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EXTREME WIND SPEEDS IN IRELAND FOR PERIODS ENDING IN 1974

By

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Corrigendum

Page 11. Delete last reference and replace by the following:-

Shellard, H.C. 1962 Extreme wind speeds over the United Kingdom for periods ending 1959. Met. Mag., 87, pp. 39-47

Shellard, H.C. 1965 Extreme wind speeds over the United Kingdom for periods ending 1963. Met. Office Climatological Memorandum No. 50.

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Summary: Annual maximum gust and mean wind speeds have been extracted from the autographic wind records of a number of stations for periods up to and including 1974. These data have been analysed, using the statistical theory of extreme values, in order to derive estimates of extreme wind speeds with various return periods. It has been found that they follow the Type 1 or Gumbel extreme value distribution. It has also been found that, at any given station, the ratio of gust speed to 10-minute mean speed is independent of return period over the range of values considered. A map, showing the distribution of the maximum gust speed with a return period of 50 years, has been prepared.

1. Introduction

Estimates of maximum wind speeds with various return periods are frequently required in connection with the design of structures such as tall buildings, television masts, bridges, oil rigs etc which are subject to significant wind loading. The wind speeds require to be averaged over a period which depends on the dimensions of the structure in question. For most structures, this period is of the order of seconds and it is therefore appropriate to use maximum gust speeds which represent an average over about 3 seconds. However, in the case of very large structures such as long bridges, mean speeds over longer periods of time become significant. Also, maximum mean speeds over periods of several hours are sometimes required in connection with prediction of maximum wave heights at sea. It is therefore necessary for the meteorologist to be able to provide estimates of maximum mean speeds as well as maximum gusts. It is usual to give mean speeds over a period of one hour, since hourly means are generally the most readily available.

Estimates of gust speeds over Ireland with a return period of 50-years based on data up to 1970, have been prepared (Logue, 1971). Estimates of mean hourly wind speeds with a 120-year return period were also prepared. However, these were not based on recorded mean hourly values but were obtained by dividing the gust speed of the same return period by a factor of 1.5.

The present study is based on recorded values of both gust and mean wind speeds from a number of stations for periods up to and including 1974.

2. Description of data

Wind data for Ireland are provided by a network of Dines pressure-tube anemometers situated where possible in open level country with the measuring head at an effective height of 10 metres. The names and locations of the stations are indicated in Fig. 1 and their periods of record, used in this study, are given in Table 5.

The following data were extracted from the records of these stations:-

(i) Annual maximum gust speeds.

(ii) Annual maximum mean speeds over any 10-minute period.

(iii) Annual maximum hourly mean speeds between exact hours G.M.T. The mean hourly wind speeds were not available for Glenamoy and, for the other stations they were available only from 1962 onwards. The effective heights of the anemometers did not differ significantly from the standard height of 10 metres except at Malin Head where, from 10th March 1966 onwards, the effective height was 18 metres. Gust speeds for Malin Head after this date were reduced to the standard height by multiplying them by the factor:

$$(Ho/H)^{0.085} = (10/18)^{0.085} = 0.95 \quad \text{(Deacon 1955)} \qquad (1)$$

In the case of 10-minute and hourly mean speeds, the factor used was:

$$(Ho/H)^{0.17} = (10/18)^{0.17} = 0.90 \quad \text{(Carruthers 1943)} \qquad (2)$$

3. Effect of surface roughness on extreme wind speeds

All other factors being equal, wind speeds over rough terrain are less than those over smooth terrain. Mean speeds are affected to a much greater extent than gust speeds and it has been found (e.g. Shellard 1962) that the ratio of the gust to the mean increases with increasing surface roughness. Shellard (1965) suggested that the ratio of the estimated 50-year gust speed to the estimated 50-year hourly mean speed could be used as a measure of roughness. However, it would appear preferable to define the gust/mean speed ratio in terms of recorded rather than estimated values. In this study, the value of the ratio chosen for investigation was the annual maximum gust speed (G) divided by the annual maximum 10-minute mean speed (M_{10}). Let this ratio be denoted by R_{10} i.e.

$$R_{10} = G/M_{10} \qquad (3)$$

Before calculating values of R_{10} for the different stations it is necessary to show that, at a particular station, the ratio is independent of the magnitude of the annual maxima i.e. that R_{10} does not increase or decrease systematically as G and M_{10} increase. For each station a value of R_{10} was calculated for each year of record and values of the quantity $(G.M_{10})^{\frac{1}{2}}$ were also calculated. The correlation coefficients of R_{10} with $(G.M_{10})^{\frac{1}{2}}$ are given in Table 1.

