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SURFACE WINDS IN HONG KONG TYPHOONS
(Preliminary Report)

by
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SECTION I - INTRODUCTION

Engineers are becoming increasingly concerned with the structure of low level winds, and the probability of the occurrence of gusts of various durations as factors to be considered for the safe and economic design of structures. These wind factors are particularly important when designing structures for areas frequented by tropical cyclones, and it is for just such conditions that reliable information is scarce. Data for decaying hurricanes have been obtained from the Lake Okeechobee (1) and Brookhaven (2) installations, but many factors are still in doubt (3).

Anemograph records for the Royal Observatory, Hong Kong, extend as far back as 1884, during which time there have been only minor changes in the location of the anemographs and - until 1958 - little change in the exposure. Since 1958 a quick-run recorder, for the Dines anemograph, has been available and it was used successfully in Typhoon Mary in June, 1960. The historical records are standardised in Section II and used in Section III to determine the probability of occurrence of extreme mean hourly wind speeds and gusts. Short period mean wind speeds measured in Typhoon Mary are presented in Section IV, and probable hourly extreme wind speeds for short period means are computed. The results of these two sections are then combined to yield the probability of extreme mean wind speeds for any period from five seconds to one hour.

It should be stated at the outset that the results that follow relate to conditions at Hong Kong where the terrain is composed of many mountainous islands and peninsulas (Figure 1). Furthermore, the extreme typhoons which frequent the Pacific, east of the Philippines, do not normally occur in the China Sea. This statement is supported by 78 years of Hong Kong observations, and by the distribution of intense typhoons as presented by Frank and Jordan (4), who classify typhoons - according to the minimum value of the central pressure - into the three categories 990-950 mb, 950-920 mb and less than 920 mb. The lowest instantaneous pressure at Hong Kong - 956.4 mb - occurred in the typhoon of September 2nd 1937, when gusts up to 145 knots (167 m.p.h.) were reliably recorded (5).

SECTION II - ANEMOGRAPH OBSERVATIONS

1. The Basic Data

The Royal Observatory, Hong Kong (Lat. 22°18'47"N, Long. 114°10'13"E) is situated on the top of a small hill 31.82m A.M.S.L. on the Kolwoon Peninsula (Fig. 1). The building is approximately regular in shape being 25.3m long, 13.7m wide and 10.4m high with a flat roof, and

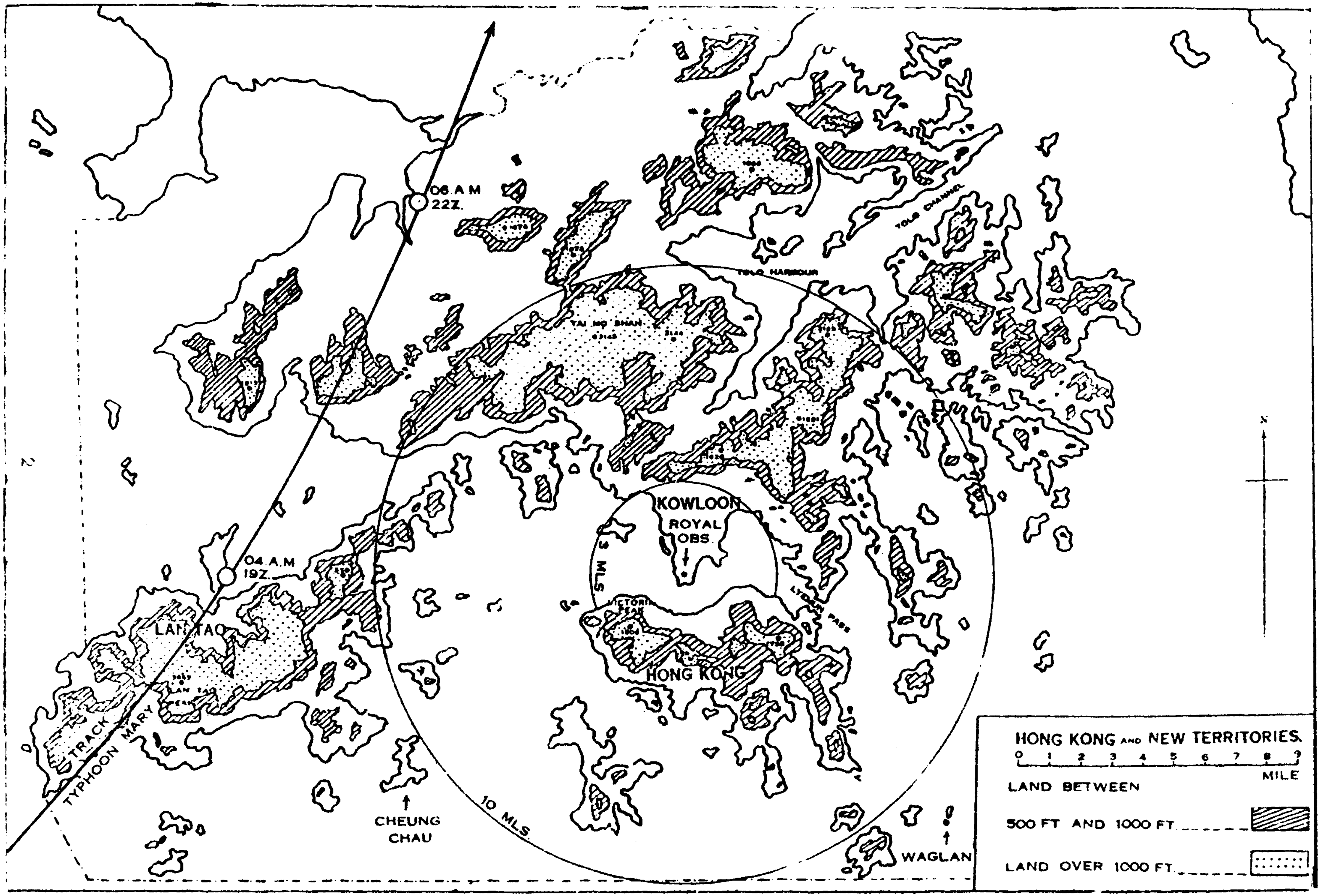


Figure 1.

The colony of Hong Kong showing the topography and places mentioned.

stands in wooded grounds, with the tops of all trees below the roof of the Observatory. Beyond the boundary of the grounds the terrain is developed, but no building interfered with the exposure of the anemometer until 1958 when blocks of flats were constructed 120m east of the anemometer with their roofs a few meters below the level of the anemometer head.

A recording four cup Beckley anemograph of the Robinson type, was set up in the center of the roof in 1884. The four cups - 23 cms in diameter - were mounted on arms 60 cms long, and the plane of rotation was 3.96 m above the roof of the Observatory. This instrument was in use until 1938. In 1910 a Baxendall Dines anemograph was installed on the roof 3.05m NNE of the cup anemograph with its head 0.15m higher than the latter. The Dines was moved to the central position when the Beckley was dismantled in 1938, and the opportunity was taken to install a new tank to record gusts up to 180 knots, since gusts exceeding 110 knots (127 m.p.h.) had been experienced in four storms. The head of the Dines was raised from 3.96m to 9.75m above the roof at this time, and it was raised a further 6.80m in 1958 in an unsuccessful attempt to clear the turbulent wake from the newly erected buildings to the east.

Mean hourly wind speeds (H-30 min to H+30 min) from the cup anemograph have been published (6) for the period from March 1884 until October 1938. The maximum gusts recorded by the adjacent Dines anemograph have been published since May 1910, and Dines mean hourly wind speeds since January 1935. The two anemographs were operated side by side for over 28 years; if these comparative readings show that the cup measurements can be converted to the Dines' standard, then a unique series of observations from 1884 to 1960 could be obtained with a break of five years (1942-1946) due to World War II.

