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METEOROLOGICAL OFFICE
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CLIMATOLOGICAL MEMORANDUM

No. 50A.

EXTREME WINDS OVER THE UNITED KINGDOM FOR PERIODS ENDING 1971

by Carol E.Hardman, N.C.Helliwell and J.S.Hopkins

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1. Introduction

In a series of papers, Shellard (references 1 to 5) has presented extreme hourly mean wind speeds and gust speeds for sites in the United Kingdom. In this memorandum, the estimates have been brought up to date by including the additional data accumulated in the period ending 31 December 1971.

It was decided that a minimum of four years' record was necessary to justify the inclusion of a station's data in the analysis. There are 144 such stations (of which 43 are no longer recording) with records up to 58 years in length.

The method used to prepare maps of extreme wind speeds is described, and the effects on wind speeds of surface roughness, averaging time and topography are discussed. An appendix considers the special problems of estimating extreme winds over Central London.

2. Terminology

Using the methods of Gumbel (9), Shellard (2, 4) estimated from a series of annual maximum values, that maximum value which is likely to be exceeded on the average only once in a period of T years. Such a value is called the "once in T year" value or the value having a return period of T years. The probability p that such a maximum value will be exceeded only once in any one year is related to the return period by the equation:

$$p\,T = 1$$

For brevity in the text, phrases such as "once in 50 years gust" or "the gust with a return period of 50 years" have been used, it being implied that maximum values are under discussion. The maximum values computed may be referred to as "extreme values" or "extremes".

3. Station details

Table 1 shows the grid references, actual and effective* heights of the

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*The "effective height" of an anemometer is the estimated height at which, in open level terrain in the vicinity of the anemometer, the same mean wind speeds would be observed as those actually recorded at the observation site.

anemographs, the lengths of record available for analysis, the highest recorded hourly mean and gust speeds and the months in which these maxima occurred. In the case of stations whose site details have altered during the period of record, the details given are those which relate to 1971 (or to the latest year of record for stations which have closed). The maximum recorded values, if measured when the anemometer was at a different effective height, z, from the one shown, have been adjusted to the latest effective height, h, by use of the equations:

$$V_h = V_z\left(\frac{h}{z}\right)^{0.17} \text{ for hourly mean winds} \qquad (1)$$

$$V_h = V_z\left(\frac{h}{z}\right)^{0.085} \text{ for gust speeds} \qquad (2)$$

The stations in Table 1 have been listed in the order in which they would appear in Table 6 of the Monthly Weather Report.

i.e. Scotland, North, East and West; Isle of Man; England, North-East, East, Midlands, South-East and North-West; Wales, North and South; England, South-West; Northern Ireland; Channel Isles.

4. <u>Calculation of extreme values</u>

At each station with 10 or more years of record, the series of annual maximum hourly mean speeds and the corresponding series of annual maximum gust speeds were reduced to a common effective height of 10 metres by applying equations (1) and (2) with h = 10. The series were then analysed using the statistical theory of extreme values.

The maximum value x_T likely to be exceeded only once in T years was calculated using the expression

$$x_T = U - \frac{1}{a}\log_e\left[-\log_e\left(1-\frac{1}{T}\right)\right] \qquad (3)$$

where U and a are determined from the mean, $\overline{x_N}$, and standard deviation, s_N, of the series of N annual maxima and the mean, $\overline{y_N}$, and standard deviation, r_N, of the series

$$y_m = -\log_e\left[-\log_e\left(\frac{m}{N+1}\right)\right] \; ; \; m = 1, 2, 3, \ldots, N$$

U and a are given by:

$$U = \bar{x}_N - \frac{1}{a}\bar{y}_N \quad ; \quad \frac{1}{a} = \frac{s_N}{\sigma_N}$$

At a station with less than 10 years of record, the extreme values were computed, following Shellard (4), by comparing the sum of the annual extremes at the station with the sum of the annual extremes, taken over the same period, of the nearest or most appropriate long period station. The factor so obtained was then applied to the extremes previously computed for the long period station, so giving estimates for the short period station.

5. Results of calculations

Table 2 presents the results of the computations at stations with 10 or more years of data, giving the values of hourly mean speeds and gust speeds likely to be exceeded on average only once in 10, 20, 50, 100 and 120 years.

Table 3 contains results at stations with less than 10 years of record, and the station used in the comparison is given. The order of stations in both tables is that used in the Monthly Weather Report. Kingsway/Holborn results are not given here, because the homogeneity of the record requires separate discussion (see Appendix).

6. Interpretation of results

The computed extremes for individual stations should be used only with caution, since it is known that at many of the sites, the exposure of the anemometer head to the general wind flow is less than perfect. In addition the length of record is important when, for example, a 50-year return period estimate is being calculated from only 15 years' data.

It is of particular concern whether the short period for which records are available has experienced a sample of "extreme" events which is typical of a much longer period. (Indeed, since the computed extremes will be used for planning structures which will be exposed to winds over the next few decades, ideally the sample should be representative of that future period).

It is possible to identify two particular aspects of the sampling problem:

a. Non-representative periods

From the 41 years' (1931-71) data at Lerwick, it is possible to identify certain periods of years whose annual maximum gusts are quite unrepresentative of the full period. Figure 1 shows the annual maximum gusts for the first and last 14-year periods (1931-44 and 1958-71), plotted on extreme-value paper with the straight lines of best fit added. The best straight line fitted to the full 41 years' data is also shown.

Table 4 Gust speeds (m/sec) at Lerwick at 10 metres for return periods:

Period of data	10	20	50	100 (years)
1931-44	43	44	46	47
1958-71	47	50	54	56
1931-71	45	47	50	52

Figure 1 and Table 4 show the differences in estimates derived from the different periods of data. There was a change of instrument and site in 1961, and although a comparison for a short overlap period at old and new sites revealed little difference in mean wind speeds, it is possible that the change resulted in different recording of extreme gusts. Comparison of the values in Table 4 with the computed extremes at Kirkwall, Benbecula, Tiree and Stornoway indicates that the later period (1958-71) yields estimates which are most consistent with these other stations, and therefore it seems likely that the records for the earlier years are not wholly reliable. It is important that this type of problem be borne in mind if use is being made of the estimated extremes shown in Tables 2, 3.

b. Occurrence of "huge" extremes

The occurrence of a single annual maximum value which is very much higher than all other recorded maxima can often lead to difficulties in interpretation of the results of the extreme-value analysis. The following three cases involving Kirkwall, Cranwell and Sheffield illustrate this point; similar action, involving less spectacular extremes, has been taken at a number of other sites to obtain the values listed in Tables 2,3.

(1) Kirkwall. Figure 2 shows gust data from Kirkwall (1957-71) plotted on extreme-value paper. The highest gust is 61 m/sec, recorded on 7 February 1969, and is the highest gust speed ever recorded at a low-level station in the UK. Figure 2 also shows the line of "best" fit calculated by the Gumbel method using all 15 years of data. The position of the line is seen to be weighted far too much by the largest value, and seems to indicate that a value of 61 m/sec should be expected to occur once in about 30 years.

If we assume that maximum gust speeds display reasonable linearity when plotted on extreme-value paper (and the vast majority of stations support this hypothesis), then we must assume that the Kirkwall maximum gust cannot be taken as representative of a 15-year period of record. The data have been re-analysed by omitting the highest value from the series, and treating the series as a 14-year record. The line of best fit to the 14 years' maxima indicates that a gust of 61 m/sec should be expected to occur once in about 200 years.

(2) Cranwell. At Cranwell on 17 December 1952, a gust of 96 knots (49.5 m/sec) was recorded. The synoptic conditions at the time have been described by Douglas (13). Figure 3 shows how this extreme gust compares with the other annual maximum gusts of the 41-year record when plotted on extreme-value paper. Line A is the "best" straight-line fitted by the Gumbel procedure to all 41 extremes. Line B is the result when the 1952 event is omitted and the remaining maxima are treated as a 40-year record.

The close approximation to linearity displayed by these 40 annual maxima seems to be a strong argument for accepting line B for estimating extremes with return period of more than 40 years. The extreme gust in 1952 would then be allocated a return period of about 800 years.

(3) Sheffield. The gales of 16 February 1962 resulted in a gust of 84 knots (43 m/sec) and an hourly mean wind of 40 knots (21 m/sec) being recorded by the Sheffield anemograph. These events were fully documented by Aanensen (14). The computed straight lines fitted to all 12 years' annual maximum hourly mean winds and gusts are shown in Figure 4 (lines A). These lines, if adopted for estimating rarer extreme values, would indicate that the 16 February gust would have a return period of only 20 years, and the corresponding hourly mean wind a return period of 25 years. Practical experience of the frequency of severe wind damage in the Sheffield area must surely indicate that these estimates of return period are too low.

The second most severe gale at Sheffield in 1962 occurred on 12 February, and if the highest gust and hourly mean wind from that event are substituted for the 16 February values in Figure 4, then it can be seen that they conform to the linearity displayed by the other annual maxima (lines B). To obtain an estimate of the return period of the event of 16 February 1962 by extrapolation of lines B, we must assume that this event belongs to the same statistical population as the other recorded wind extremes. It has been shown (reference 14) that the gales on this occasion were due to a lee-wave phenomenon induced by the Pennines. However, it was also shown that the gales of 12 February 1962 were of a similar lee-wave nature, and we have seen that the latter event conforms on an extreme-value plot to the approximate linearity displayed by the other recorded extremes.

Therefore, it seems reasonable to assume that the return period of the 16 February 1962 event can be estimated by linear extrapolation on Figure 4; return periods of 75 years (gust) and 200 years (hourly mean wind) are then obtained. These values confirm Shellard's estimates made soon after the event and reported in section 10 of (14).

7. <u>Maps of extreme wind speeds.</u>

Comparison of the extreme winds at neighbouring stations often reveals inconsistencies due to siting problems, instrument defects or short periods of record. These inconsistencies can largely be resolved by mapping the estimates and drawing isopleths of wind speed giving less weight to those stations which are known or are suspected to be unreliable. For this reason and because information on wind extremes may be needed at any site in the United Kingdom, mapping appears to be the best way of presenting the information for general use.

Maps are presented here depicting:

a. the maximum gust likely to be exceeded only once on average in a period of 50 years at 10 metres over open level country (Figure 5)

b. the maximum hourly mean wind likely to be exceeded only once on average in a period of 50 years at 10 metres over open level country (Figure 6).

Maximum gust speeds are not greatly affected by surface roughness, but hourly mean wind speeds are reduced as surface roughness increases. The ratio of 50-year gust speed to 50-year hourly mean wind speed averages about 1.5 in open level country (see section 8), and this "gust ratio" has been used in the preparation of map (b).

The method of construction of the maps was as follows. Appropriate values from Tables 2 and 3 were plotted on two maps. The values plotted on map (a) were divided by 1.5 and the derived values were then also plotted on map (b). At any station where the derived value was greater than the hourly mean speed obtained from Table 2 or 3, it was adopted as the guide for isopleth drawing.