Table 1. Correlation coefficients of R_{10} ($=G/M_{10}$) with $(G.M_{10})^{\frac{1}{2}}$ for various stations

Station	No. of years of record	Correlation Coefficient
Belmullet	18	-0.20
Birr	20	+0.11
Claremorris	22	-0.34
Clones	22	+0.21
Cork Airport	13	+0.26
Dublin Airport	22	+0.18
Glenamoy	11	+0.27
Kilkenny	17	-0.13
Malin Head	19	-0.31
Mullingar	15	+0.19
Roche's Point	19	+0.17
Rosslare	18	+0.36
Shannon Airport	22	-0.04
Valentia Obsy.	22	-0.29

None of these correlation coefficients is significant at the 10% level and their mean value is close to zero. It is therefore concluded that the gust/mean speed ratio R_{10} is independent of wind speed, at least within the range of speeds covered by the series of annual maxima. A unique value of R_{10} for each station may therefore be calculated by taking the mean of the yearly values.

In order to confirm that the ratio R_{10} may be used as a measure of surface roughness, it was decided to assign each station a roughness category based on a consideration of the type of terrain in which it was situated and to compare these categories with the values of R_{10} for the stations.

Davenport (1960) has prepared the following table, grouping types of terrain according to aerodynamic roughness.

Table 2. Types of terrain grouped according to their aerodynamic roughness

Category	Description
1.	Very smooth surfaces e.g. large expanses of open water; low unsheltered islands; tidal flats; lowlands verging on the sea.
2.	Level surfaces with only low, surface obstructions; e.g. prairie grassland; desert; arctic tundra.
3.	Level, or slightly rolling surfaces, with slightly larger surface obstructions; e.g. farmland with very scattered trees and buildings, without hedgerows or other barriers; wasteland with low brush or surface vegetation; moorland.

Table 2 (contd.)

4.	Gently rolling, or level country with low obstructions and barriers; e.g. open fields with walls and hedges, scattered trees and buildings.
5.	Rolling or level surface broken by more numerous obstructions of various sizes: e.g. farmland, with small fields and dense hedges or barriers; scattered windbreaks of trees, scattered two-story buildings.
6.	Rolling or level surface, uniformly covered with numerous large obstructions: e.g. forest, scrub trees, parkland.
7.	Very broken surface with large obstructions: e.g. towns; suburbs; outskirts of large cities; farmland with numerous woods and copses and large windbreaks of tall trees.
8.	Surface broken by extremely large obstructions: e.g. centre of large city.

Each station was allocated a roughness category C according to the descriptions in the above table. In assigning the value C, it is assumed that the station is situated in more or less level or rolling country. However, some of the stations (e.g. Clones, Cork Airport) are situated on or near the top of hills or ridges and one (Valentia Observatory) is on ground sheltered by hills through most of the horizon circle. Since these types of situation affect the value of R_{10}, the value of C was reduced by one for the former type of station and increased by one for the latter. Also, it was observed that coastal stations have lower values of R_{10} than inland stations in the same type of terrain. This is because of the expanses of smooth sea surface in the vicinity of the coastal stations. Accordingly, the values of C for these stations were also reduced by one. In Table 3, the original values of C (based on terrain type alone) together with corrections for exposure and for coastal situation and the corrected values C' are shown for each station.

Table 3 Roughness category C (after Davenport) together with corrections for exposure and coastal situation, and corrected roughness category C', for a number of stations.

Station	C	Exposure Correction	Coastal Correction	C'
Belmullet	4		-1	3
Birr	6			6
Claremorris	4			4
Clones	6	-1		5
Cork Airport	3	-1		2
Dublin Airport	4			4
Glenamoy	4			4
Kilkenny	5			5
Malin Head	4	-1	-1	2
Mullingar	6			6

Table 3 (contd.)

Roche's Point	4	-1	-1	2
Rosslare	5		-1	4
Shannon Airport	3			3
Valentia Obsy.	5	+1	-1	5

The correlation coefficient of C' with R_{10} was calculated and was found to be +0.81. This is rather a high value considering the crude and subjective manner in which C' was determined.