2. Standardisation of the Cup Anemograph Readings

The precise relationship between the readings of the two anemographs is complex since they respond differently to changes in air density and eddy structure of the wind. Variations in topography around the Observatory and the rectangular plan of the building cause the eddy structure of the wind to be dependent on velocity. The difference in readings between the two instruments is thus dependent on the speed and direction of the wind as well as the density and stability of the air. Early investigations (6) based on monthly and annual mean wind speeds, found the variation in factor to be quite large and apparently inexplicable. Heywood (7) subsequently examined in detail the hourly readings for 1938, corrected the Dines' records for variations in air density and concluded that the "run" of the cup anemograph should be multiplied by 2.5 to convert the normal and extreme values (m.p.h.) to the Dines standard. He noted that there was probably a variation with velocity, but that it was small compared with variations due to other causes and could be neglected. Published results for the cup anemograph are expressed in "miles", being the indicated hourly run of the cups multiplied by Robinson's original factor of 3.0. Heywood's factor of 2.5, being based on hourly observations, will be used for the examination of the annual extreme mean hourly wind speeds; the published hourly values must therefore be reduced by the factor 2.5/3.0. A factor of 0.72 includes this conversion to the Dines standard and the change from m.p.h. to knots.

The four annual extremes of mean hourly wind speed for which published readings are available for both anemographs, are compared in Table 1; and they suggest that the adopted factor is acceptable for this analysis of extreme winds. Further support for this choice is given later.

TABLE 1

Comparison of the Annual Extreme Mean Hourly Wind Speeds Measured by the Beckley Cup and Dines Anemographs

Year	Date	L.M.T.	Cup Run x 3.0	Cup "Miles" x .72	Dines	Difference Cup - Dines
			"miles"	Knots	Knots	Knots
1935	7 Oct	22	47	34	31	+3
1936	17 Aug	04	97	70	70	0
1937	2 Sep	04	93	67	65	+2
1938	3 May	15	40	29	28	+1

Annual extreme mean hourly wind speeds and the annual extreme gusts recorded by the Dines anemograph are shown in Table 2. Instrumental changes are indicated in the remarks column. Change number 4 in 1938, involved moving the Dines anemograph to the central position - previously occupied by the cups - and raising its head by 8.26m. The effects of this change were determined by comparing the readings with a third control anemograph - located 10.36m above the SE corner of the building - both before and after the move. Heywood analysed these comparative readings and found:

Before Moving the Anemograph

a. The old Dines (head 4.11m above the roof) produced a trace 1.43 times as broad as the control anemometer (head at 10.36m); this ratio decreased linearly with speed as the effects of turbulence generated by the building spread to greater heights and affected the control anemometer.

b. The mean hourly velocities were the same for both anemographs.

After Moving the Anemograph

a. The old Dines read slightly greater than the control anemometer on average, but the difference decreased with speed and amounted to about 3% at 20 kt. (The original Dines was smaller and had a more open scale than the Control).

TABLE 2

ANNUAL EXTREME MEAN HOURLY WIND SPEED AND DINES GUST
1884-1941, 1946-1960

NO.	YEAR	DATE	L.M.T.	"EXTREME MEAN HOURLY SPEED CUP FACTORS			DINES GUST (MAX)	GUST FACTOR	REMARKS CHANGES TO INSTRUMENTS ARE NUMBERED 1 - 5
				X3.0 "Miles"	X2.5 Kt	DINES Kt	Kt	-	
1	1884	10 Sep	00	89	64	-	-	-	1) A Beckley four cup anemograph of Robinson type was set up in Jan 1884 with its plane of rotation 3.9m above the roof of the Observatory, 13.72m above the ground and 45.54m A.M.S.L.
2	1885	17 Aug	15	53	38	-	-	-	
3	1886	7 Dec	05	54	39	-	-	-	
4	1887	17 Sep	17	69	50	-	-	-	
5	1888	28 Sep	22	50	36	-	-	-	
6	1889	16 Oct	06	61	44	-	-	-	
7	1890	13 Oct	07	53	38	-	-	-	
8	1891	19 Jul	07	64	46	-	-	-	
9	1892	27 Mar	08	46	33	-	-	-	
10	1893	2 Oct	18	81	58	-	-	-	
11	1894	25 Sep	09	86	62	-	-	-	
12	1895	28 Jul	14	53	38	-	-	-	Not associated with a tropical cyclone.
13	1896	29 Jul	22	108	78	-	-	-	
14	1897	17 Sep	17	56	40	-	-	-	
15	1898	5 Aug	01	62	45	-	-	-	
16	1899	1 Jul	11	46	33	-	-	-	
17	1900	10 Nov	05	90	65	-	-	-	
18	1901	4 Aug	04	48	35	-	-	-	
19	1902	2 Aug	22	82	59	-	-	-	
20	1903	27 Oct	09	46	33	-	-	-	
21	1904	25 Aug	18	56	40	-	-	-	
22	1905	30 Aug	16	65	47	-	-	-	
23	1906	29 Sep	09	78	56	-	-	-	
24	1907	14 Sep	04	75	54	-	-	-	
25	1908	28 Jul	02	81	58	-	-	-	Approximate; cups damaged.
26	1909	19 Oct	23	75	54	-	-	-	

Table 2 - Cont'd.

NO.	YEAR	DATE	L.M.T.	EXTREME MEAN HOURLY SPEED CUP FACTORS X3.0 "Miles"	EXTREME MEAN HOURLY SPEED CUP FACTORS X2.5 Kt	EXTREME MEAN HOURLY SPEED DINES Kt	DINES GUST (MAX) Kt	GUST FACTOR	REMARKS CHANGES TO INSTRUMENTS ARE NUMBERED 1 - 5
27	1910	30 Jun	04	48	35	-	52	1.49	2) A Dines anemograph with pipes of 1.27 cm diameter was set up in May 1910 3.05m NNE of the cups and 0.15m above them at 4.11m above the roof 45.69m A.M.S.L.
28	1911	5 Aug	07	62	45	-	67	1.48	
29	1912	13 Mar	12	46	33	-	46	1.39	
30	1913	17 Aug	11	86	62	-	91	1.47	
31	1914	3 Sep	11	42	30	-	48 (42)	1.60	The maximum gust occurred in July.
32	1915	5 Nov	16	56	40	-	60	1.50	
33	1916	7 Sep	00	55	40	-	56	1.40	
34	1917	13 Aug	15	63	45	-	81	1.80	3) In July 1917 the diameter of the pipes for the Dines anemograph was increased from 1.27cm to 2.54cms.
35	1918	15 Aug	06	63	45	-	82	1.82	
36	1919	22 Aug	19	60	43	-	73	1.70	
37	1920	31 Jul	02	51	37	-	53	1.43	
38	1921	24 Jul	11	51	37	-	60 (59)	1.62	The maximum gust occurred in Sept.
39	1922	20 Sep	21	55	40	-	65	1.63	
40	1923	18 Aug	10	106	76	-	113+	1.49	
41	1924	4 Oct	00	46	33	-	60	1.82	
42	1925	26 Jun	09	45	32	-	56 (52)	1.75	The maximum gust occurred in July.
43	1926	27 Sep	10	73	53	-	88	1.66	
44	1927	20 Aug	16	83	60	-	101	1.68	
45	1928	15 Jul	01	59	42	-	66	1.57	
46	1929	22 Aug	14	89	64	-	102	1.59	
47	1930	24 Jul	19	66	47	-	72	1.53	
48	1931	1 Aug	12	94	68	-	118+	1.74	
49	1932	17 Sep	08	55	40	-	69	1.73	
50	1933	29 Jul	21	44	32	-	58	1.76	
51	1934	1 Oct	20	48	35	-	58	1.66	
52	1935	7 Oct	22	47	34	31	55	1.77	
53	1936	17 Aug	04	97	70	70	115+	1.64	

Table 2 - Cont'd.

