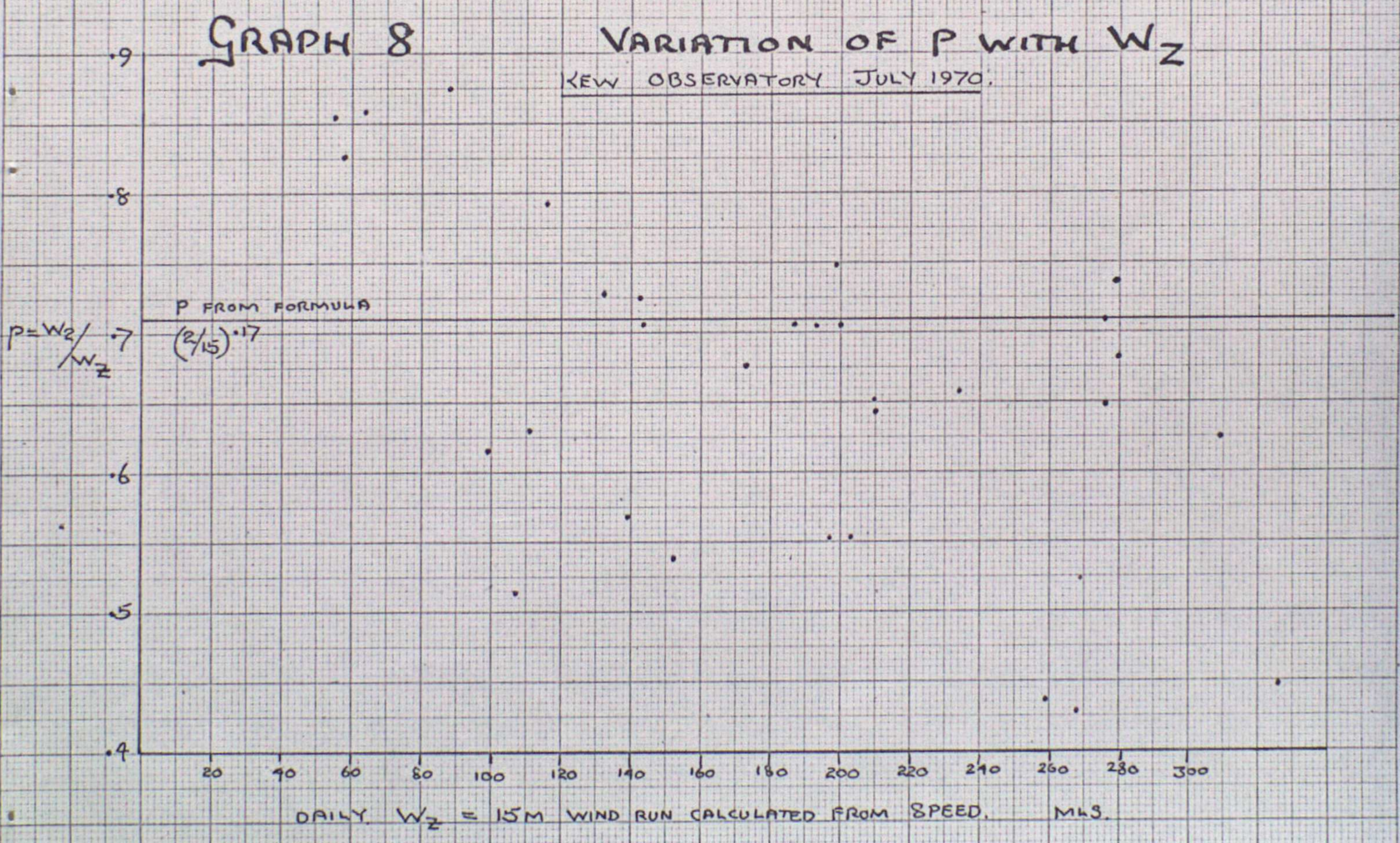




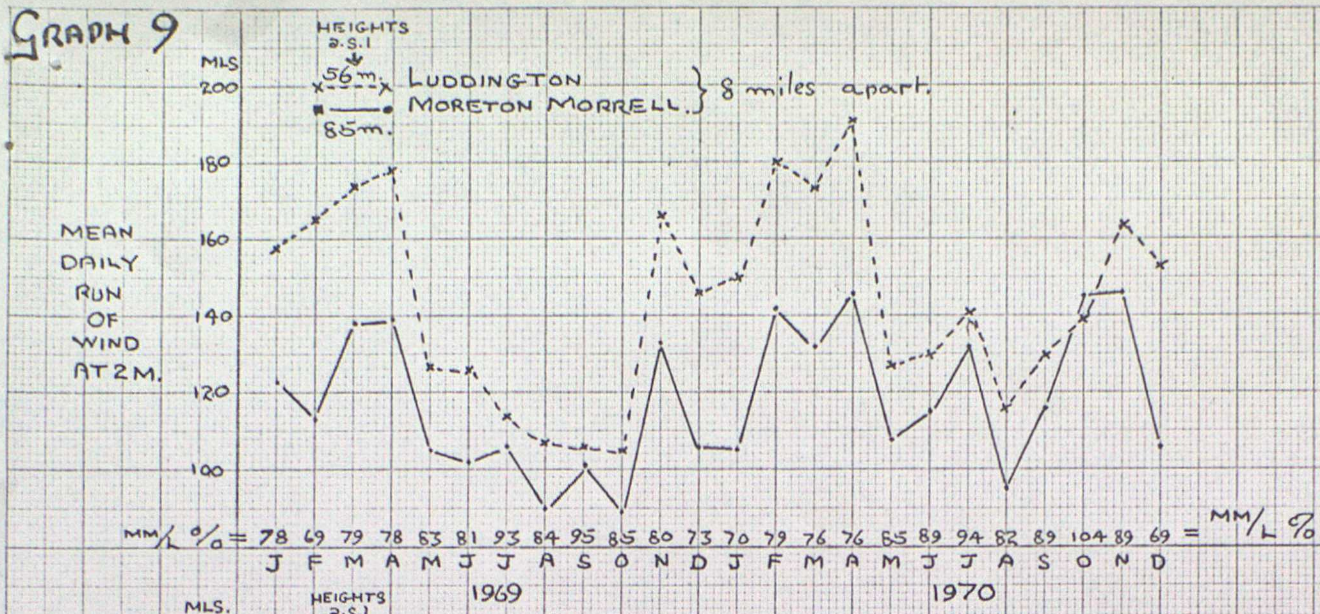
GRAPH 5
ERROR δ (MEASURED 2-M RUN MINUS 2-M RUN CALCULATED FROM SPEEDS AT Z M*)
JULY 1970.
KEW Z = 15M
CARDINGTON Z = 41M
ROTHAMSTED Z = 10M
(KEW)
Date
(ROTHAMSTED)
(CARDINGTON)
ERROR δ MLS/DAY
δ = W21 − W2
80
60
40
20
0
−20
−40
−60
1 2 3 4 6 7 8 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
* EFFECTIVE HEIGHT.


GRAPH 6 DAILY VALUES OF W2 AND W2'
KEW OBSERVATORY
JANUARY 1970
JULY 1970
W2' = RUN OF WIND AT 2M CALCULATED FROM SPEED AT EFFECTIVE HEIGHT 15 METRES MLS/DAY DAILY
W2 = MEASURED DAILY RUN OF WIND AT 2.M. MLS/DAY
x=y line