Since mean hourly wind speeds are of more interest for certain purposes than 10-minute means, the ratio of gust speed to mean hourly speed also requires to be considered. Denoting this ratio by R_{60},

$$R_{60} = G/M_{60} \qquad (4)$$

Annual maximum speeds over arbitrary sixty-minute periods are not tabulated as a routine for Irish stations. Mean hourly speeds between exact hours have however been tabulated since 1962. Also, in connection with an investigation done in 1960, annual maximum hourly means, both between exact hours and over any sixty-minute period, were tabulated for a number of stations. A total of 80 station years were tabulated in this way. Denoting the annual maximum between exact hours by M_h and the annual maximum over any sixty-minute period by M_{60}, it was found that on average

$$M_h = 0.98\ M_{60}$$

$$\therefore R_{60} = G/M_{60} = 0.98\ G/M_h \qquad (5)$$

Since M_h may be calculated for all stations (except Glenamoy) for the period 1962-1974, R_{60} may be obtained. However, it was considered that the 13 annual maxima from this period were too small a sample to give a reliable value of R_{60}. Therefore it was decided to calculate R_{60} from the monthly instead of the annual maxima, thus increasing the sample size by a factor of 12. This introduces no bias since it was found that the mean difference over all stations between values of R_{60} calculated by the two methods was virtually zero. Having calculated R_{60} for each station, the correlation coefficient between R_{60} and C' was also calculated and was found to be +0.86. The regression equation of R_{60} on C' is

$$R_{60} = 0.082\ C' + 1.38 \qquad (6)$$

To summarize, the gust/mean speed ratios R_{60} and R_{10} are rather highly correlated with C' where C' is the roughness category (according to Davenport) adjusted upwards or downwards by one unit for underexposed and overexposed stations respectively and downwards by one unit for coastal stations.

4. Fitting of extreme value distributions to data for individual stations

Consider a series of N annual maxima of any meteorological element $X_1, X_2, X_3, \ldots\ldots X_N$ arranged in order of magnitude so that X_1 is the lowest annual maximum, X_2 the second lowest and so on. Then the series may be displayed by plotting X against the "reduced variate" y where

$$y = - \ln. \ln [T/(T - 1)] \qquad (7)$$

and T is the return period of X (Jenkinson 1955). The value of T for the m th member of the series (T_m) is given by

$$(T_m - 1)/T_m = (m - 0.31)/(N + 0.38) \qquad (8)$$

a formula due to Chegodayev (1953). If the series follows the Type 1 or Gumbel distribution of extreme values, the graph of X against y is a straight line. If the series follows the Type 2 distribution, the graph is concave to the X axis and, if it follows the Type 3 distribution, it is convex to the X axis. Thus the appropriate type of extreme value distribution may be chosen and may be fitted to the data. This enables the value of X for any return period to be determined.

In the case of extreme wind speeds, the data available consisted of annual maximum series of gust speed and 10-minute mean speed for periods ranging up to 22years in length. Annual maximum series of mean hourly wind speed between exact hours (M_h) for the period 1962-74 were also available for most stations but these series were considered too short to be used with confidence in fitting a distribution.

For a given station, it would be possible to fit extreme value distributions to the gust series and the 10-minute mean series separately. However, due to the random character of the values, the parameters of the two distributions would probably differ in such a way that the ratio of the gust to 10-minute mean speed would vary with return period. It has been shown in Section 3 that the gust/mean speed ratio is independent of speed and therefore of return period. Consequently it was decided to combine the series of gusts and 10-minute means in the following manner. For each station, the annual maximum gust speeds (G) and the annual maximum 10-minute mean speeds (M_{10}) were separately arranged in ascending order. Than a new series (G') was computed, the m th member of which is given by

$$G'_m = 1/2(G_m + R_{10}M_{10m}) \qquad (9)$$

where R_{10} is the gust/10-min mean ratio for the station. G' may be regarded as a "corrected" gust, from which a "corrected" 10-min mean of the same return period may be obtained by dividing by R_{10}. Thus the difficulty associated with the separate fitting of the gust and mean speed distributions is avoided.