NO.	YEAR	DATE	L.M.T.	EXTREME MEAN HOURLY SPEED CUP FACTORS X3.0	X2.5	DINES	DINES GUST (MAX)	GUST FACTOR	REMARKS CHANGES TO INSTRUMENTS ARE NUMBERED 1 - 5
				"Miles"	Kt	Kt	Kt		
54	1937	2 Sep	04	93	67	65	130+	2.00	Observers estimated at least 130kt from the force with which the Dines piston struck the top of the tank. A calibrated anemograph about 2 miles E of the Observatory recorded 145kt.
55	1938	3 May	15	40	29	28	55	1.96	
56	1939	23 Nov	10	-	-	40	64	1.60	4) The cup anemograph was dismantled on 30 Sep 1938. New and old Dines anemographs were moved to the central position (previously occupied by the cups) on 21 Nov; the Dines head was raised to 9.75m above the roof, 53.95m A.M.S.L. Comparisons with a third Dines anemograph before and after the change were made.
57	1940	21 Aug	09	-	-	45	72	1.60	
58	1941	16 Sep	12	-	-	55	94	1.71	
	1942 - 1945		No records. Local Observers report no very severe typhoons.						
59	1946	18 Jul	-	-	-	-	95	-	No clock available to move the Dines chart - so no hourly wind speed.
60	1947	18 May	17	-	-	32	53 (42)	1.66	The maximum gust occurred in August.
61	1948	3 Sep	06	-	-	45	75	1.67	
62	1949	8 Sep	04	-	-	56	81	1.45	
63	1950	5 Oct	15	-	-	34	59	1.74	
64	1951	1 Aug	22	-	-	44	76	1.73	
65	1952	12 Jun	00	-	-	33	66 (62)	2.00	The maximum gust occurred in August.
66	1953	18 Sep	19	-	-	42	75	1.79	
67	1954	29 Aug	14	-	-	47	87	1.85	
68	1955	25 Sep	07	-	-	32	61	1.91	

Table 2 - Cont'd.

NO.	YEAR	DATE	L.M.T.	EXTREME MEAN HOURLY SPEED CUP FACTORS X3.0 "Miles"	X2.5 Kt	DINES Kt	DINES GUST (MAX) Kt	GUST FACTOR	REMARKS CHANGES TO INSTRUMENTS ARE NUMBERED 1 - 5
69	1956	25 Feb	07	-	-	32	52 (50)	1.63	Not associated with tropical cyclone.
70	1957	22 Sep	17	-	-	59	101	1.71	Maximum gust occurred in September.
71	1958	30 May	14	-	-	33	62 (59)	1.88	The maximum gust occurred in August.
72	1959	10 Sep	18	-	-	24	53 (47)	2.21	5) The Dines head was raised to 16.55m above the roof; 60.87m A.M.S.L. in July 1959 in an unsuccessful attempt to avoid the wake from new buildings east of the anemograph.
73	1960	9 Jun	02	-	-	50	103	2.06	The maximum gust occurred in June.

+ Accurate to 110 kt. The piston can travel to indicate 119 kt but spills air between 110 and 119 kt.

b. The gustiness as given by the total width of the velocity trace divided by the mean velocity during each hour - was 0.84 for the old location and 0.61 for the new location. These figures compare with 0.40 for anemographs at 12.19m over grassland in England (8).

This comparison shows that before 1938, the Cup and Dines anemographs were mounted too close to the roof to be considered well exposed, and that this increased the difficulties encountered in comparing their readings. More important, it shows that the extreme mean hourly speeds recorded by the Dines before and after moving, should be in fairly close agreement and that, in consequence, the Dines and corrected Cup observations should provide a reasonably standardized set of extremes.

For the first seven years (1911 - 1917) the Dines pressure tubes were only 1.25cm in diameter, in 1917 they were increased to 2.54cm. Although the change is not expected to have affected the measurement of mean wind speed, the old tubes certainly damped the maximum gust. The mean gust factor (maximum gust/mean hourly wind speed) for the first seven years was 1.47, for the first seven years with larger pipes it was 1.69 and for the first 20 years with larger pipes 1.67. Complete correction of the first seven extreme gusts for this damping effect is complicated, and not necessary for the present investigation as long as it is remembered that they are sub-standard.

SECTION III - THE DISTRIBUTION OF EXTREME WINDS

1. Mean Hourly Winds

Annual extreme mean hourly wind speeds have been arranged in order of increasing magnitude in Table 3. The relative frequency of occurrence - obtained by dividing the cumulative rank m by the total number of extremes N increased by one (9) - is also given. The mean hourly wind speed is then plotted against the relative frequency on extreme probability paper (Figure 2). If the extremes belong to Gumbel's double logarithmic distribution, the plotted points will approximate to a straight line, which is computed by a least squares method to minimize the diagonal distance from each plotted point to the line (11). The reduced variate $Y = \log_e(-\log_e P)$ is used as abscissa in these computations.

Confidence bands have been drawn on either side of the best line for a probability of 0.68 that the extreme mean hourly wind corresponding to any frequency will fall within the band. The distribution of extremes can be considered to be adequately represented by Gumbel's theory if two thirds of the plotted points fall within the confidence band.

2. Gusts

Similar computations were applied to the extreme gusts which are listed in order of magnitude in Table 4. The damped gusts corresponding

TABLE 3

ANNUAL EXTREME MEAN HOURLY WIND SPEEDS

1884 - 1941, 1947 - 1960

YEAR	M.H.W. kn	RANK m	P = $\frac{m}{n+1}$	YEAR	M.H.W. kn	RANK m	P = $\frac{m}{n+1}$
1959	24	1	0.014	1919	43	37	0.507
1938	28	2	0.027	1889	44	38	0.521
1914	30	3	0.041	1951	44	39	0.534
1935	31	4	0.055	1898	45	40	0.548
1925	32	5	0.069	1911	45	41	0.562
1933	32	6	0.082	1917	45	42	0.575
1947	32	7	0.096	1918	45	43	0.589
1955	32	8	0.110	1940	45	44	0.603
1956	32	9	0.123	1948	45	45	0.617
1892	33	10	0.137	1891	46	46	0.630
1899	33	11	0.151	1905	47	47	0.644
1903	33	12	0.165	1930	47	48	0.658
1912	33	13	0.178	1954	47	49	0.671
1924	33	14	0.192	1887	50	50	0.685
1952	33	15	0.206	1960	50	51	0.699
1958	33	16	0.219	1926	53	52	0.713
1950	34	17	0.233	1907	54	53	0.726
1901	35	18	0.247	1909	54	54	0.740
1910	35	19	0.260	1941	55	55	0.754
1934	35	20	0.274	1906	56	56	0.767
1888	36	21	0.288	1949	56	57	0.781
1920	37	22	0.301	1893	58	58	0.795
1921	37	23	0.315	1908	58	59	0.808
1885	38	24	0.329	1902	59	60	0.822
1890	38	25	0.343	1957	59	61	0.836
1895	38	26	0.356	1927	60	62	0.849
1886	39	27	0.370	1894	62	63	0.863
1897	40	28	0.384	1913	62	64	0.877
1904	40	29	0.397	1884	64	65	0.891
1915	40	30	0.411	1929	64	66	0.904
1916	40	31	0.425	1900	65	67	0.918
1922	40	32	0.439	1937	65	68	0.932
1932	40	33	0.452	1931	68	69	0.945
1939	40	34	0.465	1936	70	70	0.959
1928	42	35	0.480	1923	76	71	0.973
1953	42	36	0.493	1896	78	72	0.987