Because of the sparseness of the anemograph network, in the positioning of the isopleths between station values the meteorologist must incorporate into his analysis knowledge of the variations of wind in space and time. Thus since the final product is a somewhat subjective assessment of the values shown in

Tables 2 and 3, when using the maps it is important to note that

(1) the values arise from statistical calculations, the results of which could have appreciable standard errors (see section 6a above)

(2) subjective smoothing and interpolation have been used in the construction of the isopleths

(3) assumptions regarding the variation of strong winds with height and surface roughness have been made.

Figure 5 is an updated version of Figure 1 in reference (15), and for the estimation of design wind speeds should be used as recommended in that publication.

The maps refer to "open level country", and in some regions of the UK, this concept is not easy to reconcile with the actual local terrain. However, at a particular spot, a value interpolated from one of the maps should be taken as referring to an open level area, 300 m or so in radius, at a height above sea level equal to the general terrain level. The effects of major topographical features at greater distances from the site can be considered to have been incorporated in a general way in the drawing of the maps, but if a particular site departs appreciably from the general terrain level, then a correction should be applied to the map value as indicated in sections 10, 11.

During the preparation of Figure 6 in the manner described above, it became obvious that, in areas where the "open level country" concept is far removed from reality, there was a considerable discrepancy between the final values indicated by the isopleths and the 50-year hourly mean winds computed from observations in valleys. In other words, even in open valleys which were wide enough for the 300 m criterion to hold, the gust ratio was appreciably higher than 1.5. This was very noticeable in the Grampians, and would presumably apply to other mountainous areas of considerable spatial extent, such as the Pennines and the Welsh Mountains.

It is appreciated that for some applications, an estimate of the "open level country" hourly mean wind is not particularly relevant in mountainous terrain. Therefore, Figure 7 is presented, which is based more strictly on hourly mean winds as plotted at valley sites in mountainous areas. The gust ratio at these sites is assumed to be about 1.7. The isopleths over these areas (Scottish Highlands, Southern Uplands, Northern Pennines and Welsh Mountains) can be taken as representing once in 50 year hourly mean winds at valley sites below about 250 m amsl. Very sheltered valleys will require special consideration - see section 11.

For other areas of the country where the assumption of 1.5 for the gust ratio is not truly valid (eg large urban areas like London), no similar action has been taken, since it is considered that urban roughness can be of a very localised nature varying significantly within a mile or so. Variation of hourly mean wind over this sort of space scale could obviously not be represented adequately on a map of the scale of Figure 7.

Figure 7 is therefore described as the "open country" hourly mean wind map.

8. Effect of surface roughness on gust/mean wind ratio

Shellard (1) suggested that a measure of surface roughness could be obtained from the ratio of the extreme gust speed to the extreme hourly mean wind speed, both having a return period of 50 years. Using the results shown in Table 2, these ratios have been computed for all stations with 10 years or more of data.

Each of these stations has been classified subjectively according to the type of terrain surrounding the anemograph site. The categories used were:

Terrain 1: Open level country with no shelter (eg flat coastal areas, fens, airfields, open moorland)

Terrain 2: Flat or undulating country with small obstructions such as hedges, scattered trees, occasional buildings

Terrain 3: Areas with numerous large obstructions such as well-wooded parkland, small towns and open suburbs

Terrain 4: Centres of large towns and cities.

Table 5 shows the average, highest and lowest ratios obtained for each terrain class.

Table 5. Distribution of gust/mean wind ratios with terrain class

Terrain class	No of stations	Average ratio	Highest ratio	Lowest ratio
1	24	1.56	1.75	1.38
2	43	1.64	1.91	1.42
3	16	1.81	2.17	1.63
4	6	2.13	2.40	1.88

All stations in Table 2 except Rothamsted and Coryton have been used in the preparation of Table 5. Both these stations displayed ratios which were much higher than would be expected from their terrain types.

It is suggested that for building design purposes, the gust/hourly mean wind ratios be taken as 1.5, 1.7, 1.9, 2.1 for the 4 terrain types defined above.

9. Estimation of speeds averaged over short periods of time

Durst (6) has analysed open scale recordings of wind at 15 metres above ground at Cardington to produce estimates of the ratio of the maximum speed averaged over time t to that averaged over 1 hour. Faber and Bell (7) have prepared a similar analysis for Hong Kong and Deacon (8) used some data at Sale in Australia for the same purposes.

Deacon's data were in 4 groups:

A - open country with few trees and short vegetation

B - level or rolling country with fairly numerous hedges and scattered trees

C - country with numerous trees or buildings like the outskirts of a large city

D - similar country to C.

Measurements were made at 10 metres above ground except for case D, where 25 metres was the height adopted.

Results from the above investigations are collected in Table 6.

Table 6 Ratio of maximum speed averaged over short time periods to that averaged over 1 hour.

Author	Site	Height (metres)	1 hour	10 (minutes)	3 (minutes)	1 (minutes)	30 (seconds)	20 (seconds)	15 (seconds)	10 (seconds)	5 (seconds)	3 (seconds)	2 (seconds)	gust
Durst	Cardington	15	1.00	1.06		1.24	1.33	1.36		1.43	1.47			
Faber and Bell	Hong Kong	not known	1.00	1.05		1.28	1.42	1.50		1.64	1.72	1.81		2.05
Deacon	Sale A	10	1.00	1.06	1.14	1.25	1.31		1.37	1.43		1.51	1.54	
	Sale B	10	1.00	1.07	1.19	1.30	1.41		1.49	1.56		1.66	1.70	
	Sale C	10	1.00	1.11	1.24	1.39	1.51		1.61	1.67		1.81	1.85	
	Sale D	25	1.00	1.13	1.33	1.56	1.71		1.87	1.93		2.15	2.22	

Shellard (10) has prepared an analysis of open scale records at Goonhilly over open rolling country in Cornwall and at the Post Office Tower in Bloomsbury, London. Further analyses of the Post Office Tower data have been carried out by Helliwell (11, 12). The results are shown in Table 7, which also includes relevant information from Table 6.

Table 7 Ratio of maximum speed averaged over short time periods to that averaged over 1 minute.

Author	Site	Height (metres)	1 min	30 (seconds)	20 (seconds)	10 (seconds)	5 (seconds)	3 (seconds)	2 (seconds)	gust
Shellard	Goonhilly	10	1.00	1.05	1.08	1.12	1.16			1.21
Helliwell (revised)	Post Office Tower, London	43	1.00	1.07	1.12	1.18	1.22			1.36
		61	1.00	1.07	1.11	1.16	1.20			1.32
		195	1.00	1.04	1.06	1.09	1.11			1.17
From Table 6:										
Durst	Cardington	15	1.00	1.07	1.10	1.15	1.19			
Faber and Bell	Hong Kong	not known	1.00	1.11	1.17	1.28	1.34	1.41		1.60
Deacon	Sale A	10	1.00	1.05		1.14		1.21	1.23	
	B	10	1.00	1.08		1.20		1.28	1.31	
	C	10	1.00	1.08		1.21		1.30	1.33	
	D	25	1.00	1.10		1.24		1.38	1.42	

General rooftop level around the Post Office Tower is about 25 m and values of the ratio at about 36 m above the rooftop level do not differ greatly from the Cardington data at about 15 m above ground. The Sale A data and the Goonhilly data are similar; the ratios at 18 m above rooftop at the PO Tower are similar to the Sale B data, but at about 170 m above rooftop, ratios are smaller than at lower levels.

The "gust" ratio at Goonhilly, obtained as the ratio of the maximum gust speed recorded on the open scale recorder to the minute speed, is equal to the 3 sec Sale A ratio, and the gust ratio at 61 m at the PO Tower is similar to the 2 sec ratio from the Sale B and C data.

Table 8 summarises the above results and suggests ratios to be adopted at 10 m over the 4 broad terrain classifications given in section 8. In addition, ratios to be used at 200 m over cities are suggested.

Table 8

Terrain	t = 1 min	30 sec	20 sec	15 sec	10 sec	5 sec	gust
1	1.00	1.05	1.08	1.10	1.12	1.16	1.21
2	1.00	1.07	1.10	1.12	1.15	1.19	1.30
3	1.00	1.08	1.11	1.14	1.18	1.21	1.34
4	1.00	1.09	1.12	1.15	1.20	1.23	1.38
At 200 m over a city	1.00	1.04	1.06	1.08	1.09	1.11	1.17

Using these values, and the 50-year gust speed (from Figure 5), it is possible to estimate the maximum speed (averaged over a time interval t) which is likely to be exceeded on the average only once in 50 years.

10. Extreme winds on hill tops

Shellard (5), discussing wind speeds on hill tops, suggested that maximum wind speeds on isolated hill tops like Lowther Hill and Drum are not much different from those at the same height in the free air upwind and so could be computed from data at nearby lowland stations. Hourly mean wind speeds could apparently be estimated by applying the power law with exponent 0.17 up to a height of about 400 m and assuming that speeds do not vary with height above that level. Extreme gust speeds could best be estimated not by the use of a power law but by multiplying the predicted hourly mean speed by a factor of about 1.4.

There are now 8 years of record at Lowther Hill and 10 years at Great Dun Fell. Comparisons have been made between these stations and others in Southern Scotland and Northern England.

Table 9, column (7), shows the values which would result if the hourly mean speed at a nearby station were used to estimate the speeds on top of Great Dun Fell or Lowther Hill using a power law with exponent 0.17 up to a height of 400 m. The reference level above which the power law has been applied is the general height of the ground around the reference station concerned. For example, at Moor House, the reference level has been taken as 597 - 15 = 582 metres above MSL. The estimated 50-year hourly mean wind at Great Dun Fell is therefore given by

$$31\left(\frac{857-582}{14}\right)^{0.17}$$

Column (9) of Table 9 shows a similar set of estimates of gust speeds using an exponent of 0.085. A gust factor of 1.4 has also been applied to the estimated maximum hourly mean speeds to get a further estimate of the extreme gusts - column (10).

Table 9 - Estimates of extreme winds on exposed hill tops (metres/sec)

Station	Length of record (years)	Height of anemometer (metres): Above MSL	Above ground	Effective hgt	Once in 50 year hourly mean speed at effective height (6)	Once in 50 yr hourly mean speed at hill top site estimated using power law with exponent 0.17 up to 400 m (7)	Once in 50 year gust speed at effective height (8)	Once in 50 yr gust speed at hill top site estimated using power law with exponent 0.085 up to 400 m (9)	(7)x1.4 (10)
Great Dun Fell	10	857	10	10	50		72		70
						At Gt Dun Fell		At Great Dun Fell	
Moor House	12	597	15	14	31	51	49	63	71
Spadeadam	12	292	16	15	28	49	42	56	69
Durham	34	119	16	10	26	49	47	64	69
Sellafield	22	25	12	11	26	48	43	58	67
South Shields	38	22	17	13	28	50	43	57	70
Lowther Hill	*8	736	13	10	47		66		66
						At Lowther Hill		At Lowther Hill	
Eskdalemuir	58	259	10	10	27	50	44	60	70
Prestwick	28	21	10	10	27	50	45	61	70

*50-year extreme hourly mean wind and gust speeds estimated using Prestwick as a comparison station.

