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PAPER 2

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Some Characteristics of Winds related to the Building Code in Hong Kong

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1. Introduction

The design of safe and comfortable buildings against meteorological extremes is clearly a collaborative undertaking involving both engineering knowledge and detailed meteorological information. Among the various meteorological parameters, strong or gusty winds can be extremely destructive and certainly merit the attention of this seminar.

The effects of wind on buildings had been assessed in various studies in Hong Kong (Lun (1970), Mackey (1970), Chen (1975), Choi (1983)). The results are incorporated into the "Code of Practice on Wind Effects" promulgated by the Building Development Department of the Hong Kong Government. The Code which was updated in 1983, particularly utilized a determined peak gust velocity with a return period of 50 years to derive the design wind pressure, the forces on complete buildings and building elements as well as the dynamic effects and stability of a building.

This paper attempts to look at the derivation of this threshold of wind. Different values of this threshold can be arrived at using different statistical methods. The variation of winds in Hong Kong is also assessed through time and space in this paper.

2. Higher Winds in Hong Kong

Monsoon winds dominate during a large part of the year in Hong Kong. In general there are four fairly well-marked seasons of unequal durations. A cold dry winter with continental north to northeast monsoon lasts from November to February. A damp and misty spring with spurts of east to northeasterly monsoon is mainly confined to March and April. A hot and wet summer from May to mid-September has a nearly constant temperature and on average about six tropical cyclones that necessitate the hoisting of warning signals in Hong Kong. The short autumn from mid-September to the beginning of November is pleasantly clear and dry. These are also the months with early surges of continental air from China.

The monthly distribution of the more destructive higher winds, or gale force winds of 17.5 ms^{-1} or over, is shown in Table 1. Nearly 85% of the gale force or above mean hourly winds at Waglan Island occur during the months from June to October. The majority of these are due to tropical cyclones, although it can also been seen that the months of September and October are also affected by a notable proportion of windy monsoon occasions. In fact, the months of September and October have the highest proportion or nearly 50% of gale force winds in the year. In the year as a whole, about 84% of gale force winds are associated with tropical cyclones, 15% with monsoon winds and the rest, or 1%, due to other weather systems which include squally thunderstorms, downbursts, or other phenomena of a more transient nature.

3. Estimating Extreme Values of Wind in Hong Kong

(a) Concept of a mean recurrence period

The proper statistical description of rare events in meteorology depends on the use of extreme value analysis. The description of rare events is usually expressed in terms of the magnitude of a stated meteorological event that is likely to occur with a given probability in a given year. For example, a mean recurrence period of once in 50 years has been widely adopted for wind loading codes, e.g. in Hong Kong, United Kingdom, etc. There is a probability in any one year of 1 in 50 of these design values being exceeded, or, over a period of 50 years there is a probability of 0.64 that it will be exceeded at least once. There is also a probability of 0.36 that it will not be exceeded even once every 50 years. Table 2 gives the probability of the number of years in a 50-year and a 20-year period in which the 50-year mean recurrence event will be exceeded.

In the 1983 Hong Kong Code, the estimated 50-year return period gust velocity for Waglan Island is chosen as a basis for estimating wind loading in Hong Kong. Some recently used values of mean occurrence period for various aspects of meteorological loading designs used in other countries are given in Table 3.

(b) Statistical techniques for estimating extreme values

As the wind speed varies from month to month depending on the meteorological regime, a set of monthly maxima from different months in a period of years does not form a consistent series for the purposes of extreme value analysis. The annual maxima is thus used. The distribution function describing the annual maxima of wind is, however, usually not the normal distribution (Page (1976)).

Different distribution functions have been used to calculate extreme values on an appropriate statistical basis. In Hong Kong Chen (1975) and Lun (1970) have applied the Gumbel distribution satisfactorily. In the USA and USSR, the Frechet extreme value distribution provides a reasonable basis for obtaining design loads for wind. Application of the Type III extreme, or Weibull distribution to the winds in Hong Kong is also made in this paper.

Gumbel

The Gumbel distribution of maxima (or minima) is given by the functional equation.

$$P^n(x) = P(a_n x + b_n) \quad \ldots\ldots \quad \ldots\ldots \qquad (1)$$

where x is the random variable

a_n and b_n are parameters

n is the number of events in N samples

Assuming an unbounded distribution which is expotential as x increases

$$P(x) = \exp[-\exp - \alpha(x - \beta)] \quad \ldots\ldots \qquad (2)$$

where P (x) is the cumulative probability

α is the dispersion and

β is the mode.