The next step was to determine which of the three types of extreme value distribution most closely fits the series of G' values for the stations in question. It was assumed that the same type of distribution must apply to all stations. The G' series for each station was first summarised by means of a procedure due to Jenkinson (1975) which makes no assumption about the type of distribution followed. To do this, each ordered series was divided into quartiles and the mean value of G' for each quartile was obtained. The highest value of G' in the series was also noted. These five values were expressed as proportions of the mean of the two middle quartiles which is approximately equal to the median value of the series. The appropriate values of the reduced variate y against which the five G' ratios may be plotted are

$$-0.75, \quad 0.04, \quad 0.78, \quad 2.24, \quad 3.33 \qquad (10)$$

These refer to a sample size of 19 (which is the median sample size for all the stations) but vary very little over the range of sample sizes in question (11 to 22). For each of the 14 stations, the five G' ratios described above were set out and the median value over all stations of each ratio was obtained. These were as follows:

$$0.88, \quad 0.96, \quad 1.04, \quad 1.19, \quad 1.30 \qquad (11)$$

When this set of values is plotted against the set of y values given by (10), they fall almost exactly on a straight line. It was therefore concluded that the Type 1 extreme value distribution fits the annual maximum series of G'.

For each station, a Type 1 extreme value distribution was fitted by least squares to the G' series. If the distribution is expressed

$$G' = A + By \qquad (12)$$

where G' is in metres/sec. and A and B are the parameters of the distribution, then the values of A and B for each station are given in Table 4.

Table 4. Estimated values of parameters A and B of the extreme value Type 1 distribution, for various stations

Station	A(m/s)	B(m/s)
Belmullet	37.3	3.94
Birr	30.5	3.36
Claremorris	31.8	4.96
Clones	33.6	4.25
Cork Airport	32.0	3.40
Dublin Airport	31.3	2.90
Glenamoy	35.3	3.32
Kilkenny	28.9	3.95
Malin Head	37.5	4.33
Mullingar	30.6	3.04
Roche's Point	34.9	3.77
Rosslare	32.5	3.10
Shannon Airport	33.1	3.66
Valentia Obsy.	34.1	3.89

The parameter A is equal to the value of G' when y = 0 and B is equal to the slope of the line on the graph of G' against y. It may be seen that, in general, A is highest for coastal and western stations and lowest for midland and eastern stations. B, on the other hand, shows no clear geographic pattern and appears to vary in a random manner. It is not significantly correlated with A.

For the sample sizes in question, B is rather poorly estimated. Making use of the usual formulae for standard errors (see, for example, Cunnane, 1975), it may be shown that, for the extreme value Type 1 distribution, the standard error of B is given approximately by

$$se(B) \simeq 1.05\ B/(N)^{\frac{1}{2}} \qquad (13)$$

where N is the sample size. Replacing N by the maximum sample size (22) and B by the mean of the values in Table 4 (3.70 m/s), this becomes

$$se(B) \simeq 0.83 \text{ m/s} \qquad (14)$$

None of the values of B in Table 4 differ from the mean by more than two standard errors. It was therefore decided to adopt the hypothesis that B is the same for all stations and is equal to 3.70 m/s.

If we assume this constant slope for all stations, then the fitting of the straight line to the data reduces simply to the determination of the mean $(\bar{G'},\bar{y})$ of the points plotted on the G', y graph. Then the required line is the one with slope 3.70 m/s passing through the mean. Once the distribution has been fitted, the gust speed for any return period may be calculated. The 10-minute mean speed and the hourly mean speed with the same return period may then be found by dividing by R_{10} and R_{60} respectively. This procedure was applied to all stations and, in Table 5, gust speeds with various return periods are shown for each station together with the highest gust on record and the values of R_{60}.