From Table 9 columns (6), (8) it can be seen that neither the hourly mean speed nor the gust speed with return period 50 years appears to be greatly affected by height above sea level if the site is not on an exposed hill top; apart from Lowther Hill and Great Dun Fell all the speeds are similar in magnitude and it could be argued that any differences arise from inaccuracies of the method of estimation rather than geographical location. This would not apply if the site were in a sheltered valley.

The Table also shows that the use of the power law expression up to 400 m above the low-level site tends to give estimates on the mountain top which for hourly mean speeds are all within 3 m/sec of the value estimated from the original records; for gust speeds the power law expression provides estimates which are lower than the value obtained from the original records, but the application of a gust factor of 1.4 to the hourly mean speeds gives estimates which are comparable. For gust speeds it is suggested that the latter method will be satisfactory for most purposes.

It should be noted that this method is not applicable if the high-level site is not fully exposed to free air winds. Thus, an attempt to estimate the extreme wind at Moor House from data at Spadeadam would yield an answer which would be too high when compared with Moor House observations. This is because Moor House, although almost 600 m above MSL, lies in a valley and cannot be considered exposed to the free air. To estimate an extreme hourly mean wind on an exposed hill top from the map (Figure 6), the power law with exponent 0.17 up to a height of 400 m should be applied to the value read from the isopleths, with the reference level for the calculation being the estimated general terrain level at the foot of the hill.

11. Extreme winds in sheltered valleys

The stations at Fort Augustus and Tummel Bridge were established in 1964 and 1965 respectively. Both are in well-sheltered positions, the first being in the Great Glen 58 m above MSL, and the second at 161 m above MSL in a deep wide valley sheltered in all directions by the Grampians. The station at Rannoch lies between the two at 307 m above MSL and in a more exposed position.

The average annual maximum values given in Tables 2, 3 can be used to estimate the sheltering effect of a deep valley.

For both Tummel Bridge and Fort Augustus, the ratio of average annual maximum hourly wind speed to the average at Rannoch is 0.70, and for gust speeds the ratio (again for both stations) is 0.83. It is suggested that these ratios represent about the maximum allowance which can be made for shelter effect. In less deep but nevertheless sheltered valleys in Wales, Northern England and Scotland, values may be nearer 0.8 and 0.9 for mean speeds and gusts, respectively.

APPENDIX: EXTREME WINDS OVER CENTRAL LONDON

A1. Sites

The longest series of measurements of wind speed and direction in Central London has been made in the Kingsway/Holborn area. The site has changed three times, as shown in Table A1.

Table A1

Site	Instrument	Period	Height of anemometer (m)		Height of general rooftop level in area (m)	Height of anemometer above general rooftop level (m)
			Above ground	Above roof		
I Victory House	D	1943-48	46	9	35	11
II Victory House	D	1949-58	49	13	35	14
III Prince's House	E	1959, 1961-64	44	12	25 (from west)	19
IV State House	E	1965-71	70	16	25	45

D = Dines' pressure tube anemograph; E = electrical cup anemograph.

Victory House (sites I, II) was on the eastern side of Kingsway, a street running approximately NNE-SSW. To the north and south, and on the western side of Kingsway, buildings rose to the same general level as Victory House, but further west the general rooftop level was lower and immediately to the east was the open square of Lincoln's Inn Fields. The two sites at Victory House differed for practical purposes only in the height of the anemograph head above the rooftop.

Prince's House (site III) was about 200 metres south of site I on the western side of Kingsway. As mentioned above, the general rooftop level to the west was lower than that along Kingsway, so the anemograph was more exposed to winds from the west. All annual maximum hourly mean winds in the period 1959-64 were from directions between 200° and 260°.

State House (site IV) is on Holborn, about 300 metres north-east of site I and the anemograph is on a 16 m mast mounted on the roof. The buildings around rise to between 15 and 30 m, with an average rooftop level of about 25 m above ground.

Before the data from the four sites can be combined for analysis, it is necessary to reduce the data to a common effective height. This is not an easy task, since the complex nature of the surrounding urban area makes the estimation of representative effective heights difficult.

A2. Allocation of effective heights

The effective heights at sites I, II and III were formerly assumed to be simply the heights of the anemometer heads above the roofs on which they were mounted. To estimate the effective height at site IV, three approaches have been adopted:

a. The anemometer cups at IV are 26 metres above the cups at III. Assuming the effective height at III to be 12 metres, the effective height at IV is 26 + 12 = 38 metres.

b. During the period Jan-June 1965, data at both sites III and IV were obtained. Mean wind speeds at IV were about 1.25 times those at III. Using the power law with exponent 0.20 for mean wind speeds (as indicated by evidence in references 10, 12), and again assuming the effective height at III to be 12 metres, an effective height of 39 metres at IV was derived.

c. From Post Office Tower experiments reported in (12), it has been shown that the power law can best be fitted to observational data if the concept of a "zero plane" is adopted above which the power law should be applied. For 5-minute mean wind speeds, it appeared that the zero plane should be positioned approximately 7 metres above the general rooftop level. This concept should be considered purely as a mathematical convenience for extrapolation to greater heights, since the power law so applied will obviously not give physically realistic wind speeds in the layer immediately above rooftop level. Applying the zero plane concept to sites III and IV, the effective heights above zero plane work out to be 19 - 7 = 12 metres at III, and 45 - 7 = 38 metres at IV (ie in very good agreement with estimates derived by methods a. and b.).

If the zero plane concept is also applied to sites I and II, effective heights of 4 and 7 metres respectively are obtained.

A3. Consistency of data

Table A2 shows the average annual maximum hourly mean wind speeds for the 4 sites, as recorded and as reduced to a common height of 10 m above zero plane using the power law with exponent 0.2.

Table A2

Site (1)	No. of years' data (2)	Estimated effective height (m) above zero plane (3)	Average annual max hourly mean wind speed as recorded (m/sec) (4)	Values in column 4 reduced to 10m above zero plane (5)	Average annual max hourly mean wind speed at Kew at 10m (m/sec) (6)	(5)÷(6) (7)
I	5	4(9)	13.4	16.2(13.7)	13.4	1.21(1.02)
II	10	7(13)	12.6	13.5(12.0)	12.7	1.06(0.95)
III	5	12	13.3	12.8	13.4	0.95
IV	7	38	15.0	11.5	12.5	0.92

Also shown are values at Kew for the same periods of record. It can be seen that although the relationship between Kew and Central London seems reasonably consistent for the two later periods III and IV, the two earlier periods display no such consistency. Thus it is evident that the same considerations for allocation of effective height cannot be applied to sites I and II as have been applied to sites III and IV. Indeed, the correspondence between the figures in columns (4) and (6) of Table A2 suggests that the effective heights at I and II should be close to the 12 m allocated to site III.

Thus, it would appear reasonable to take the originally-estimated effective heights of 9 m and 13 m at sites I and II (ie simply the heights of the anemometers above the roofs upon which they were mounted) despite the fact that this does not agree with the zero plane concept.

The bracketed figures in Table A2 show the results of taking different effective heights at I and II,and it can be seen that a better consistency is achieved in column (7).

A4. Conclusions

Due to difficulties in reconciling data from sites I and II with those from sites III and IV, extreme value analyses have been performed both on the whole period of record (data for sites I, II, III and IV - bracketed values in Table A3) and on the later part of the record only (data for sites III and IV - unbracketed values in Table A3).

It is recommended that, until a homogeneous record of 10 years becomes available at State House, the larger values in Table A3 be used for design purposes in Central London. These values should be assumed to apply at 10 m above the zero plane. For extrapolation to heights up to about 200 m, the power law with exponents 0.20 (for hourly mean winds) and 0.085 (for gusts) may be used, using as a reference level a zero plane which, according to currently-available evidence, should be assumed to lie about 7 m above general rooftop level.

Table A3

	Average annual maximum	Return period (years) 10	20	50	100	120
Hourly mean wind speed (m/sec)	12.0(12.3)	14(15)	15(16)	16(17)	16(18)	17(18)
Gust speed (m/sec)	26.5(26.2)	31(31)	33(34)	35(37)	36(39)	37(40)

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Table 1 ANEMOGRAPH STATION DETAILS

STATION	N.G.R.	HEIGHT OF ANEMOMETER ABOVE MEAN SEA LEVEL (metres)	HEIGHT OF ANEMOMETER ABOVE GROUND (metres)	EFFECTIVE HEIGHT (metres)	NUMBER OF YEARS (C=station) (now closed)	PERIOD OF RECORD	HIGHEST GUST (m/sec)	MONTH(S) OF OCCURRENCE	HIGHEST HOURLY MEAN WIND (m/sec)	MONTH(S) OF OCCURRENCE
Lerwick	HJ(411)453397	93	10	10	41	1931-71	49	Jan 1961	32	Jan 1953, Jan 1961
Kirkwall (Bignold Park)	HY(310)454103	52	12	11	14C	1930-43	45	Jan 1938	27	Jan 1938
Kirkwall	HY(310)483076	41	15	10	15	1957-71	61	Feb 1969	30	Jan 1961
Dounreay	NC (29)991674	34	12	9	13	1959-71	>50	Sep 1969	36	Sep 1969
Wick	ND (39)363524	45	10	10	7	1965-71	46	Sep 1969	30	Sep 1969
Halkirk	ND (39)091527	83	12	12	4C	1959-62	41	Feb 1962	26	Sep 1961
Butt of Lewis	NB (19)516665	52	12	11	6C	1930-35	45	Jan 1935	29	Jan 1934
Shin	NH (28)573974	24	10	10	9	1963-71	40	Sep 1969	25	Sep 1969
Stornoway Airport	NB (19)459332	12	10	10	4	1968-71	40	Sep 1969	28	Sep 1969
Stornoway CG	NB (19)443305	37	12	11	33C	1937-69	50	Feb 1962	35	Jan 1968
Duirinish	NG (18)777316	38	20	17	13	1959-71	44	Sep 1961	28	Apr 1960, Sep 1961
Benbecula	NF (08)784555	16	10	10	15	1957-71	49	Feb 1957	30	Dec 1961
Corpach	NN (27)081764	23	15	12	5	1967-71	>47	Jan 1968	30	Jan 1968
Fort Augustus	NH (28)356085	58	16	16	8	1964-71	31	Feb 1967	19	Jan 1968
Dalcross	NH (28)771521	19	10	10	4	1968-71	31	Oct 1970	20	Sep 1969
Cairngorm	NJ (38)005049	1075	10	10	5	1967-71	64	Mar 1967	34	Oct 1971
Kinloss	NJ (38)067627	18	13	13	8	1964-71	41	Sep 1969	26	Sep 1969
Lossiemouth	NJ (38)213699	31	24	18	11	1961-71	47	Feb 1961	33	Feb 1961
Dyce	NJ (38)878124	72	10	10	20	1952-71	45	Jan 1953	28	Jan 1953
Aberdeen	NJ (38)939084	37	12	10	15C	1933-47	37	Feb 1943	20	Feb 1935
Balmakewan	NO (37)664677	43	8	6	21C	1915-35	38	Dec 1920	21	Dec 1920
Bell Rock	NO (37)763272	39	40	38	41	1930-55,57-71	49	Jan 1968	33	Dec 1951
Rannoch	NN (27)423578	307	17	17	13	1959-71	>48	Jan 1968	32	Jan 1968
Tummel Bridge	NN (27)772590	161	16	16	7	1965-71	36	Jan 1968	21	Jan 1968
Auchterhouse	NO (37)347390	251	19	15	5C	1960-64	33	Feb 1962	22	Feb 1962
Leuchars	NO (37)457202	25	13	13	23	1949-71	47	Jan 1968	29	Jan 1968
Turnhouse	NT (36)151737	43	13	10	10	1962-71	46	Jan 1968	32	Jan 1968
Blackford Hill	NT (36)258706	148	12	7	50C	1915-33,36-66	45	Dec 1964	31	Dec 1964
Tiree	NL (07)999446	24	16	12	45	1927-71	53	Jan 1968	34	Jan 1968
Cumbernauld	NN (27)755760	166	10	10	5	1966-67,69-71	39	Sep 1968	22	Sep 1969
Paisley	NS (26)478642	57	25	9	58	1914-71	46	Jan 1927	21	Feb 1957
Renfrew	NS (26)513663	22	13	11	20C	1946-65	43	Jan 1954	24	Dec 1951
Abbotsinch	NS (26)478667	16	10	10	5	1967-71	46	Jan 1968	27	Jan 1968
Millport	NS (26)175544	15	10	10	14C	1950-63	48	Dec 1951	26	Jan 1958, Jan 1963
Hunterston	NS (26)180515	13	10	10	7	1963-68,71	43	Jan 1968	25	Jan 1968
Prestwick	NS (26)364266	21	10	10	28	1944-71	46	Jan 1968	25	Jan 1958
Lowther Hill	NS (26)890107	736	13	10	8C	1961-68	56	Jan 1968	44	Jan 1963