Weibull

The Weibull distribution was shown by Stewart and Essenwanger (1978) to be a flexible distribution for describing wind speeds. It had also been used for various studies in wind energy (Justus et al (1976) and Hennessey (1977)).

The density function takes the form

$$P(x) = 1 - \exp\left[-\left(\frac{x - \alpha}{\beta - \gamma}\right)^{\alpha}\right] \quad \ldots \qquad (3)$$

where α is the shape parameter

γ the location parameter

and $\beta - \gamma$ the scale parameter.

The 3 parameters α, β and γ are estimated by the method of moments from computer programs given in Kite (1977).

(c) Comparison of results using different statistical techniques

Waglan Island's annual maximum hourly and gust speeds (1953-85) fitted to the Gumbel and Weibull probability distributions are shown in Figures 1 and 2 respectively. It can be seen from the graphs that either distribution fits the annual extreme values reasonably well. Applying the Kolmogorov-Smirnoff test for goodness of fit to the 33 observations for either distribution yielded acceptable P values of less than 0.23.

The 50-year return period estimation of maximum hourly and gust speeds at Waglan Island for both the Gumbel and Weibull distributions are tabulated in Table 4. The previous results of Chen (1975) and Lun (1970) are also shown for comparison.

Even though both Gumbel and Weibull distributions yielded reasonably good fit for the Waglan wind extreme values, it can be seen from Table 4 that appreciably different values can be obtained for the 50-year return period. There are several possible reasons: the different density functions place emphasis on different values of the samples; the use of different data periods; different basic data treatment and also possibly different curve fitting techniques used by different authors. Differences in the estimated 50-year speed values are particularly large for the hourly means compared to the gust speed. In the 1983 Code, the value of 70.5 ms^{-1} is used as the determined peak gust velocity to derive the wind pressure (q) from the dynamic wind pressure equation (see Chapter 3 in Choi (1983)). It is of interest to note that this chosen value of 70.5 ms^{-1} falls in the middle ranges of the various estimates for gusts in Table 4.

4. Vairation of Winds in Hong Kong

(a) Observations of surface winds

A network of 23 stations over the territory provide on a regular basis observations of wind to the Royal Observatory. Four of these stations are manned round-the-clock by Observatory personnel, five are automatic stations and the rest have been set up in co-operation either with other government departments or private concerns. Waglan Island is usually regarded as the most ideally exposed and unobstructed site. Wind records from this station is usually taken as a standard for comparison. A map showing locations of these stations is at Figure 3.

(b) Topography

Because of the rugged and hilly land, observed surface winds vary widely with location. Even at the same location, winds can be sheltered from one direction but well exposed to another so that wind speeds at the point depend on the wind direction. It is therefore not possible to just use winds observed at the well-exposed Waglan Island and then derive a one-to-one relationship between winds experienced at different locations in

Hong Kong. On one occasion, winds experienced at one station may be higher than the other, but on another, they may be lower.

Due to obstacles and topography, wind speeds recorded at certain stations depend very much on the wind direction. For instance, the Star Ferry station is relatively sheltered by high buildings from northerly winds but has a good exposure to easterly ones. Among all stations, Waglan Island usually records the highest mean winds and the Royal Observatory, one of the lowest. Tate's Cairn and Cheung Chau also record high winds except winds recorded during easterly monsoons are relatively light at these stations. Winds recorded at the Airport are close to those at King's Park except for easterlies when the former records higher winds than the latter. Green Island sometimes exhibit dramatic chanelling of easterlies but when winds are coming from the north during winter monsoon, speeds are relatively lower. The Castle Peak station is sheltered by mountain ranges to the east and west. Winds from these directions are usually low, but northerly and southerly wind speeds are usually high.

Figure 4 shows the wind roses of some of the stations mentioned above. It also illustrates some of the points mentioned in the previous paragraph.

(b) Variation in mean wind gust due to site

To further assess the variability of winds over Hong Kong both in time and space, one can examine the trends of gustiness of various stations. Figure 5 shows the trends for stations - Waglan Island, Cheung Chau, Hong Kong International Airport and the Royal Observatory. For each station, a plot of the annual maximum mean wind and gust in time is shown. For Waglan Island and Cheung Chau, little change in trend of either the mean wind or gust can be detected. This is reasonable, as the topography and exposure of these stations have been generally unchanged during the period particularly for Waglan Island, which enjoys a fair wind fetch over water in most directions. At the Royal Observatory site, a notable decrease of the mean wind is seen. This can be attributed to the building developments in the vicinity since the 1960s, despite the heightening of the anemometer mast to 29.1 m above the ground in 1959, and to 43.8 m above the ground (71.7 m above msl) in 1982. A point of interest to note also, is the gusts at the Royal

Observatory exceeded those at Waglan Island in the years 1962 and 1971, during the passages of T. Wanda and T. Rose respectively. This has a certain bearing on the comparison of 50-year return gusts to be discussed in Section 4(e).