Table 5. Gust speeds (m/s) likely to be exceeded only once in the stated number of years at 10m above the ground at a number of stations

Station	Period of record	Return period (yrs.) 10	20	50	100	Highest on record	R_{60}
Belmullet	1957-74	46	49	52	55	48	1.57
Birr	1955-74	39	41	45	47	44	1.93
Claremorris	1953-74	41	44	47	50	49	1.75
Clones	1953-74	42	45	48	51	45	1.82
Cork Airport	1962-74	40	43	46	49	48	1.64
Dublin Airport	1953-74	39	42	45	48	39	1.64
Glenamoy	1963-73	43	46	50	52	44	-
Kilkenny	1958-74	37	40	43	46	40	1.90
Malin Head	1956-74	46	49	52	55	50	1.57
Mullingar	1958-72	39	41	45	47	41	1.83
Roche's Point	1956-74	43	46	49	52	47	1.51
Rosslare	1957-74	41	43	47	49	45	1.58
Shannon Airport	1953-74	41	44	48	50	48	1.62
Valentia Obsy.	1953-74	43	45	49	51	45	1.74

In interpreting Table 5, it should be borne in mind that the estimated return perbd of the highest value recorded in N years is not equal to N, as might be assumed intuitively, but may be obtained from equation (8) by putting m = n. This gives

$$T_N = (N + 0.38)/0.69 \qquad (15)$$

5. Mapping of 50-year maximum wind speeds

The calculation of 50-year maximum gust and mean wind speeds for individual stations has been described in the previous section. However, maps of these quantities cannot be drawn directly from the station values. This is because of the fact that wind speeds recorded at a station depend on the roughness of the surrounding terrain and on the location of the station relative to hills and to the coast. It is therefore necessary to specify that the maps refer to level terrain of a certain standard roughness and to make appropriate adjustments to the 50-year speeds for those stations whose exposure differs from this standard.

The standard roughness chosen in this case is that corresponding to roughness category C = 3. This corresponds to the "open level country" frequently referred to in connection with extreme wind speeds. No Irish station has C less than 3 and it is unlikely that there is any extensive area in Ireland where C = 2 ("prairie, desert, arctic tundra") or less. From equation (6), the gust/mean speed ratio R_{60} = 1.63 when C' = C = 3. For coastal stations however, C' = C - 1 = 2 and R_{60} = 1.54. Thus the standard values of R_{60} are 1.63 for inland stations and 1.54 for coastal stations. In previous work on extreme winds (Logue, 1971), a ratio of 1.50 had been used for all areas, but it may be seen from Table 5 that this value is too low, especially for inland areas. For inland stations, the gust/mean hourly ratio always exceeds 1.6 even for stations with a very open exposure such as those at airports.

From Table 5, it may be seen that the values of R_{60} for several stations differ from the standard values. Therefore, the 50-year gust speeds for these stations must be adjusted before they can be plotted on the map. To do this, it is necessary to determine the magnitude of the effect which changes in surface roughness have on maximum gust speeds. Regression of the mean annual maximum "corrected" gust speed $\overline{G'}$ on R_{60} for 13 stations gave

$$\overline{G'} = 57 - 13\, R_{60}, \qquad r = -0.66 \qquad (16)$$

However, part of the decrease of $\overline{G'}$ as R_{60} increases is due to the fact that the stations with the lowest values of R_{60} happen to be near the north, west and south coasts where, on physical grounds, wind speeds would be expected to be highest. It is assumed that about half of this rate of change is due to the effect of rough terrain in reducing maximum gust speeds. Accordingly, the calculated 50-year gust speeds for the stations were increased by 0.06 m/s for every 0.01 difference between the value of R_{60} for the station and the standard value of R_{60}. The greatest such adjustment was +1.8 m/s, in the case of Birr.

The adjusted values of the 50-year gust speed were plotted on a map and isolines were drawn (Fig. 2). The standard error of $\bar{G}'$ is about 1 m/s and the standard error of the 50-year gust must be at least as great as this, This fact was borne in mind in drawing the isolines. Where drawing exactly for a plotted value would lead to a distorted pattern or to an excessive crowding of the lines, it was permitted to adjust the value, provided that the adjustment did not exceed two standard errors. Thus the value for Clones was adjusted downwards by about 2 m/s and those for Cork Airport and Glenamoy were adjusted upwards by between 1 and 2 m/s. No adjustment was made for any other station.

Hardman, Helliwell and Hopkins (1973) have prepared a map showing the distribution of the 50-year gust speed over Great Britain and the north of Ireland. The differences between their map and Fig 2 do not exceed 2 m/s and appear to be due mainly to differences in the method of analysing the data.

6. Use of Fig. 2

For any location in Ireland, the maximum gust speed with a return period of 50-years may be obtained from Fig. 2.