Table 1 (continued)

STATION	N.G.R.	HEIGHT OF ANEMOMETER ABOVE MEAN SEA LEVEL (metres)	HEIGHT OF ANEMOMETER ABOVE GROUND (metres)	EFFECTIVE HEIGHT (metres)	NUMBER OF YEARS (C=station now closed)	PERIOD OF RECORD	HIGHEST GUST (m/sec)	MONTH(S) OF OCCURRENCE	HIGHEST HOURLY MEAN WIND (m/sec)	MONTH(S) OF OCCURRENCE
Eskdalemuir	NT(36)233029	259	10	10	48	1914-45,56-71	45	Jan 1968	26	Jan 1930
West Freugh	NX(25)114542	25	10	10	10	1962-71	42	Dec 1962	28	Dec 1962
Ronaldsway	SC(24)279688	25	10	10	11	1961-71	44	Dec 1966	28	Dec 1964
Point of Ayre	NX(25)464049	20	10	10	35	1936-71	40	Dec 1936,Dec 1966	29	Sep 1945
Durham	NZ(45)267416	119	16	10	34	1938-71	46	Jan 1968	24	Nov 1970
South Shields	NZ(45)373677	22	17	13	38	1934-71	39	Apr 1943,Jan 1945	29	Jan 1945
Catterick	SE(44)249970	67	14	10	10C	1933-42	39	Jan 1936	22	Jan 1936
Leeming	SE(44)305890	42	10	10	6	1966-71	36	Jan 1968	23	Mar 1967
Middlesbrough	NZ(45)541232	23	19	19	4	1968-71	37	Jan 1968	22	Mar 1968
Spurn Head	TA(54)405115	20	13	10	32C	1922-46,48-50,54, 56-58	41	Apr 1943	26	Jan 1928
Cranwell	TF(53)003494	68	13	13	42	1928-44,46-48, 50-71	49	Dec 1952	22	Apr 1943, Mar,Apr 1947
Binbrook	TF(53)196958	118	10	10	5	1967-71	33	Feb 1967,Mar 1968	22	Mar 1968
Manby	TF(53)387864	26	10	10	6	1966-71	30	Mar 1968	19	Mar 1968
Marham	TF(53)726094	29	10	10	4	1968-71	31	Mar 1968	15	Nov 1970
Coltishall	TG(63)262229	27	10	10	4	1968-71	31	Apr 1969	18	Jan 1968
Gorleston	TG(63)534037	16	13	13	45	1913-31,34-39,41-48, 51-57,63,65,68,70-71	38	Mar 1947	27	Mar 1948
Mildenhall	TL(52)683779	30	25	18	32C	1938-69	44	Mar 1947	28	Mar 1947
Bedford	TL(52)049597	94	13	9	9	1963-71	30	Mar 1968	19	Mar 1966
Cardington	TL(52)081463	69	41	41	40	1932-71	42	Mar 1947	28	Mar 1947,Nov 1947
Garston	TL(52)123017	94	15	10	10	1962-71	29	Jan 1965	16	Dec 1966
Rothamsted	TL(52)132134	141	13	10	17	1955-71	32	Nov 1957	13	Nov 1957,Mar 1968
Stansted	TL(52)531226	108	10	10	9	1963-71	29	Mar 1966	18	Jan 1965
Stanstead Abbots	TL(52)389100	42	13	12	5C	1958-62	28	Jan 1958	14	Dec 1960
Felixstowe	TM(62)286328	26	23	20	22C	1931-35,37-38,44-52	40	Feb 1938	23	Nov 1952
Stevenage	TL(52)257257	146	12	10	10C	1950-59	33	Nov 1957	17	Nov 1957
Dunstable	TL(52)006218	173	17	10	14C	1944-48,51-59	37	Mar 1947	21	Mar 1947
Amersham	SU(41)995975	152	15	15	8C	1961-68	31	Jan 1962	15	Jan 1962,Dec 1966 Feb,Sep 1967
Shoeburyness	TQ(51)948857	36	32	28	46	1926-71	39	Jan 1962	28	Jan 1962
Sheffield	SK(43)339873	162	25	11	12	1959-66,68-71	43	Feb 1962	21	Feb 1962
Church Fenton	SE(44)528380	18	10	10	4	1968-71	35	Jan 1968	23	Jan 1968
Finningley	SK(43)658995	19	10	10	4	1968-71	31	Jan,Mar 1968	21	Mar 1968
Cottesmore	SK(43)909154	143	10	10	4	1968-71	30	Jan,Mar 1968	19	Jan 1968
Leicester	SK(43)623042	117	18	10	10C	1938-40,43-45,47-50	38	Mar 1947	19	Mar 1947
Edgbaston	SP(42)046864	196	36	22	48	1924-71	38	Nov 1938	20	Mar 1947,Nov 1954
Elmdon	SP(42)171837	105	10	10	11	1961-71	33	Feb 1962	21	Feb 1962

Table 1 (continued)

STATION	N.G.R.	HEIGHT OF ANEMOMETER ABOVE MEAN SEA LEVEL (metres)	HEIGHT OF ANEMOMETER ABOVE GROUND (metres)	EFFECTIVE HEIGHT (metres)	NUMBER OF YEARS (C=station now closed)	PERIOD OF RECORD	HIGHEST GUST (m/sec)	MONTH(S) OF OCCURRENCE	HIGHEST HOURLY MEAN WIND (m/sec)	MONTH(S) OF OCCURRENCE
Keele	SJ(33)820446	215	15	10	19	1953-71	38	Jan 1953	17	Nov 1954
Pershore	SO(32)973495	47	10	10	8	1964-71	35	Nov 1965	20	Mar 1966
Avonmouth	ST(31)505787	28	19	10	17	1953-66,69-71	38	Jan 1962,Nov 1963	23	Jan 1962
Southgate	TQ(51)299952	252	30	-	25C	1939-41,45-66	27	Apr 1947	13	Jan 1946,Mar 1947 Nov 1957
Kingsway	TQ(51)307811	63	44	13	21C	1944-64	36	Mar 1947	16	Dec 1962
South Kensington	TQ(51)260796	42	34	9	8C	1931-38	32	Nov 1938	14	Nov 1938
London Wea. Cen.	TQ(51)308816	70	16	38	7	1965-71	33	Dec 1965	17	Mar 1966
Heathrow	TQ(51)077769	34	10	10	12	1960-71	31	Nov 1963	19	Jan 1962
Hampton	TQ(51)132694	42	31	30	21	1951-71	34	Dec 1959,Nov 1969	19	Jan 1962
Kew	TQ(51)171757	28	23	15	41	1931-71	32	Nov 1938,Mar 1947	18	Jan 1962
Croydon	TQ(51)312637	95	32	21	27C	1928-39,44-58	36	Nov 1928	23	Jan 1930
Gatwick	TQ(51)265407	69	10	10	12	1960-71	36	Jan 1962,Mar 1966	19	Jan 1962,Mar 1966
Coryton	TQ(51)746823	20	17	15	10C	1959-68	32	Oct 1967	16	Oct 1967
Isle of Grain	TQ(51)879749	15	12	10	14	1956-69	32	Jul 1956,Nov 1957	20	Jan 1963
Dover	TR(61)320410	21	12	19	36	1924-39,48-50, 53-64,66-70	41	Nov 1957	26	Dec 1966
Lympne	TR(61)111352	127	23	15	29C	1923-29,31-43,45-53	39	Jan 1949	25	Nov 1928
Rye	TQ(51)966225	16	13	10	8C	1945-52	37	Feb 1951	23	Feb,Mar 1951
Manston	TR(61)335666	62	18	18	18	1943-55,67-71	37	Jan,Oct 1949	22	Mar 1951
Thorney Island	SU(41)756027	16	10	10	29	1943-71	37	Nov 1954	21	Oct 1967
Abingdon	SU(41)482990	90	12	12	25	1944-45,49-71	35	Dec 1956	19	Jan 1962
Hurn	SZ(40)117978	23	13	11	12	1960-71	32	Jan 1962	20	Jan 1962
Calshot I	SU(41)488024	18	15	13	24C	1920,22-41,50-52	39	June 1938	23	June 1938
Calshot II	SU(41)486018	15	13	10	13	1959-71	31	Oct 1967	20	Jan 1962,Dec 1966, Feb 1967,Feb 1970
South Farnborough	SU(41)867548	97	21	11	24C	1945-68	36	Mar 1947	22	Jan 1946,Mar 1947
Larkhill	SU(41)137447	145	13	10	40	1931-65,67-71	36	Feb 1967,Dec 1971	21	Sep 1935,Jan 1943
Boscombe Down	SU(41)172403	130	16	16	39	1933-71	41	Mar 1947	24	Jan 1943
Porton	SU(41)210366	120	10	10	18	1954-71	33	Nov 1969	20	Mar 1966
Sellafield	NY(35)027032	25	12	11	22	1950-71	39	Dec 1952	23	Jan 1965
Carlisle	NY(35)384603	41	13	9	11	1961-71	41	Jan 1965	25	Jan 1968
Spadeadam	NY(35)599720	292	16	15	12	1960-71	40	Jan 1965	25	Jan 1965
Gt Dun Fell	NY(35)710322	857	10	10	10	1962-71	60	Jan 1968	44	Jan 1968
Moor House	NY(35)758328	597	15	14	14	1956-71	42	Jan 1968	26	Dec 1967
Squires Gate	SD(34)316317	26	6	11	9	1963-71	39	Jan 1965,Dec 1966	27	Dec 1966
Aigburth	SJ(33)385855	38	23	11	4	1968-71	34	Jan 1968	21	Jan 1968
Southport	SD(34)357199	19	14	11	57	1913-54,57-71	39	Oct 1927	28	Oct 1927
Fleetwood	SD(34)333482	34	15	9	44	1924-43,46-57, [illegible]	41	Dec 1952	27	Apr 1925