MEAN = 45.2 kn MODE = 39.4 kn

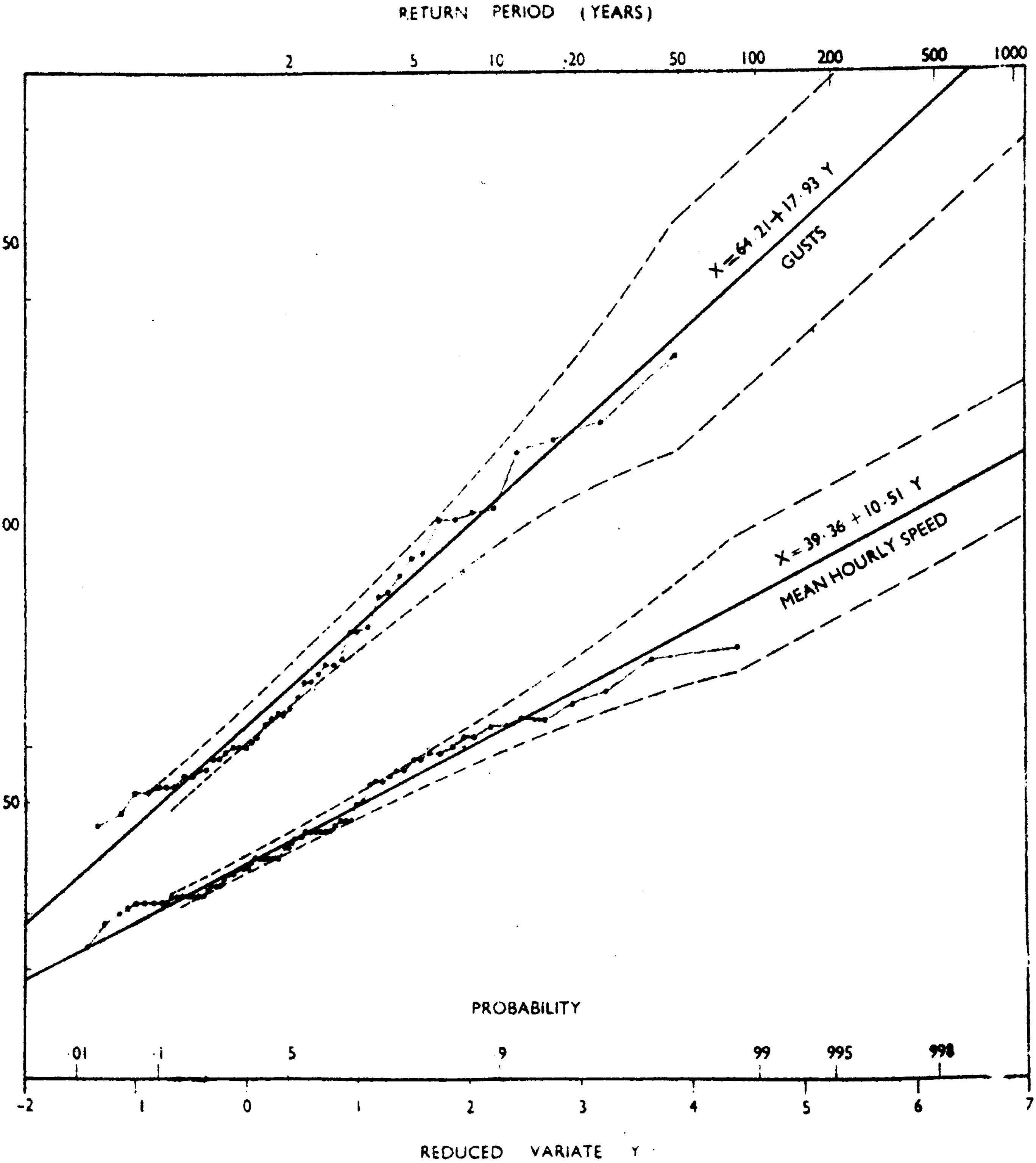

RETURN PERIOD (YEARS)
2
5
10
20
50
100
200
500
1000
WIND SPEED X (kt)
150
100
50
X = 64·21 + 17·93 Y
GUSTS
X = 39·36 + 10·51 Y
MEAN HOURLY SPEED
PROBABILITY
·01
·1
·5
·9
·99
·995
·998
-2
-1
0
1
2
3
4
5
6
7
REDUCED VARIATE Y