Gust speeds with other return periods may be obtained by plotting the 50-year value against $y = 3.90$ on a graph of gust speed versus y, drawing a line with a slope of 3.70 m/s through that point and reading off the required speed against the appropriate value of y, which is related to return period by equation (7) For example, suppose that it is required to find the maximum gust speed with a return period of 10 years at Waterford. From equation (7), the value of y corresponding to $T = 10$ is $y = 2.25$. From Fig. 2, the 50-year gust speed at Waterford is 47 m/s and in Fig. 3 this is plotted against $y = 3.90$. AB is a line with slope 3.70 m/s passing through this point. The 10-year gust speed may be obtained by following the vertical dashed line at $y = 2.25$ to where it intersects AB and thence horizontally to the required value (41 m/s) on the axis of gust speed.

Maximum mean hourly wind speeds may be obtained by dividing the gust speed of the required return period by a factor of 1.54 for coastal areas and 1.63 for inland areas. All these values refer to a height of 10 metres above open level country (roughness category C = 3).

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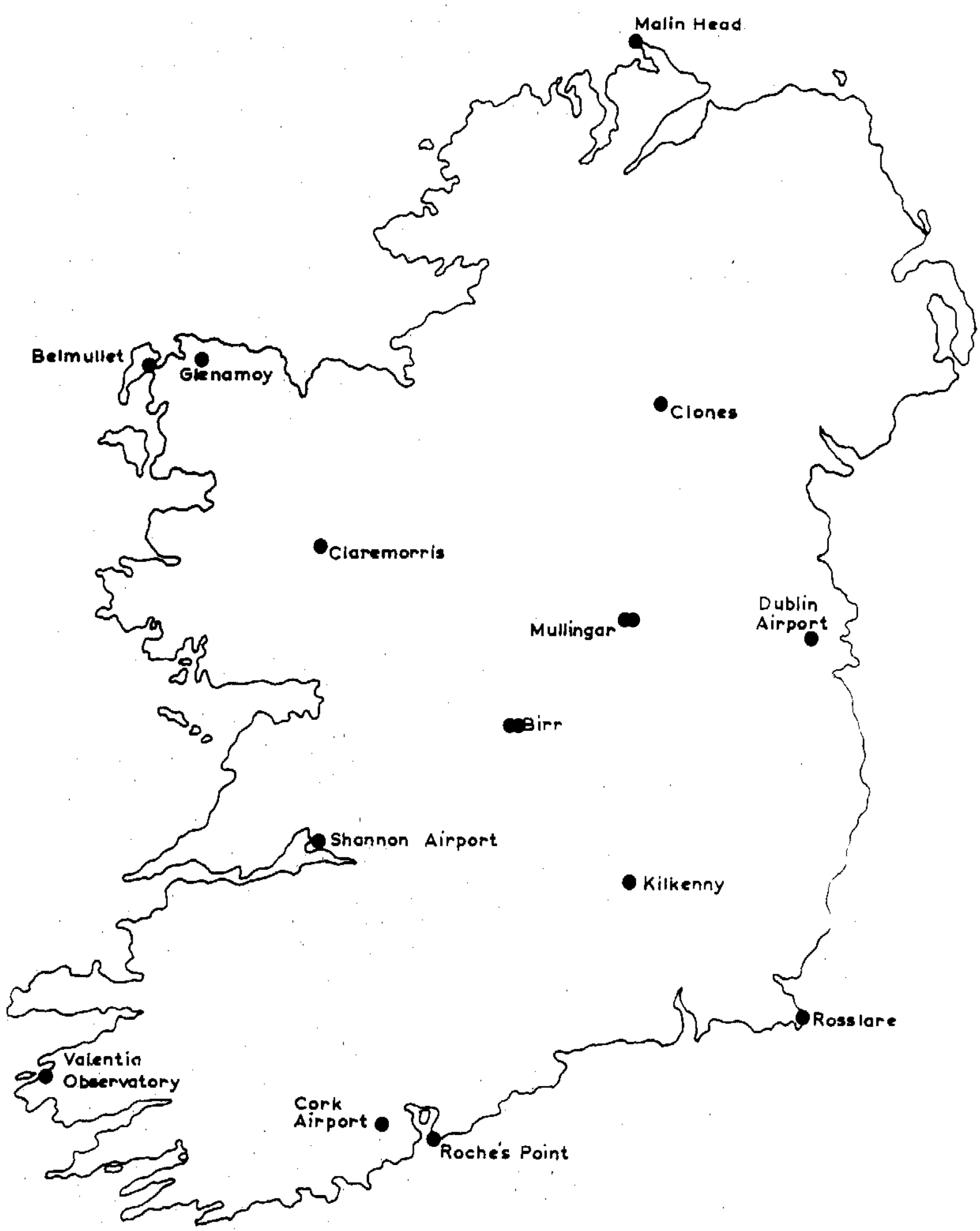

Fig. 1. Stations used in deriving estimates of extreme wind speed.