Table 1 (continued)

STATION	N.G.R. (*Irish Grid) (†U.T.M. Grid)	HEIGHT OF ANEMOMETER ABOVE MEAN SEA LEVEL (metres)	HEIGHT OF ANEMOMETER ABOVE GROUND (metres)	EFFECTIVE HEIGHT (metres)	NUMBER OF YEARS (C=station now closed)	PERIOD OF RECORD	HIGHEST GUST (m/sec)	MONTH(S) OF OCCURRENCE	HIGHEST HOURLY MEAN WIND (m/sec)	MONTH(S) OCCURRENCE
Speke	SJ(33)415839	30	10	10	23	1948-50,52-71	40	Mar 1966	23	Nov 1960
Manchester Weather Centre	SJ(33)839985	82	45	17	11	1961-71	41	Jan 1968	19	Mar 1966
Manchester (Barton)	SJ(33)746967	47	25	24	8C	1934-41	41	Oct 1938	25	Oct 1938
Bidston	SJ(33)287897	80	20	12	42C	1929-70	45	Jan 1938	29	Oct 1938
Ringway	SJ(33)818350	80	10	10	27	1942-50,54-71	39	Apr 1943	24	Apr 1943
Holyhead	SH(23)252831	21	13	11	19C	1933-51	48	Feb 1937	29	Oct 1938
Valley	SH(23)310758	26	16	12	20	1952-71	43	Jan 1965	29	Dec 1966
Trawsfynydd	SH(23)691388	194	10	10	4	1967-68,70-71	35	Feb 1970	20	Feb 1970
Sealand	SJ(33)335695	25	20	13	19C	1928-41,43-47	39	Nov 1928	25	Nov 1928
Aberporth	SN(22)242521	147	12	12	25C	1945-69	42	Nov 1954	27	Dec 1966
Kete	SM(12)801044	76	15	11	4C	1952,54-56	49	Nov 1954	29	Nov 1954
St Anns Head	SM(12)807031	65	21	65	14C	1935-46,48-49	>51	Jan 1945	36	Nov 1938
Milford Haven I	SM(12)907069	75	15	11	12C	1951-62	43	Nov 1954	23	Nov 1954
Milford Haven II	SM(12)892054	47	10	10	7	1965-71	38	Sep 1965,Dec 1966	23	Dec 1966,Sep 1957
Port Talbot	SS(21)789867	28	10	11	20	1952-71	37	Jan 1962	24	Dec 1957,Jan 1962
Rhoose	ST(31)060670	77	10	10	12	1960-71	38	Nov 1963	22	Jan 1962
Winfrith	SY(30)820870	49	15	11	4C	1960-63	31	Jan 1962	20	Jan 1962
Portland Bill	SY(30)677684	58	47	47	6C	1963-68	46	Jan 1966	33	Oct 1967
Plymouth Hoe	SX(20)478537	58	27	20	41C	1921-43,47-48,50-65	43	Mar 1922	29	Dec 1929
Mount Batten	SX(20)492527	64	13	13	7	1965-71	35	Jan 1965	24	Dec 1966
Chivenor	SS(21)494347	22	16	13	4	1968-71	31	Jan 1969	20	Jan 1969
Scilly	SV(00)913121	70	20	17	45	1927-71	49	Dec 1929	31	Sep 1946,Nov 1954
Lizard	SW(10)701119	96	23	18	34	1935-42,45-47,49-71	44	Nov 1954	33	Nov 1954
St Mawgan	SW(10)871642	120	13	13	5	1967-71	32	Nov 1969	21	Nov 1969
Pendennis	SW(10)824318	78	20	78	20C	1929-38,41-50	46	Feb 1950	31	Dec 1929
Ballykelly	IC(24)627238*	16	15	11	13C	1958-70	47	Sep 1961	27	Feb 1963
Aldergrove	IJ(33)147798*	80	10	10	43	1927-46,49-71	39	Nov 1928	23	Sep 1961
Nutts Corner	IJ(33)193776*	105	9	9	5C	1958-62	41	Oct 1959	23	Oct 1959
Ballypatrick Forest	IJ(33)176387*	166	13	13	4	1968-71	42	Jan 1968	27	Jan 1968
Belfast Harbour	IJ(33)353777*	21	18	18	6	1966-71	36	Dec 1966	24	Dec 1966
Kilkeel	IJ(33)315140*	35	18	14	8	1964-71	40	Jan 1965,Dec 1966	25	Dec 1966
Orlock Head	IJ(33)559833*	51	16	12	4	1968-71	41	Jan 1968	25	Jan 1968
Portadown	IJ(33)019555*	26	10	10	4	1967-70	28	Jan 1968	15	Jan 1968
Carrigans	IH(23)[illegible]34310*	129	10	10	7	1965-71	42	Nov 1965	23	Jan 1965
Castle Archdale For.	IH(23)1[illegible]9593*	80	13	13	8	1964-71	40	Jan 1968	22	Nov 1965
Jersey	[illegible]+	93	18	12	14	1958-71	48	Oct 1964	35	Oct 1964

Table 2 ESTIMATED EXTREME VALUES AT STATIONS WITH 10 OR MORE YEARS OF DATA

STATION	Maximum Hourly Mean Wind Speeds (m/s) At 10m above the Ground: Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years: 10	20	50	100	120	Maximum Gust Speeds (m/s) At 10m above the Ground: Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years: 10	20	50	100	120
Lerwick	26.0	32	34	37	39	40	39.4	47	50	54	56	57
Kirkwall (Bignold Park)	22.4	26	27	29	31	32	36.7	41	43	46	48	49
Kirkwall*	25.2	30	32	34	36	37	40.4	48	51	55	58	59
Dounreay	25.9	32	35	39	41	42	39.9	50	54	60	64	65
Stornoway CG	26.8	32	34	36	38	39	40.2	48	51	55	58	59
Duirinish	21.3	26	28	31	33	34	35.6	42	44	47	50	51
Benbecula	25.2	30	31	34	35	36	39.5	47	50	54	56	57
Lossiemouth	21.8	28	30	34	37	38	34.0	42	47	52	56	57
Dyce	19.5	24	25	28	29	30	32.1	40	43	47	50	51
Aberdeen	15.9	20	21	23	25	26	30.3	35	37	40	42	43
Balmakewan	16.5	20	22	24	25	26	28.1	35	37	40	43	44
Bell Rock	21.7	25	26	28	29	30	33.9	40	42	45	47	48
Rannoch	21.1	24	26	28	30	31	34.4	43	47	52	56	58
Leuchars	20.3	24	25	27	29	30	32.0	39	43	47	50	51
Turnhouse	21.8	29	32	36	39	40	36.3	44	47	51	54	55
Blackford Hill	22.7	26	28	30	31	32	39.2	44	46	49	51	52
Tiree	23.9	29	31	34	36	37	37.2	45	49	53	57	58
Paisley	16.1	18	20	21	22	23	33.1	39	41	44	46	47
Renfrew/Abbotsinch ***	18.9	23	25	27	29	30	33.9	42	45	49	52	53
Millport	21.5	26	28	31	33	34	35.5	44	47	52	55	56
Prestwick	19.5	23	25	27	28	29	32.7	40	43	47	50	51
Eskdalemuir	20.2	23	25	27	28	29	33.6	39	41	44	46	47
West Freugh	22.1	28	30	32	34	35	34.7	42	45	49	51	52
Ronaldsway	24.3	29	31	34	36	37	36.0	42	44	47	48	49
Point of Ayre	22.2	26	27	29	31	32	34.3	39	41	44	46	47
Durham	18.9	22	24	26	27	28	35.2	41	44	47	50	51
South Shields	19.3	23	25	27	28	29	30.6	36	39	42	44	45
Catterick	17.3	22	24	27	29	30	31.8	38	41	44	47	48
Spurn Head	22.3	25	26	27	28	29	32.7	38	40	43	45	46
Cranwell *	17.1	20	22	23	25	26	28.9	34	36	39	41	42
Gorleston	19.6	22	24	25	26	27	29.5	34	36	38	40	41
Mildenhall	16.4	20	22	24	25	26	30.9	37	40	43	46	47
Cardington	16.4	20	21	23	25	26	28.4	34	36	39	41	42

Footnotes:

* Max observed gust omitted from calculations (see text)

*** Renfrew and Abbotsinch records considered homogeneous and so combined

Table 2 (cont.) ESTIMATED EXTREME VALUES AT STATIONS WITH 10 OR MORE YEARS OF DATA

STATION	Maximum Hourly Mean Wind Speeds (m/s) At 10m above the Ground						Maximum Gust Speeds (m/s) At 10m above the Ground					
	Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years					Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years				
		10	20	50	100	120		10	20	50	100	120
Felixstowe	17.4	20	21	23	24	25	29.7	36	38	42	44	45
Stevenage	15.2	18	19	21	22	23	28.3	34	36	39	41	42
Dunstable	16.7	21	22	24	25	26	27.8	35	38	43	46	47
Garston	12.8	16	17	19	20	21	25.1	29	31	33	35	36
Rothamsted	11.9	14	14	15	16	17	26.6	30	31	33	34	35
Shoeburyness	18.2	21	23	25	26	27	29.0	34	36	38	40	41
Sheffield **	12.6	15	17	18	19	20	30.0	36	38	42	44	45
Leicester	14.8	20	22	25	27	28	29.1	37	41	45	48	49
Edgbaston	13.5	16	17	19	20	21	27.3	32	35	37	39	40
Elmdon	17.0	20	21	23	24	25	30.3	34	36	38	39	40
Keele	14.2	16	17	18	19	20	29.4	34	37	39	41	42
Avonmouth	19.9	23	24	26	27	28	30.3	36	38	41	43	44
Southgate	12.2	14	15	16	17	18	24.2	27	29	30	31	32
Heathrow	16.6	19	19	20	21	22	27.8	32	33	35	37	38
Hampton	12.9	15	16	17	18	19	26.6	31	33	35	37	38
Kew	12.9	15	16	16	17	18	27.2	31	32	34	36	37
Croydon	15.5	18	19	21	22	23	28.6	33	35	37	39	40
Gatwick	16.5	20	21	22	24	25	30.1	36	39	42	45	46
Coryton	13.8	16	16	17	18	19	27.5	30	32	33	34	35
Isle of Grain	16.3	19	21	22	24	25	27.8	33	35	37	39	40
Dover	17.3	20	21	22	24	25	29.5	35	38	41	43	44
Lympne	18.8	21	22	24	25	26	31.2	36	38	41	43	44
Manston	17.7	20	21	23	24	25	30.4	35	36	39	40	41
Thorney Island	16.2	19	20	22	23	24	29.1	34	36	39	41	42
Abingdon	14.5	17	18	19	20	21	26.1	31	33	36	38	39
Hurn	15.6	18	19	20	21	22	27.0	31	33	35	37	38
Calshot I	19.2	22	24	26	27	28	30.1	36	38	41	43	44
Calshot II	18.1	20	21	22	23	24	27.1	31	33	35	36	37
South Farnborough	16.4	20	22	24	25	26	29.5	34	35	38	39	40
Larkhill	17.4	20	21	22	23	24	31.4	35	37	39	41	42
Boscombe Down	17.6	21	22	24	25	26	29.2	34	37	39	41	42
[illegible]	17.7	20	20	21	22	23	28.7	33	34	36	38	39
[illegible]	19.2	23	24	26	27	28	30.9	37	39	42	45	46