Fig. 2

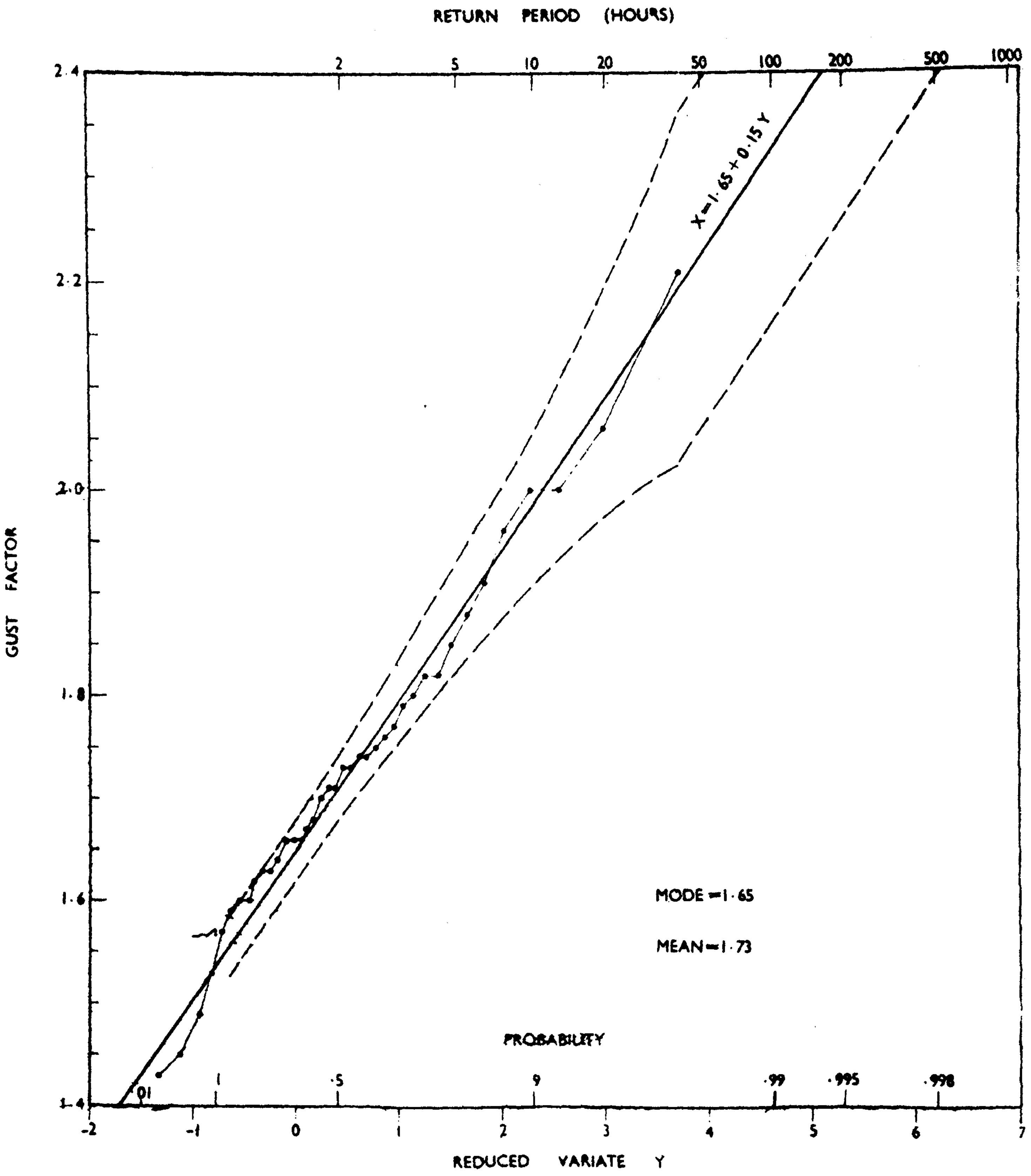

RETURN PERIOD (HOURS)
2
5
10
20
50
100
200
500
1000
GUST FACTOR
2·4
2·2
2·0
1·8
1·6
1·4
X = 1·65 + 0·15 Y
MODE = 1·65
MEAN = 1·73
PROBABILITY
·01
·1
·5
·9
·99
·995
·998
-2
-1
0
1
2
3
4
5
6
7
REDUCED VARIATE Y

Fig. 3

TABLE 4

ANNUAL EXTREME GUSTS (DINES-UNCORRECTED)

1911 - 1941, 1946 - 1960

YEAR	GUST kn	RANK m	$p = \frac{m}{n+1}$
1912	46	1	.0208
1914	48	2	.042
1910	52	3	.062
1956	52	4	.083
1920	53	5	.103
1947	53	6	.125
1959	53	7	.146
1935	55	8	.167
1938	55	9	.187
1916	56	10	.208
1925	56	11	.229
1933	58	12	.250
1934	58	13	.271
1950	59	14	.292
1915	60	15	.312
1921	60	16	.333
1924	60	17	.354
1955	61	18	.375
1958	62	19	.396
1959	64	20	.417
1922	65	21	.437
1928	66	22	.458
1952	66	23	.479
1911	67	24	.500
1932	69	25	.521
1930	72	26	.542
1940	72	27	.562
1919	73	28	.583
1948	75	29	.604
1953	75	30	.625
1951	76	31	.646
1949	81	32	.667
1917	81	33	.687
1918	82	34	.708
1954	87	35	.729
1926	88	36	.750
1913	91	37	.771
1941	94	38	.792
1946	95	39	.812
1927	101	40	.833
1957	101	41	.854
1929	102	42	.875
1960	103	43	.896
1923	113	44	.917
1936	115	45	.937
1931	118	46	.958
1937	130	47	.979

MEAN 74.0 kn MODE 64.2 kn

to the observations with narrow tubes on the Dines anemograph have been included in Table 4 and Fig. 2. The computations were performed three times: - i) using all gusts, ii) omitting the first seven years and iii) using all the observations but increasing the damped gusts by the factor 1.67/1.47, regardless of wind speed. The last two computations produced a more linear distribution of points in the middle and upper speed ranges but showed increased departures at, and below, 50kt. The line of best fit was not significantly affected by these changes.

Court (12) describes how the average return periods given in Fig. 2 can be used to determine the maximum wind to be expected over any given number of years, at any given level of risk.

3. Gust Factors

Since the gusts listed in Table 2 are extreme gusts, the tabulated gust factors constitute a set of extremes for the appropriate mean hourly wind speeds. Fig. 3 shows that they conform to the double logarithmic distribution with a mean of 1.73 and a mode of 1.65.

Gust factors before 1935 were determined using standardized Cup anemograph hourly means, after 1935 Dines hourly means were used. The gust factors constitute a reasonably homogeneous set - as can be seen by inspection, by reference to Fig. 3 and by computing the distribution and mean for the two sets - and therefore lend support to the method used to standardise the cup anemograph readings.

The data of Table 2 indicate a tendency for the extreme gust factor to decrease with increasing wind speed up to 35kt; thereafter the factor is widely distributed - about a mean of 1.69 - and a reliable determination of the trend is not possible from this data alone.

SECTION IV. QUICK-RUN ANEMOGRAPH OBSERVATIONS IN TYPHOON MARY, JUNE 1960

1. Data

A clock mechanism was fitted to the Royal Observatory Dines in 1958, to enable an hourly or daily rotation period to be selected, the former yielding a scale of one minute per 0.61cms. Using the remote recording facility, both normal and quick-run records were simultaneously obtained during Typhoon Mary on June 9th, 1960. In all, twenty four hours of quick-run records were obtained, but the first twelve hours were spoiled by the building to the east; fortunately, the wind veered off the building before the height of the storm, and one and a half hours of south-east to south-south-east winds were recorded before Hong Kong Island sheltered the Observatory anemograph. A further two hours of good records were obtained from a south-west to west-south-westerly direction before the storm moved inland and weakened (Fig. 1).

The one and half hours of south-easterly winds and the similar period of west-south-westerly winds were selected for analysis. The ten minute mean wind speeds remained substantially constant throughout both these periods i.e. there was no trend - although the south-easterlies were considerably more gusty than the south-westerlies. All available observations suggest that the period selected for study covers a steady state in the life of the storm, and that weakening - consequent on a trajectory over land - did not start until several hours later.

At its closest the storm center was 13 miles WNW of the Royal Observatory with a minimum central pressure (from island barograms) of about 967mb; this puts the storm in the least intense class of Frank and Jordan's (4) typhoon classification by pressure. The internationally accepted definition of a typhoon (hurricane) calls for sustained winds of 64kt or more. Both Waglan Island and the Royal Observatory recorded winds over this value for several minutes, and if it is accepted that a 10 minute mean represents a sustained wind, then it is most likely that this was just achieved offshore.

Since mean wind speeds over different time intervals are of interest to the engineer, it was decided first to obtain these means over intervals ranging from one hour to a few seconds, and then to examine their relationship to each other. The response of the Dines anemograph to changing wind speed, and its variation with pipe length and diameter, have been studied at the National Physical Laboratory (13). The response improves with wind speed and Table 5 (14) gives an indication of the magnitude of the time of response at mean speeds of 52 and 18 knots. From these measurements Giblett (13) concludes that for accurate work, speeds should not be taken over intervals of less than five seconds.

TABLE 5

RESPONSE OF THE PRESSURE-TUBE ANEMOGRAPH MKII TO PRESSURE VARIATION APPLIED THROUGH 30.5m AND 2.54cm PIPING

WIND SPEED OF 52KN		WIND SPEED 18KN.	
Periodic Time of Applied Pressure Variation	Indicated Press. Range / Applied Press. Range	Periodic Time of Applied Pressure Variation	Indicated Press. Range / Applied Press. Range
Sec.		Sec.	
-	-	10	0.96
4.6	1.0	4	0.70
2.3	1.0	2	0.47
1.65	0.42	-	-
1.15	0.14	-	-

The Hong Kong quick-run records were photographically enlarged approximately seven times, and at this scale five second means were readily obtained by the method of equal areas; in all 1,884 five second intervals were measured and checked. Means for one hour, 600, 300, 60, 30 and 10 seconds were obtained from the five second means. Thirty second means were also measured independently and used as check on errors and accuracy.

From the Cardington observations Giblett has shown that, if OP_r and OP_{r+1} (Fig. 4) represent successive 5 second mean winds then the mean of the moduli of the vector difference of the consecutive 5 second means i.e. $\sum |P_r P_{r+1}|/n$ is linearly related to the mean wind, under lapse conditions.