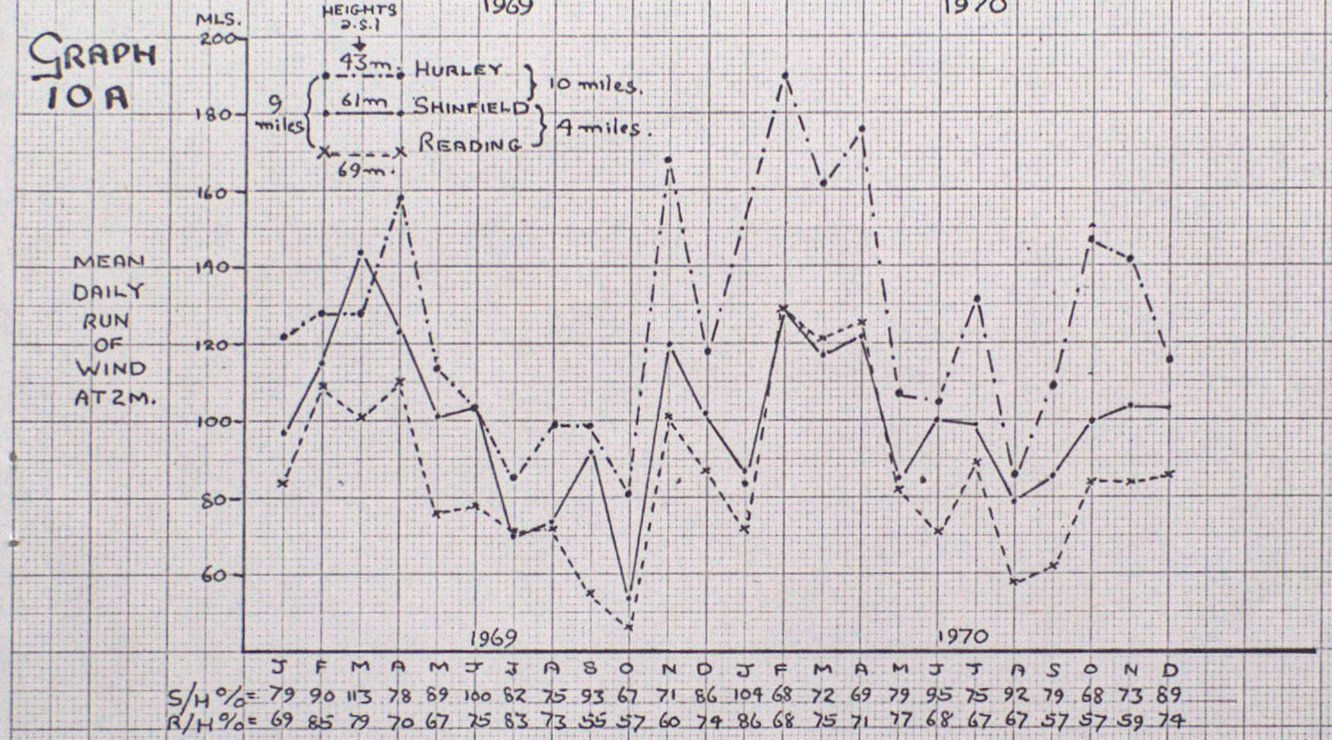

GRAPH 7
KEW OBSERVATORY.
JANUARY 1970.
VARIATION OF δ WITH W2'
MLS/DAY.
δ = W2' − W2
16 days
15 days
W2' = 2M RUN OF WIND CALCULATED FROM SPEED AT 15M (EFFECTIVE)
400 MLS/DAY.


GRAPH 8
VARIATION OF P WITH Wz
KEW OBSERVATORY JULY 1970.
P FROM FORMULA
(2/15)^.17
P = W2/Wz
DAILY Wz = 15M WIND RUN CALCULATED FROM SPEED. MLS.