** Max observed hourly mean wind & max observed gust omitted from calculations (see text)

Table 2 (contd) ESTIMATED EXTREME VALUES AT STATIONS WITH 10 OR MORE YEARS OF DATA

STATION	Maximum Hourly Mean Wind Speeds (m/s) At 10m above the Ground						Maximum Gust Speeds (m/s) At 10m above the Ground					
	Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years					Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years				
		10	20	50	100	120		10	20	50	100	120
Carlisle	19.5	25	27	30	33	34	31.8	40	44	48	51	52
Spadeadam	19.5	23	25	27	28	29	32.6	37	39	42	44	45
Gt. Dun Fell	34.0	42	45	50	53	54	44.9	59	65	72	78	79
Moor House	22.1	26	27	29	30	31	34.9	41	44	43	50	51
Southport	22.3	26	28	30	31	32	33.5	39	41	44	46	47
Fleetwood	22.9	27	29	31	33	34	34.1	39	42	44	47	48
Speke	19.6	22	24	25	26	27	32.7	39	41	45	47	48
Manchester Weather Centre	14.9	19	20	22	23	24	32.4	40	42	46	49	50
Bidston	20.7	25	26	28	30	31	36.1	42	44	47	50	51
Ringway	18.4	22	24	26	28	29	30.8	36	39	43	46	47
Holyhead	23.1	27	28	30	32	33	35.4	40	43	46	48	49
Valley	23.6	28	29	31	33	34	35.5	41	44	47	49	50
Sealand	18.5	22	23	25	26	27	31.6	37	39	42	45	46
Aberporth	21.2	25	27	29	30	31	33.4	39	41	44	47	48
St Ann's Head	20.4	26	28	31	33	34	36.1	43	46	50	52	53
Milford Haven I	19.5	23	24	25	27	28	33.1	39	42	45	47	48
Port Talbot	19.3	23	25	27	29	30	31.9	37	39	41	43	44
Rhoose	19.3	23	24	26	28	29	30.8	37	40	43	45	46
Plymouth Hoe	20.4	24	25	27	28	29	29.8	35	37	40	42	43
Scilly	23.2	27	29	31	33	34	37.0	42	45	48	50	51
Lizard	24.0	27	29	30	32	33	36.7	41	43	46	48	49
Pendennis	19.0	21	22	24	25	26	32.6	39	41	44	46	47
Ballykelly	21.5	27	30	33	35	36	36.0	44	48	52	56	57
Aldergrove	18.1	22	23	25	27	28	31.7	37	39	42	45	46
Jersey	23.0	28	30	33	35	36	35.6	42	45	48	50	51

Table 3 ESTIMATED EXTREME VALUES AT STATIONS WITH LESS THAN 10 YEARS DATA

STATION	COMPARISON STATION	Maximum Hourly Mean Wind Speeds (m/s) At 10m above the Ground: Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years: 10	20	50	100	120	Maximum Gust Speeds (m/s) At 10m above the Ground: Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years: 10	20	50	100	120
Wick	Dounreay	22.9	28	30	33	35	36	36.1	46	49	54	58	59
Halkirk	Lerwick	21.2	24	25	27	28	29	34.1	37	39	42	44	45
Butt of Lewis	Kirkwall	22.6	32	34	36	37	38	39.7	45	47	50	52	53
Shin	Lossiemouth	19.3	26	27	31	34	35	34.0	43	48	53	57	58
Stornoway Airport	Benbecula	25.1	32	34	37	39	40	36.3	47	49	53	56	57
Corpach	Tiree	22.9	27	30	33	34	35	38.7	46	49	53	57	58
Fort Augustus	Duirinish	15.1	20	21	23	25	26	28.4	35	37	39	41	42
Dalcross	Lossiemouth	16.1	21	23	26	28	29	26.1	34	38	42	46	47
Cairngorm	Dyce	30.7	36	39	42	45	46	55.8	66	71	76	83	85
Kinloss	Lossiemouth	21.2	28	31	35	37	38	33.2	43	47	53	57	58
Tummel Bridge	Leuchars	14.7	17	18	19	20	21	28.6	35	36	39	41	42
Auchterhouse	Leuchars	13.4	21	23	25	26	27	29.7	36	39	43	46	47
Cumbernauld	Paisley	20.1	24	25	27	28	29	32.5	41	44	47	49	50
Abbotsinch - see Renfrew in Table 2													
Hunterston	Prestwick	21.0	25	27	29	31	32	33.4	39	42	45	48	49
Lowther Hill	Eskdalemuir	35.5	40	42	45	48	49	48.7	53	56	60	63	64
Leeming	Durham	20.0	22	24	25	27	28	30.9	34	36	39	41	42
Middlesbrough	Durham	18.2	20	21	23	24	25	31.2	33	35	38	40	41
Binbrook	Cranwell	19.4	24	25	27	29	30	30.3	39	42	45	48	49
Manby	Cranwell	16.5	20	21	23	24	25	25.4	32	35	37	39	40
Marham	Cranwell	14.5	18	19	20	22	23	25.4	34	36	39	41	42
Coltishall	Cranwell	16.1	20	21	23	24	25	26.6	35	38	41	43	44
Bedford	Cardington	17.0	22	23	25	27	28	27.6	35	37	40	43	44
Stansted	Kew	15.2	18	19	20	21	22	25.9	30	31	33	35	36
Stanstead Abbotts	Kew	12.7	14	15	16	17	18	25.4	30	31	33	34	35
Amersham	Kew	12.8	14	15	16	16	17	23.7	30	31	33	35	36
Church Fenton	Durham	19.2	21	23	24	26	27	30.7	33	35	37	39	40
Finningley	Cranwell	17.9	22	23	25	26	27	27.3	36	39	42	44	45
Cottesmore	Cranwell	17.2	20	21	23	24	25	27.4	35	38	41	43	44
Pershore	Edgbaston	17.3	23	25	27	28	29	29.1	39	41	45	47	48
South Kensington	Kew	12.0	13	14	15	16	17	27.9	31	33	35	36	37