In addition, he showed that the mean eddy speed, as given by the mean of the moduli of the vector difference between the five second mean and the mean wind i.e. $\sum |MP_r|/n$ is also linearly related to the mean wind speed but with considerably less precision. Using the same data Durst (15) has recently shown that - apart from rare occurrences - the distribution of the 5 second mean wind speeds M(5) about the 600 second mean wind speed M(600) closely follows the normal distribution, and that the standard deviation given by $\sigma(600,5) = \sum \left[[M(600) - M(5)]^2/(600/5-1) \right]^{\frac{1}{2}}$ was nearly proportional to M(600) - he derived correlation co-efficients of about 0.9 for the case of five second and 60 second means.

The short period means from Typhoon Mary were examined to determine if the standard deviation was related to the mean in the manner described by Durst. The standard deviation of five second means about the ten minute means $\sigma(600,5)$ was determined for five ten minute periods of south-westerly winds; the values are shown in Table 6. The ten minute mean ranged from 19kt to 50kt, but the 19kt value had to be obtained from observations in tropical storm Nora September 1960. The mean value of $\sigma(600,5)/M(600)$ for the five means was 0.180 with a standard deviation of 0.018kt. The observations have been plotted in Fig . 5 where the full line - constrained to pass through the origin - represents their mean ratio of 0.180. Durst obtained an average value of 0.145 for this ratio from seven cases in the speed range 10kt to 36kt; the corresponding line is shown in Fig. 5.

In the case of south-easterly winds, the speed range covered is not sufficient to satisfactorily examine the relationship between σ and M. However, there is no reason to suppose that the south-easterlies should differ from the south-westerlies and Cardington observations in this respect, and it will therefore be assumed that $\sigma(600,t)/M$ is approximately constant for south-easterlies as well as south-westerlies in the mean hourly speed range of 30kt to 100kt and for all values of t between 5 sec and 600 sec.

The wind direction did not veer clear of the building to the east of the anemometer until the speed was greater than 39kt, but the seventeen ten minute periods of south-easterly winds have been analyzed and the data is shown in Table 6 and plotted in Fig. 5.

It will be seen that the points corresponding to the south-easterlies show a considerable scatter. On examining the original anemograms it is clearly seen that the points close to line A contain a strong squall component with a period approximating to two minutes (Fig. 6). The points close to line C derive from traces with a normal appearance whilst the six points close to line B were obtained from traces showing

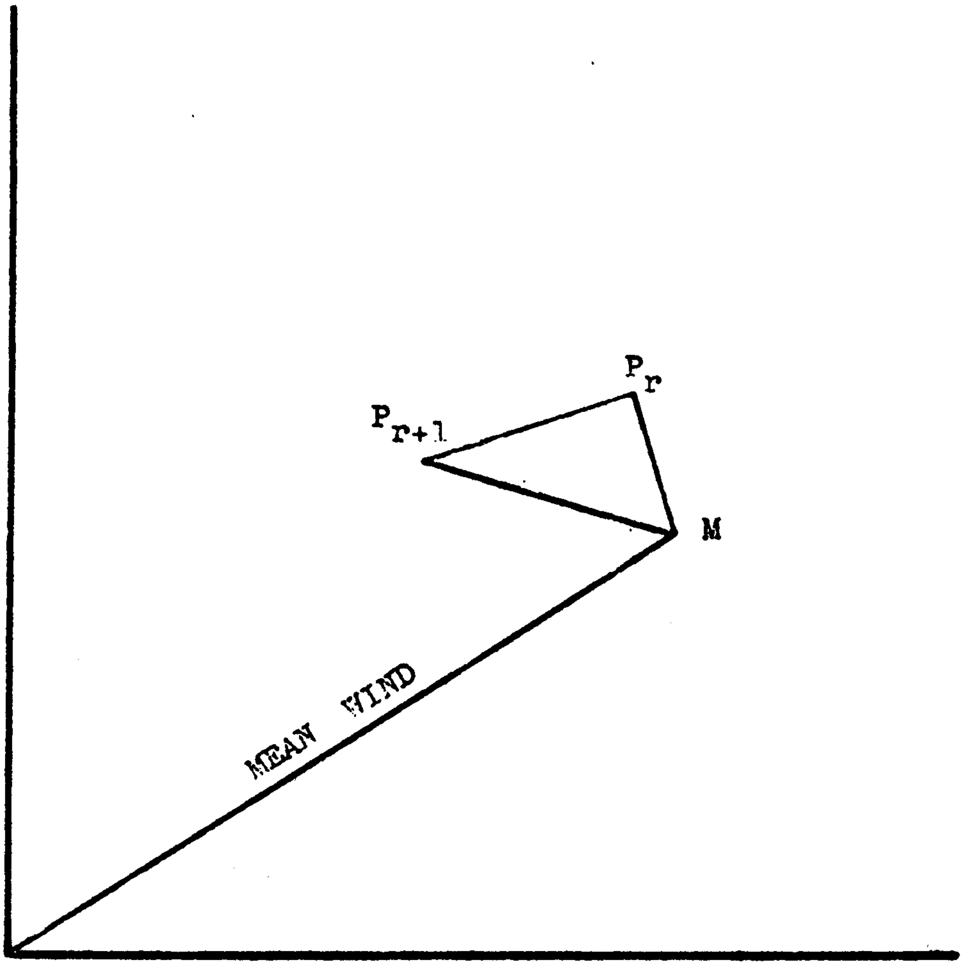


Fig. 4.

P_r and P_{r+1} are consecutive five second means.

TABLE 6

STANDARD DEVIATIONS OF FIVE SECOND MEANS ABOUT TEN MINUTE MEANS

SOUTH WESTERLIES

TEN MINUTE NO.	TEN MINUTE MEAN M(600) Kt	$\sigma(600,5)$ Kt	$\frac{\sigma(600,5)}{M(600)}$	
1	51.1	7.43	0.146	MEAN
2	51.3	9.07	0.177	0.180
3	50.8	8.91	0.176	σ : 0.018
4	32.3	6.03	0.187	
"Nora"	19.05	4.05	0.213	

SOUTH EASTERLIES

TEN MINUTE NO.	TEN MINUTE MEAN M(600) Kt	$\sigma(600,5)$ Kt	$\frac{\sigma(600,5)}{M(600)}$	
1	47.3	9.93	0.210	
2	48.0	9.56	0.192	
3	49.1	10.35	0.211	
4	46.1	11.34	0.246	
5	43.3	12.20	0.282	
6	44.5	12.84	0.288	MEAN
7	47.6	11.04	0.232	0.237
8	48.2	12.33	0.255	
9	48.8	12.74	0.261	σ : 0.029
10	47.1	11.69	0.248	
11	47.8	11.71	0.245	
12	52.3	10.58	0.200	
13	49.7	11.40	0.229	
14	47.5	10.86	0.228	
15	45.0	9.03	0.201	
16	41.2	8.52	0.207	
17	38.9	10.56	0.271	