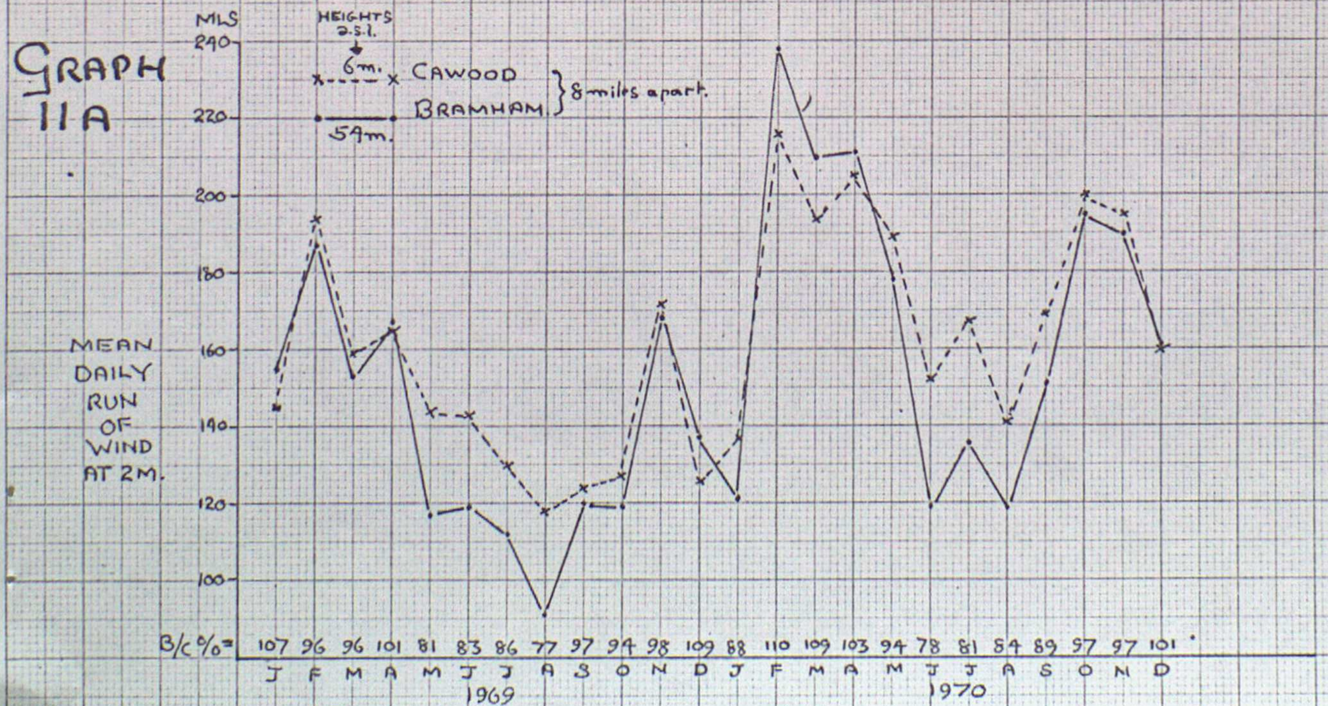
Graph 9



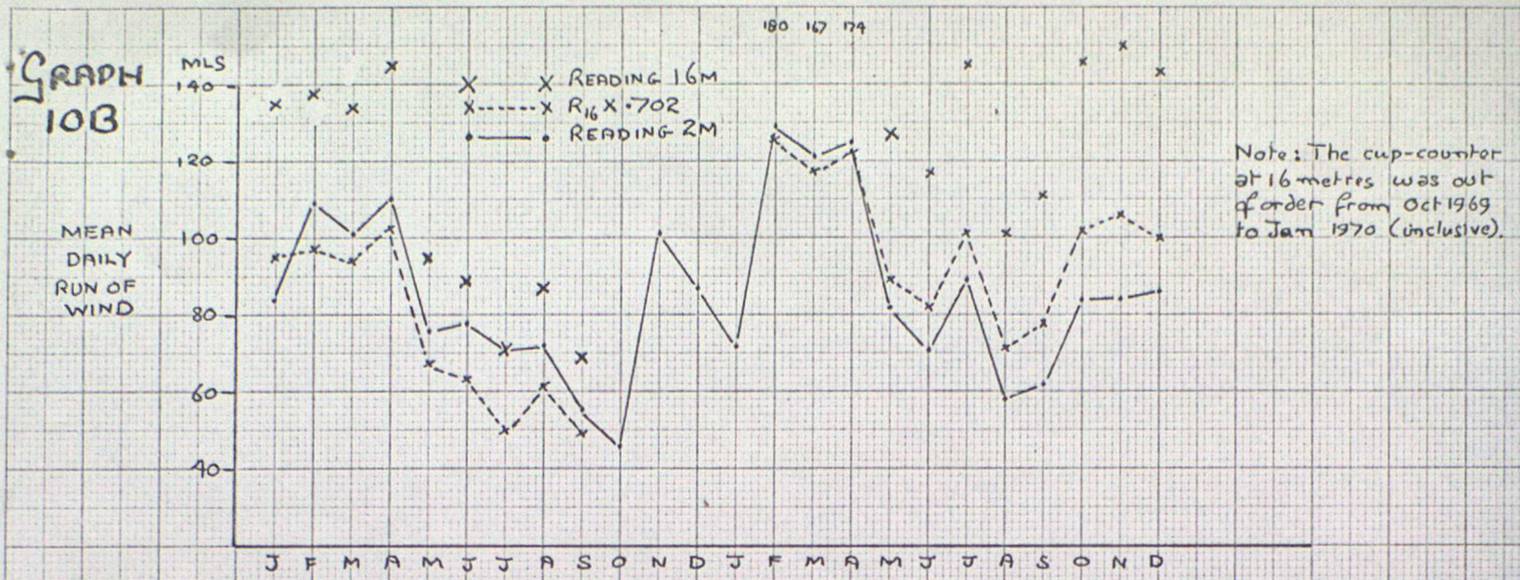
Graph 10A

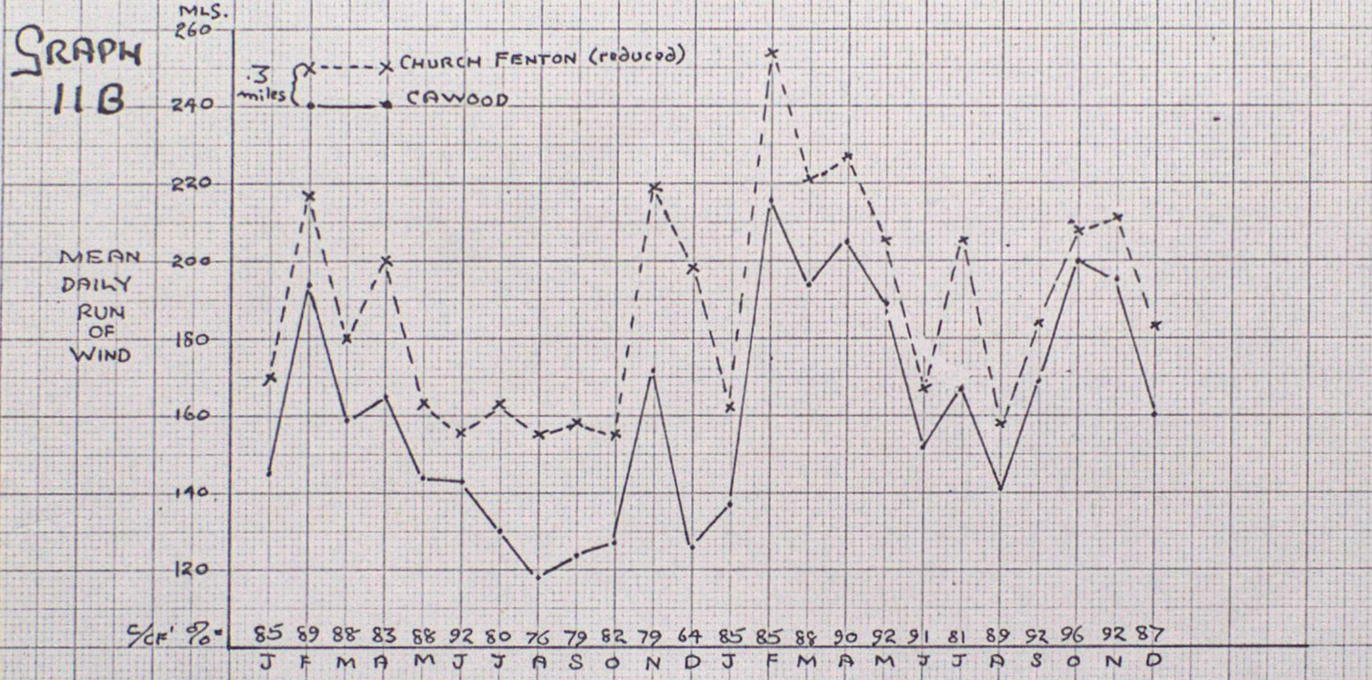


Graph 11A



Comparison of mean daily run-of-wind at 2 metres above ground for 24 months at 3 sets of stations (stations in any set being not more than 10 miles apart).





COMPARISON OF MEAN DAILY RUN-OF-WIND AT 2 METRES ABOVE GROUND FOR 24 MONTHS AT 2 SETS OF STATIONS (one set being a pair of instruments at the same station). IN EACH CASE ONE INSTRUMENT IS AN ANEMOGRAPH OR HIGH-LEVEL CUP-COUNTER ANEMOMETER.