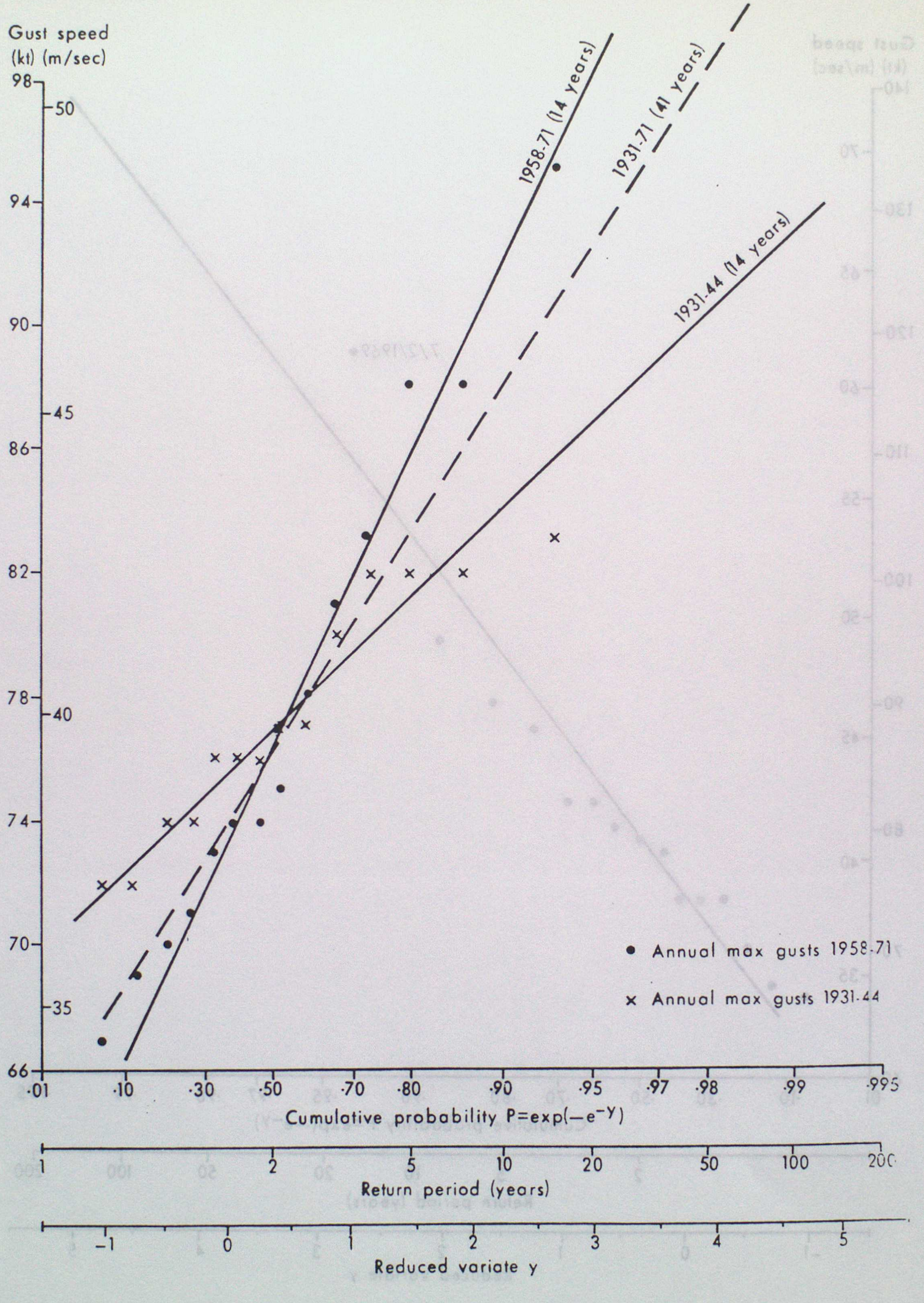

Figure 1 Annual maximum gust speeds at 11·9 metres. LERWICK

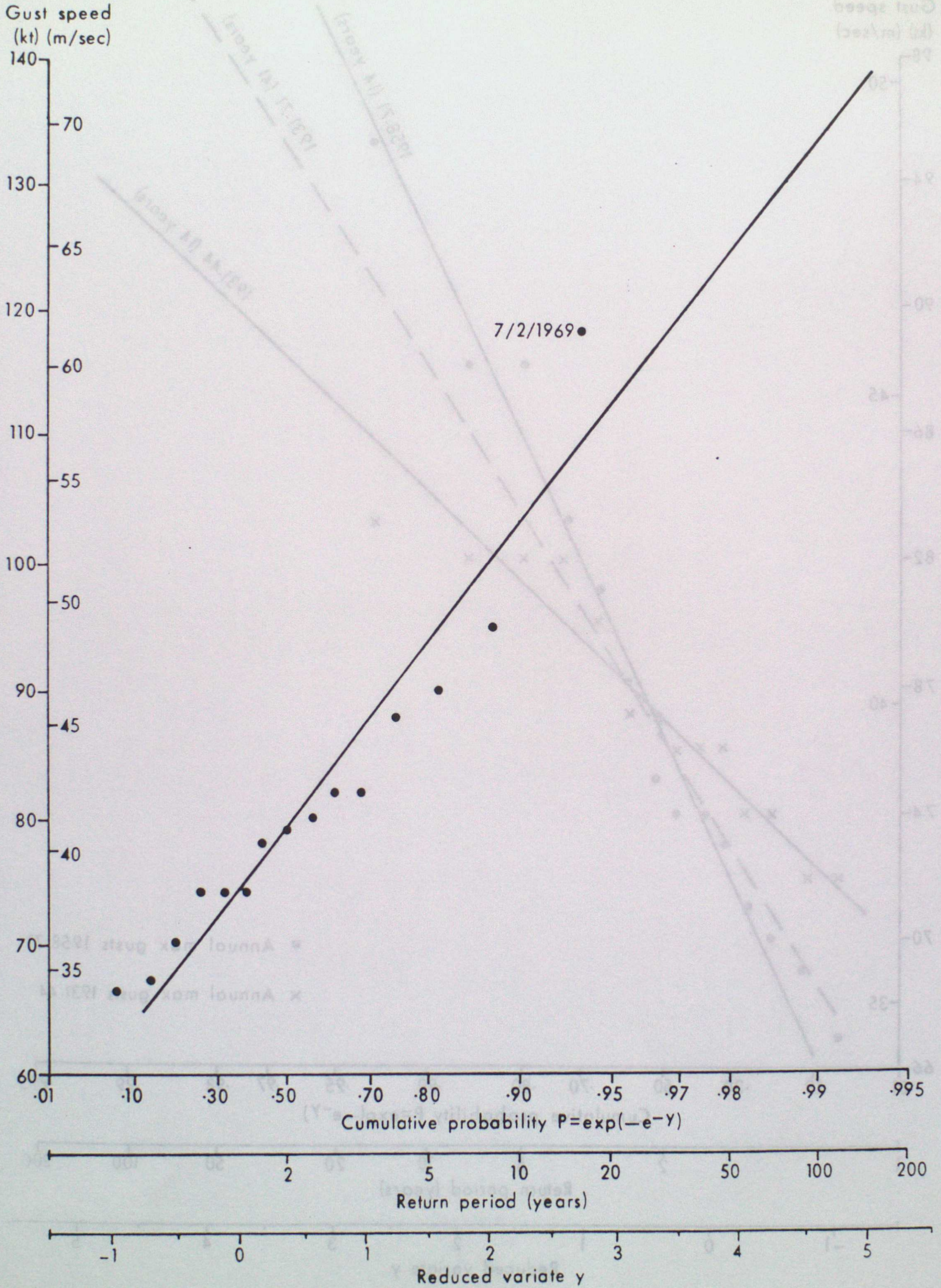

Figure 2 Annual maximum gust speeds at 10 metres. KIRKWALL (1957-71)

Table 3 (contd.) ESTIMATED EXTREME VALUES AT STATIONS WITH LESS THAN 10 YEARS DATA

STATION	COMPARISON STATION	Maximum Hourly Mean Wind Speeds (m/s) At 10m above the Ground: Average Annual	Speeds Likely to be Exceeded Only Once in the Stated Number of Years: 10	20	50	100	120	Maximum Gust Speeds (m/s) At 10m above the Ground: Average Annual Maximum	Speeds Likely to be Exceeded Only Once in the Stated Number of Years: 10	20	50	100	120
Rye	Lympne	18.3	21	23	24	25	26	28.7	34	36	38	40	41
Squires Gate	Fleetwood	22.3	29	31	34	36	37	32.8	38	41	43	46	47
Aigburth	Speke	17.7	21	22	23	24	25	29.8	39	42	45	48	49
Manchester (Barton)	Southport	18.4	21	22	24	25	26	24.4	37	39	42	44	45
Trawsfynydd	Valley	17.4	20	21	22	23	24	30.9	37	39	42	44	45
Milford Haven II	Port Talbot	20.5	30	32	35	37	38	32.4	40	42	45	47	48
Kete	Aberporth	21.8	27	29	31	33	34	37.7	41	44	47	49	50
Winfrith	Thorney Island	16.2	24	25	28	29	30	29.8	36	38	41	43	44
Portland Bill	Hurn	22.0	26	28	30	31	32	33.8	40	42	45	47	48
Mount Batten	Lizard	20.7	25	26	28	29	30	32.0	37	39	41	43	44
Chivenor	Rhoose	18.7	25	27	29	30	31	29.1	39	41	45	48	49
St Mawgan	Lizard	18.4	23	24	25	26	27	28.6	35	37	39	40	41
Nutts Corner	Aldergrove	20.0	21	23	24	26	27	33.5	38	40	43	45	46
Ballypatrick Forest	Aldergrove	20.9	27	29	31	33	34	33.6	46	48	52	55	56
Belfast Harbour	Aldergrove	18.9	23	25	27	28	29	30.2	39	42	45	47	48
Kilkeel	Aldergrove	20.4	24	26	28	30	31	31.0	39	41	44	47	48
Orlock Head	Aldergrove	22.4	29	31	33	35	36	35.6	48	51	55	58	59
Portadown	Aldergrove	13.5	17	18	20	21	22	23.2	31	33	35	37	38
Carrigans	Aldergrove	18.5	22	24	26	27	28	33.3	42	44	43	50	51
Castle Archdale Forest	Aldergrove	16.9	20	22	24	25	26	31.8	40	42	45	48	49

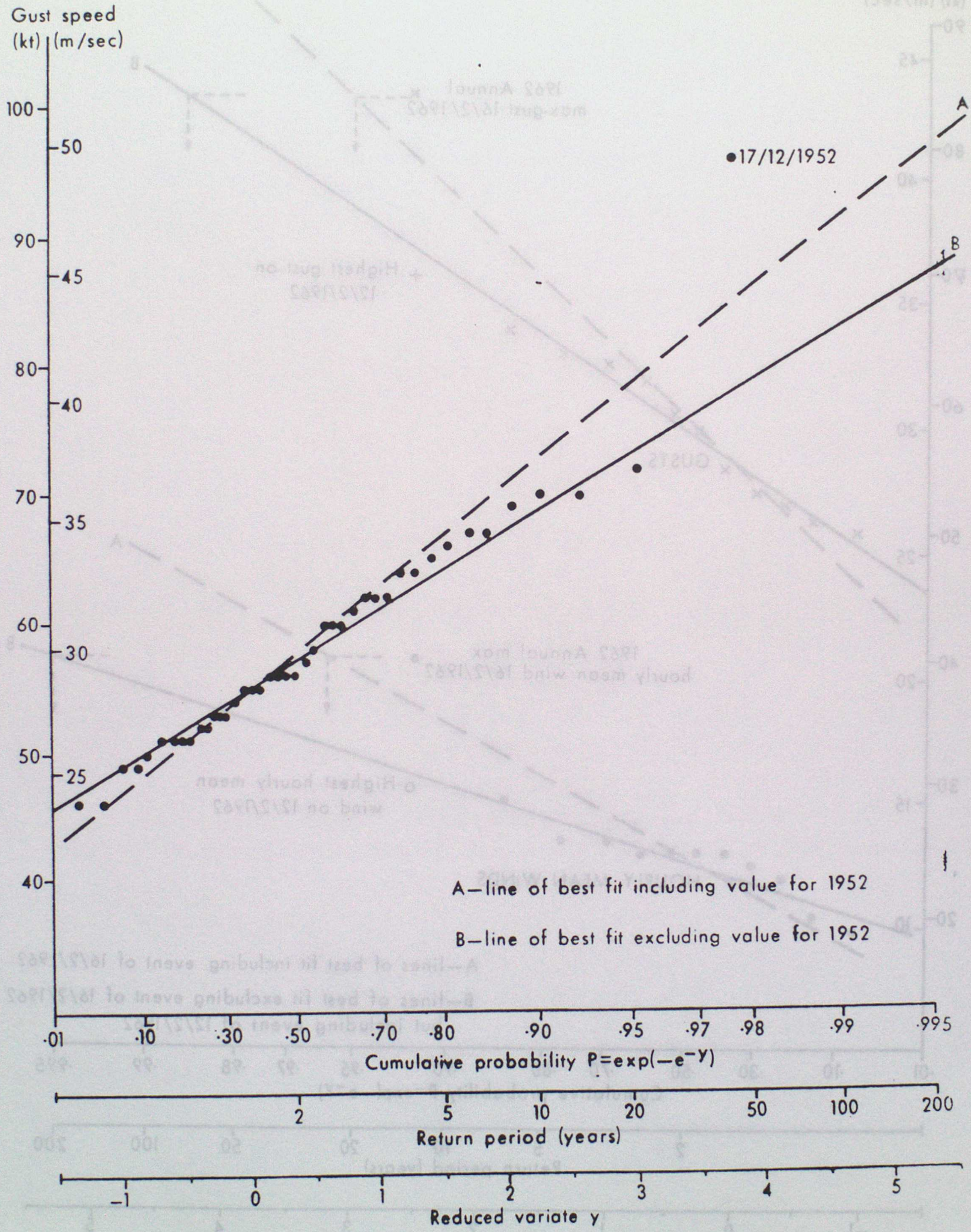

Figure 3 Annual maximum gusts at 14·3 metres. CRANWELL (1928-44, 1947-8, 1950-71)