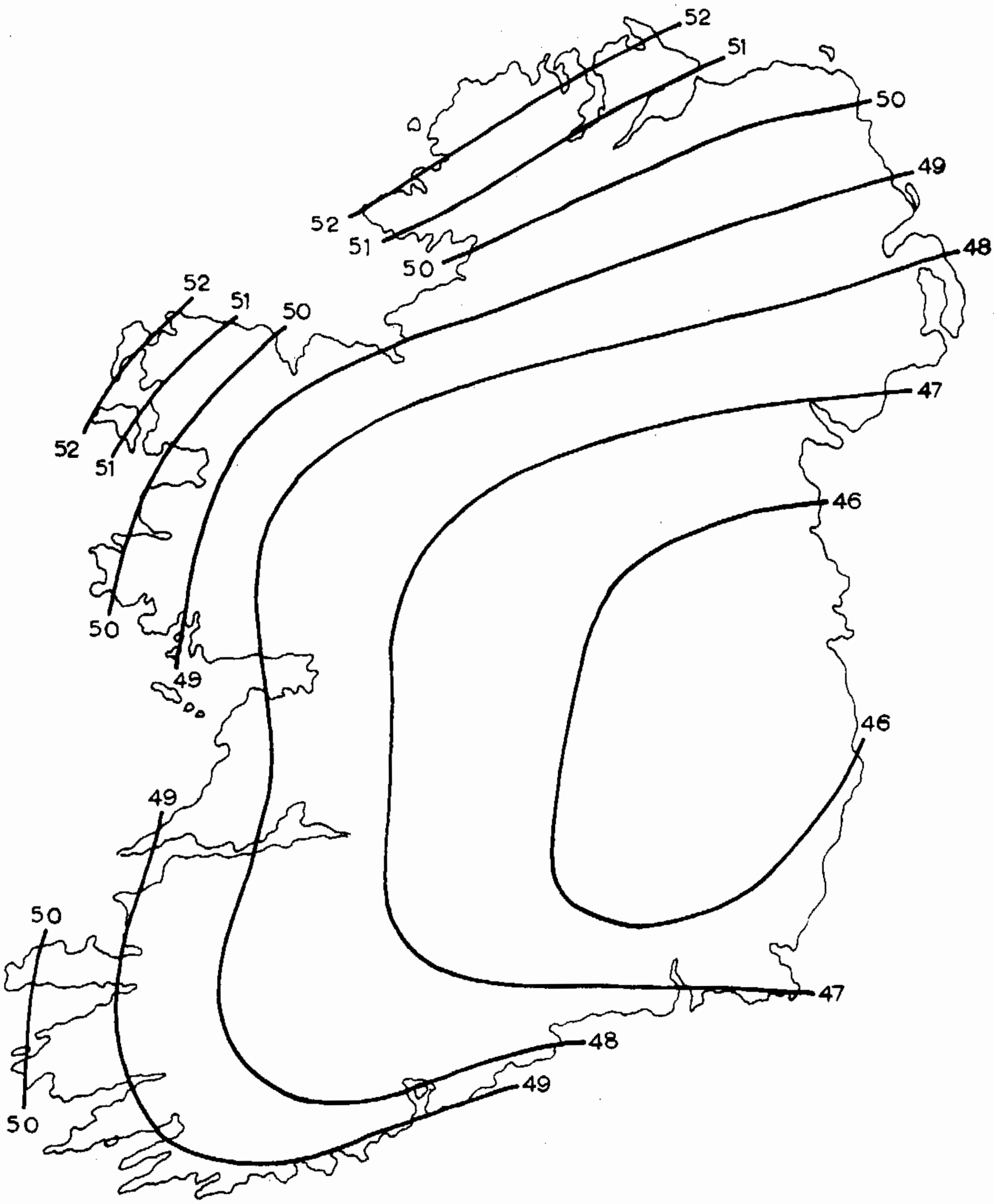

Fig. 2. Maximum wind speed in a gust (m/s) with return period 50 years. Values refer to a height of 10 m above open level country.