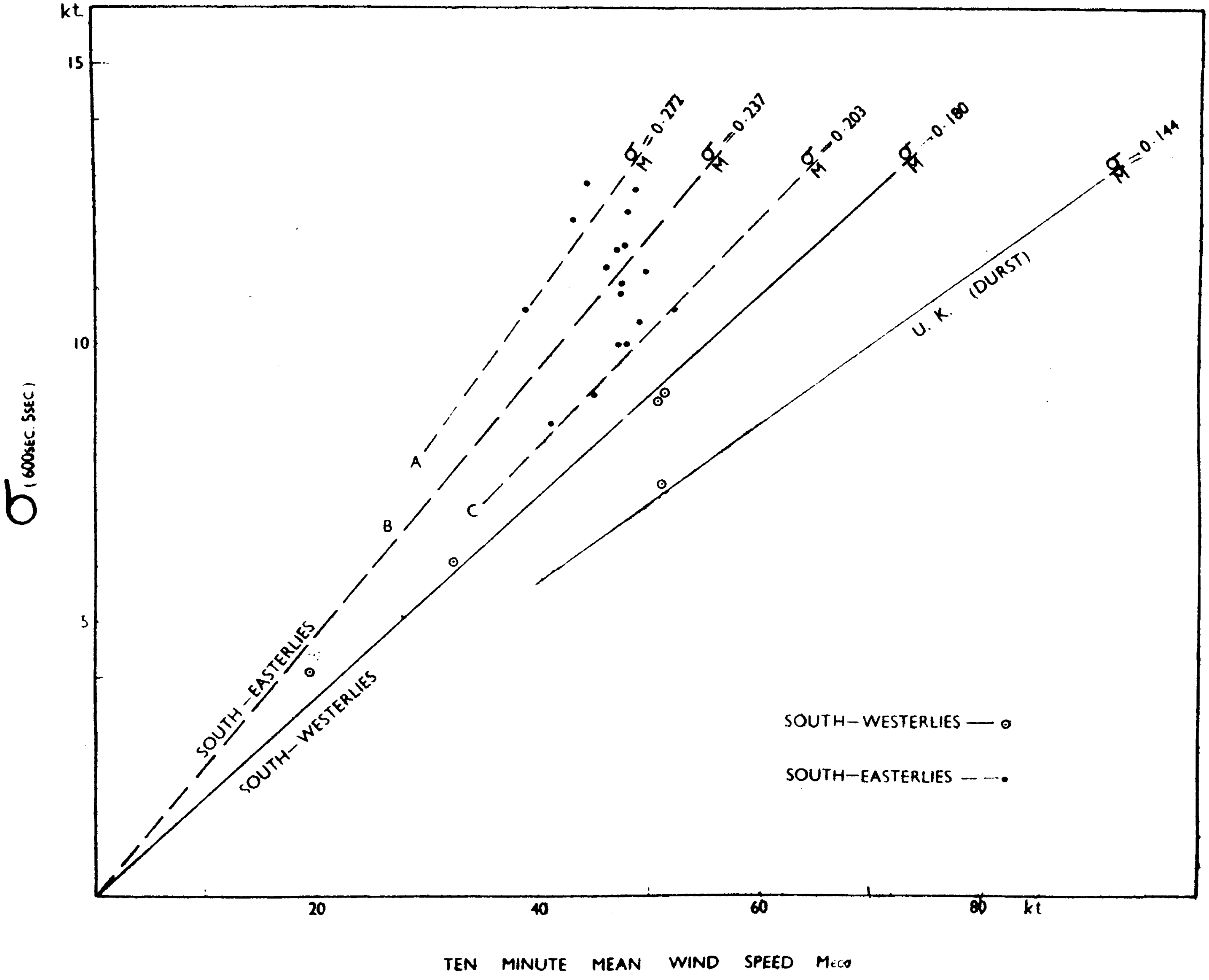
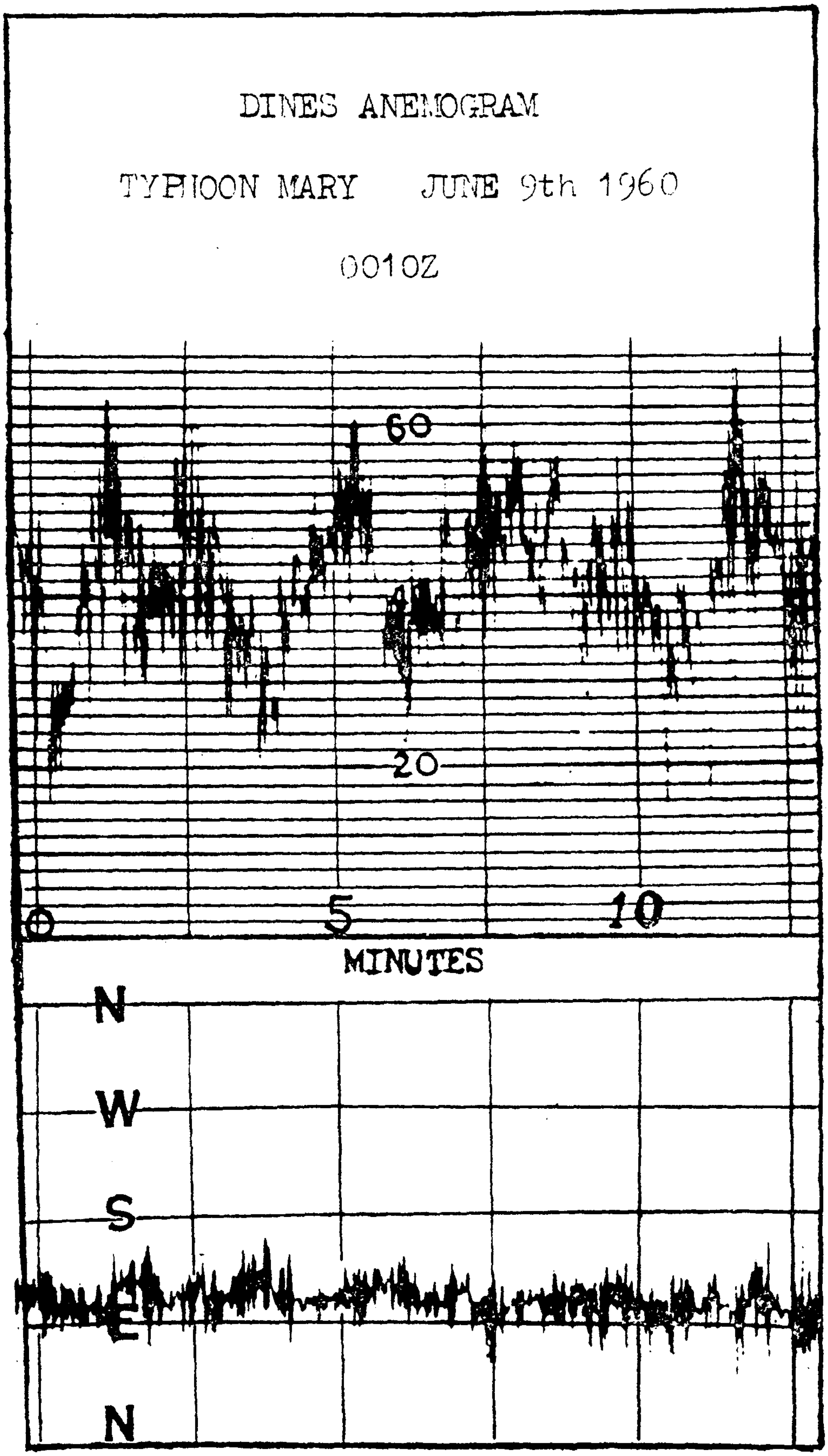

kt
15
10
5
σ (600sec. 5sec)
σ/M = 0·272
σ/M = 0·237
σ/M = 0·203
σ/M = 0·180
σ/M = 0·144
A
B
C
U. K. (DURST)
SOUTH–EASTERLIES
SOUTH–WESTERLIES
SOUTH–WESTERLIES —— ⊙
SOUTH–EASTERLIES – – •
20
40
60
80
kt
TEN MINUTE MEAN WIND SPEED Mₑcₒ

Fig. 5


DINES ANEMOGRAM
TYPHOON MARY JUNE 9th 1960
0010Z
60
20
0
5
10
MINUTES
N
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E
N

Fig. 6

a lesser, irregular, two minute component together with a component of approximately five minutes period. The analysis will proceed using the mean value of $\sigma(600,5)/M(600)$ i.e. 0.237, but the effects of using values corresponding to the lines A and C will subsequently be evaluated.