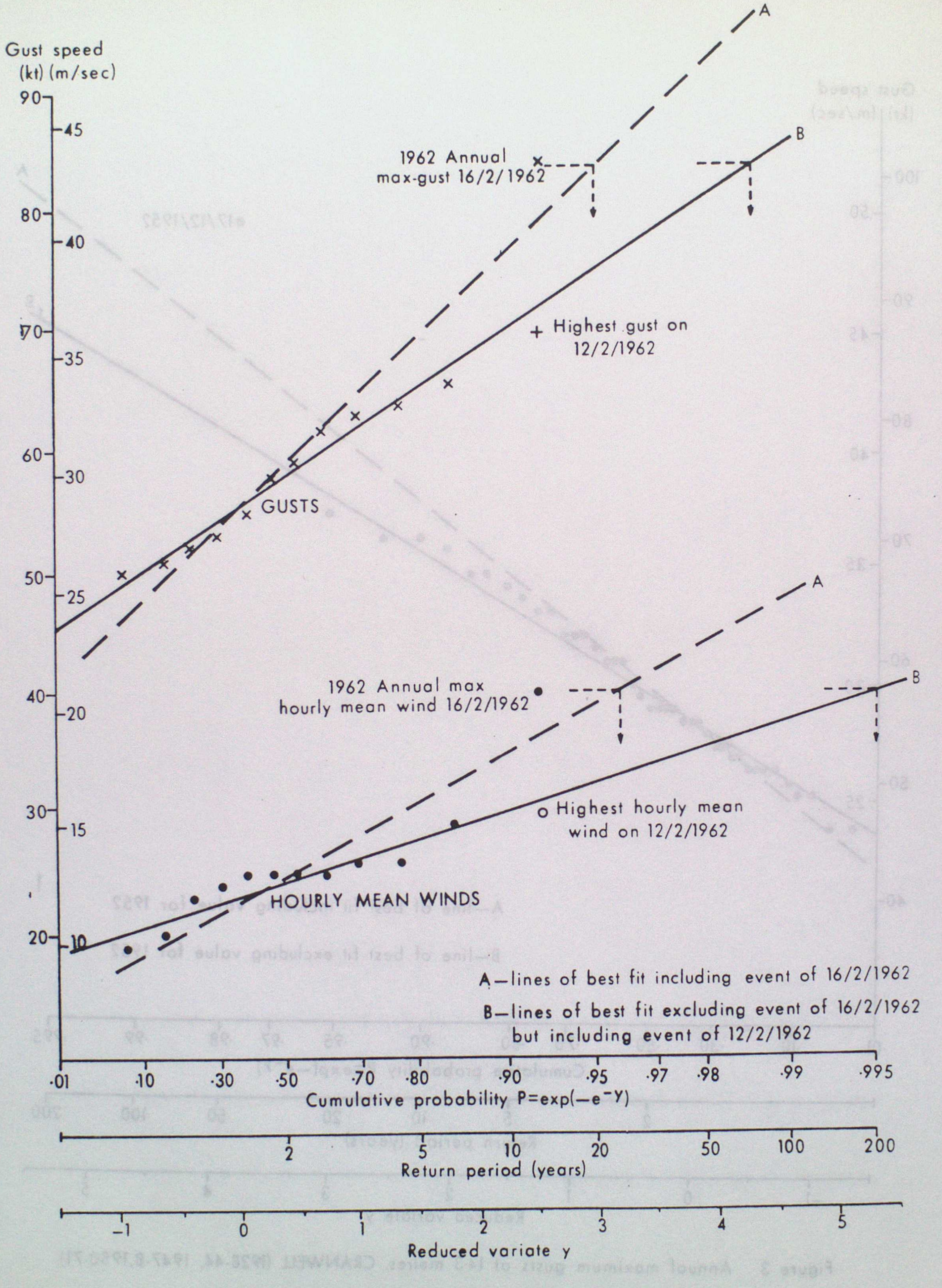

Figure 4 Annual maximum hourly mean winds and gusts at 10·7 metres. SHEFFIELD (1959-71)

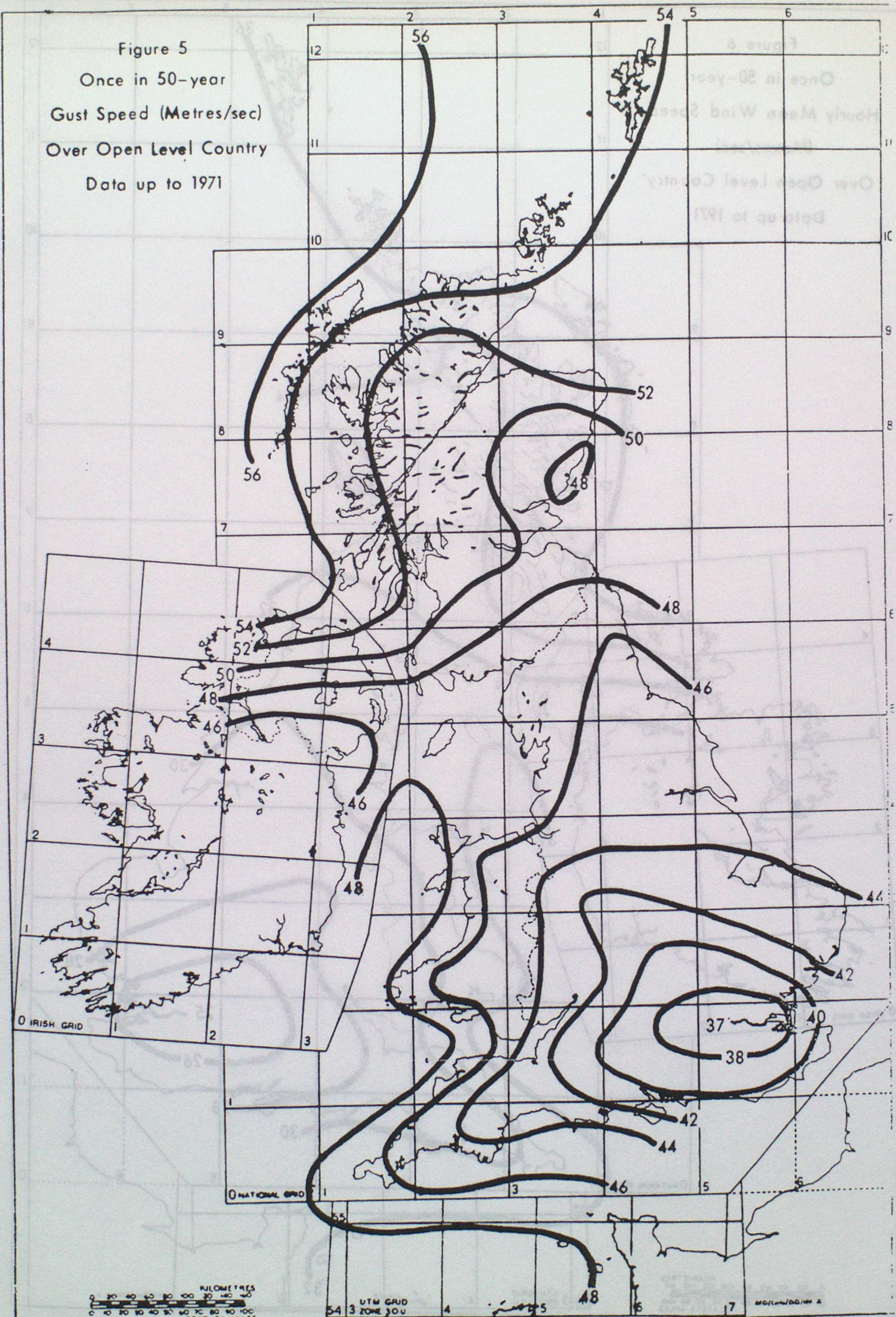

Figure 5
Once in 50-year
Gust Speed (Metres/sec)
Over Open Level Country
Data up to 1971

Figure 6

Once in 50-year

Hourly Mean Wind Speed

(Metres/sec)

Over Open Level Country

Data up to 1971

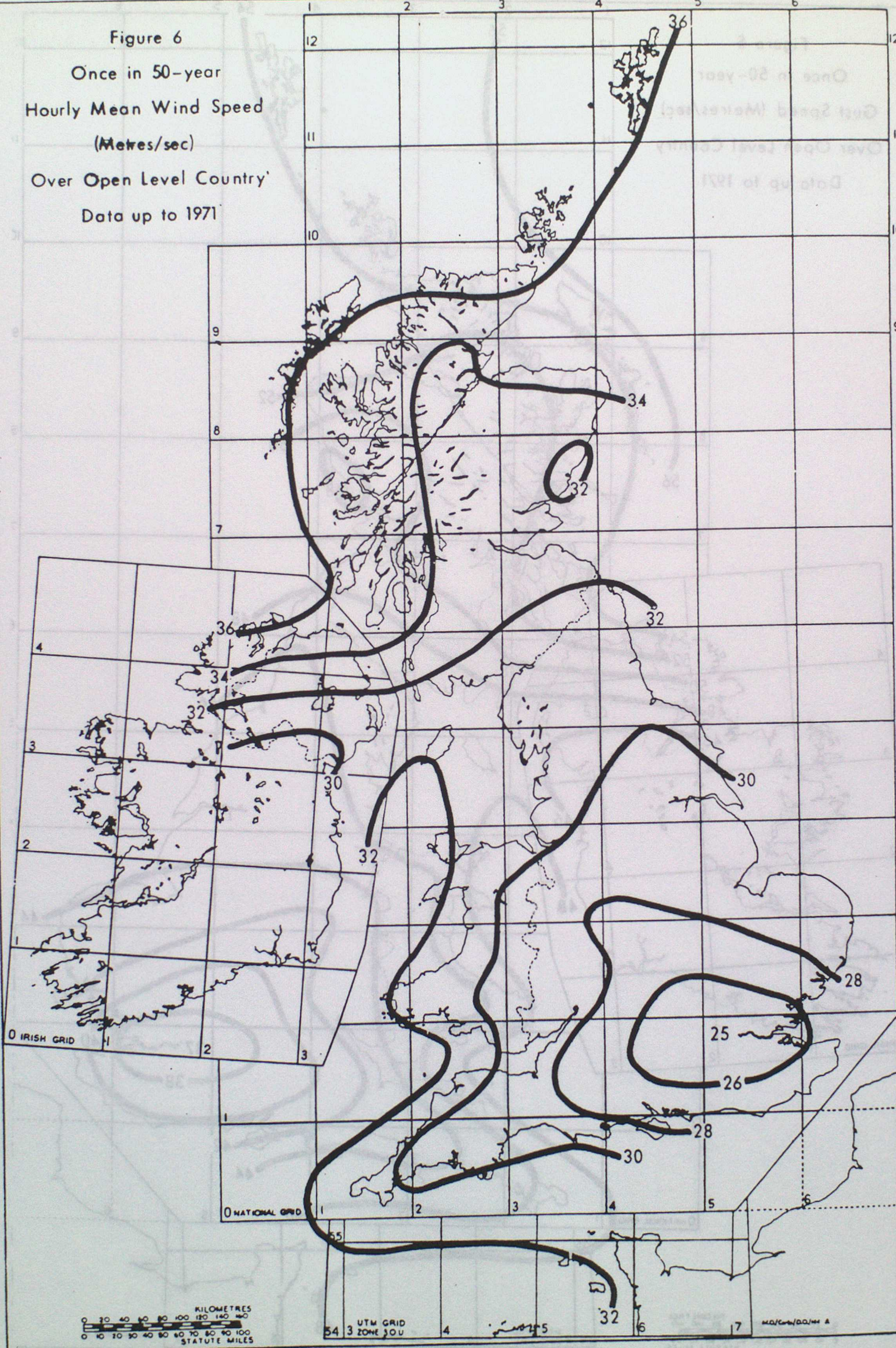

Figure 7
Once in 50-years
Hourly Mean Wind Speed
(Metres/sec)
Over Open Country
below about 250m amsl
Data up to 1971