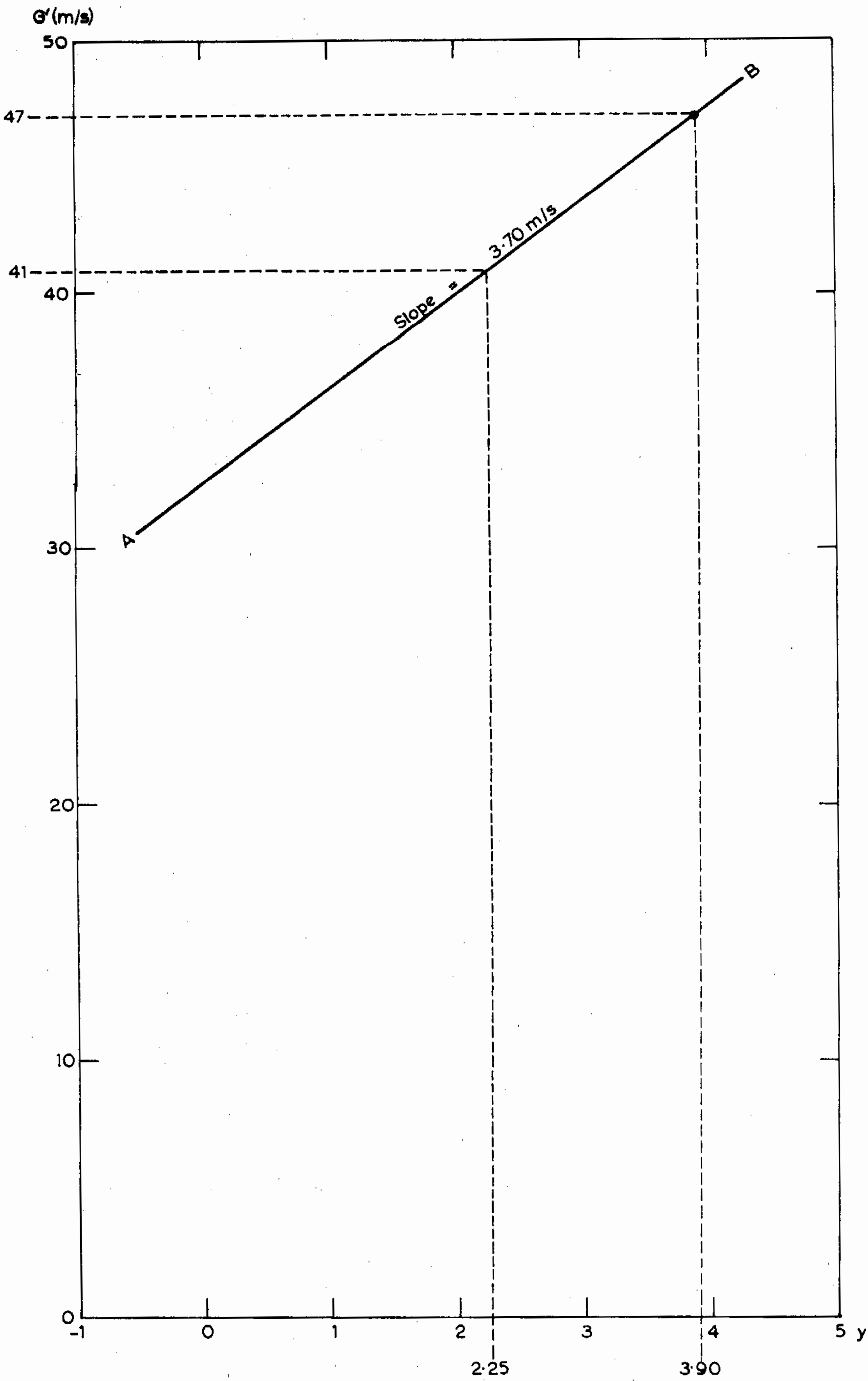

Fig. 3. Example of derivation of gust speed with a return period other than 50 years. (see text for explanation)