Frequencies of five, ten, thirty and sixty second mean wind speeds in each ten minute period were plotted on normal probability paper. For twenty-four ten minute runs, no marked departure from a normal distribution was found. In general, the short period means for the less turbulent south-westerlies fitted the normal distribution more precisely than the squally south-easterlies.

2. Computation of Probable Hourly Extremes

Following Durst, we can now compute the probable maximum short period mean wind speed during one hour, for each of the chosen intervals. Standard deviations for various combinations of mean hourly wind speed and short period means are multiplied by a factor - dependent on sample size - to obtain the probable extreme departure in one hour. The probable normal extremes for sample size n are found at f times the standard deviation from the mean, where f has the following values:

Duration of short period mean t	600sec	300sec	60sec	30sec	10sec	5sec
Sample size n = 3600/t	6	13	60	120	360	720
Factor for extremes - f	1.2	1.5	2.1	2.4	2.8	3.0

Table 7 shows values of $\sigma(1hr,t)/M(1hr)$ for various values of t and for south-easterlies, south-westerlies and squally south-easterlies. Durst's values have been included for comparison. Using values of σ/M from runs number one and three, Table 8 has been derived to yield standard deviations for various values of M(1hr). Multiplying these standard deviations by the appropriate factor f, and adding the result to the relevant hourly mean we obtain the probable maximum short period means listed in Table 9. The extreme short period means observed in Typhoon Mary have been entered in parenthesis against the appropriate mean hourly wind speed of 50kt. The differences do not amount to 5%, and for mean hourly wind speeds close to 50kt the earlier assumption would appear to be justified. To calculate the maximum velocities which would occur if the squally south-easterlies persisted for a whole hour, it is necessary to determine $\sigma(1hr,t) / M(1hr)$ for these winds. This is done by combining $\sigma(1\,hr,600) / M(1hr)$ for south-easterlies with the value of $\sigma(600,5) / M(600)$ for the squally south-easterlies using the relation:

$$\sigma(1hr,t) / M = \left[\left[\sigma(1hr,600)/M\right]^2 + \left[\sigma(600,6)/M\right]^2 \right]^{\frac{1}{2}}$$

Values of $\sigma(1hr,5)$ and $\sigma(1hr,60)$, as computed, are given in Table 7.

TABLE 7

VALUES OF $\sigma(1hr,t)/M(1hr)$ FOR VARIOUS VALUES OF t

	RUN NO.	HOURLY MEAN SPEED	t							
			600sec	300sec	120sec	60sec	30sec	20sec	10sec	5sec
		kt	$\sigma(1hr,t)/M(1hr)$							
SOUTH EASTERLIES	1	48	0.045	0.061	-	0.133	0.177	-	0.228	0.240
	2	49	0.048	0.058	-	0.111	0.151	-	0.224	0.244
SOUTH WESTERLIES	3	51	0.016	0.035	0.064	0.098	0.132	0.136	0.148	0.167
SQUALLY SOUTH EASTERLIES	1	48	0.045	0.061	-	0.148	-	-	-	0.276
CARDINGTON (DURST)	-	-	0.065	-	-	0.115	0.132	0.140	0.150	0.159

TABLE 8

VALUES OF σ(1hr,t) JUNE 1960

SOUTH EASTERLIES

	σ(1hr,t)/M(1hr)					
MEAN HOURLY WIND SPEED	0.045	0.061	0.133	0.177	0.228	0.240
M(1hr) kt	600sec	300sec	60sec	30sec	10sec	5sec
	σ(1hr,t) knots					
30	1.35	1.83	3.99	5.31	6.84	7.20
40	1.80	2.44	5.32	7.08	9.12	9.60
50	2.25	3.05	6.65	8.85	11.40	12.00
60	2.70	3.66	7.98	10.62	13.68	14.40
70	3.15	4.27	9.31	12.39	15.96	16.80
80	3.60	4.88	10.64	14.16	18.24	19.20
90	4.05	5.49	11.97	15.93	20.52	21.60
100	4.50	6.10	13.30	17.70	22.80	24.00

SOUTH WESTERLIES

	σ(1hr,t)/M(1hr)					
MEAN HOURLY WIND SPEED	0.016	0.035	0.098	0.132	0.148	0.167
M(1hr)	600sec	300sec	60sec	30sec	10sec	5 sec
kt	σ(1hr,t) knots					
30	0.48	1.05	2.94	3.96	4.44	5.01
40	0.64	1.40	3.92	5.28	5.92	6.68
50	0.80	1.75	4.90	6.60	7.40	8.35
60	0.96	2.10	5.88	7.92	8.88	10.02
70	1.12	2.45	6.86	9.24	10.36	11.69
80	1.28	2.80	7.84	10.56	11.84	13.36
90	1.44	3.15	8.82	11.88	13.32	15.03
100	1.60	3.50	9.80	13.20	14.80	16.70

TABLE 9

PROBABLE VALUE OF THE MAXIMUM t SECOND MEAN WIND SPEED EXPECTED DURING ONE HOUR FOR DIFFERENT VALUES OF THE MEAN HOURLY WIND SPEED

SOUTH-EASTERLIES

STEADY MEAN HOURLY WIND SPEED	t 600sec	 300sec	 60sec	 30sec	 10sec	 5sec
	knots					
30	32	33	38	43	49	52
40	42	44	51	57	66	69
50	53 (53)	55 (53)	64 (61)	71 (69)	82 (81)	86(82)
60	64	66	77	85	98	103
70	74	76	90	100	115	120
80	85	87	102	114	131	138
90	95	98	115	128	147	155
100	105	109	128	142	164	172

SOUTH WESTERLIES

STEADY MEAN HOURLY WIND SPEED	t 600sec	 300sec	 60sec	 30sec	 10sec	 5sec
	knots					
30	31	32	36	40	43	45
40	41	42	48	53	57	60
50	51 (51)	53 (52)	60 (57)	66 (65)	71 (72)	75 (74)
60	61	63	72	80	85	90
70	71	74	84	92	99	105
80	82	84	96	106	113	121
90	92	95	108	115	127	135
100	102	105	121	132	141	150

Wind speeds measured in Typhoon Mary are shown in parenthesis but the south-westerly observations refer to only twenty four minutes of observation.

Using these values it is found that the maximum short period means listed in Table 9 for south-easterlies should be increased by 6% to obtain the values which would obtain if the squally type of flow persisted for a whole hour. From the available data this would seem to be an unlikely event, and Table 9 shows that the use of the average values gives good results.

The probability of a mean hourly wind of any magnitude can be obtained from Fig. 2, and by entering Table 9 at the appropriate mean hourly wind speed the associated maximum short period means can be obtained. The probability of extreme mean winds over any period from five seconds to one hour can thus be determined.

SECTION V. CONCLUSION

Work on gust factors - Table 9 provides a set - and energy spectra is still in hand, and until these analyses are completed it is too soon to comment on the causes and periods of the observed eddy components. In an effort to determine how much of the wind structure observed in Typhoon Mary is due to topography, a quick-run recorder has been fitted to the well exposed Dines anemometer on Waglan Island, where it awaits the next typhoon.

SECTION VI. ACKNOWLEDGEMENTS

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