Another way of looking at the gustiness trend is by the gustiness factor, which is defined as the ratio of the maximum gust to the sustained wind over the same interval of time. Figure 6 is a plot of the annual mean gustiness factors in strong winds or above at the Royal Observatory and Waglan Island. The Figure indicates a sharp rise in the gustiness factor at the Royal Observatory around 1957 while the Waglan Island trend has remained quite constant. This clearly illustrate the effect of increasing the roughness in the urban area around the former site.

The effect of buildings on the wind regime is complex. There are urban situations, where strong funnelling may occur between buildings. Strong winds for example can occur between tall slab blocks arranged in a Y formation. The perturbation of wind in the gap can cause a heavy loading. The siting criteria for meteorological instrument, however, do not recommend anemometers to be sited at such locations. Hence the documentation of such situations are rare, if at all. The effect of future urban forms in a small scale such as a building block may produce complex changes in an urban wind field.

(d) Case studies

In this section, an attempt is made using readily available records, to show graphically the highly variable characteristic of winds in Hong Kong under different meteorological regimes.

The hilly terrain of Hong Kong and the proximity to the sea provide favourable ingredients for meso- to microscale variations in the flow regimes in different parts of Hong Kong. Terrain forces air to flow either around or over a mountain, causing leeside effects such as the formation of a trough or vortex. When the synoptic scale flow is weak, local circulation due to daytime heating dominates, producing wind directions that can be very different than those of the synoptic scale.

Six cases are presented to demonstrate such variability. In three of the cases, the synoptic scale forcing was strong and thus diurnal variation was minimal. Terrain effects therefore controlled the variability. Two of the other three cases involved weak synoptic scale flow. Daytime heating became the main contributing factor to the wind variability although the terrain still played a significant part in modifying the flow patterns. If daytime heating is absent (as in a cloudy or overcast day) when the synoptic scale forcing is weak, the variability is similar to that of the first three cases. The last case shows that the existence of two flow regimes over the territory as a result of land effects over south China.

Points of interest for each case are annotated as follows:

CASE 1: Strong north to northwesterly flow associated with T. Lynn (87102406) (Figure 7(a))

. turning of the winds to west-northwesterly in the western part of the harbour due to leeside effects of mountain terrain to the north

. confluence over the southeastern part of Hong Kong resulting from the turning of the winds observed in (a)

. diffluence over Lantau Island as a result of deflection by mountain range on the island

CASE 2: Intense northerly surge (87112906) (Figure 7(b))

. vortex formation over Tsing Yi Island due to leeside effect

. weak trough extending across the Territory at about the latitude as Tsing Yi Island probably due to the mountain ranges to the north

. winds much weaker inside the harbour as a result of sheltering

CASE 3: Strong northeasterly winds associated with T. Wayne (86082012) (Figure 7(c))

. turning of the winds to almost northerly in the western part of the harbour and west of Lantau Island due to leeside effects

CASE 4: Weak northerly flow with sunshine (87110900-87110906) (Figure 7(d))

. prior to daytime heating (87110900):

(i) westerly winds in the harbour areas due to sheltering

(ii) trough extending across Hong Kong along the latitude of the harbour in the morning due to leeside effects

. around the peak of land heating (87110906):

(i) sea breeze from all sides towards land, winds in the eastern part becoming easterly and those in the western part westerly

(ii) formation of vortices in areas where convergence between two different flow regimes occurred

(iii) main trough extending from northwestern part of the NT to south of Tai Mo Shan and then almost eastward to the Sai Kung area

(iv) ridge flow over Lantau Island and Hong Kong Island

CASE 5: Weak easterly flow with sunshine (87100600-87100606) (Figure 7(e))

. Prior to daytime heating (87100600):

(i) northeasterly flow in the western part of the NT and Lantau Island due to leeside effects

. Around time of maximum heating (87100606):

(i) easterly winds remaining to the eastern part part but winds over the western part of the NT becoming west to southwesterly

(ii) convergence between the two flow regimes led to the formation of a vortex over Deep Bay

CASE 6: Convergence between easterly and northerly after a northerly surge (87110218 & 87110518) (Figure 7(f))

. Initial northerly surge:

(i) winds turning to westerly inside the harbour, as is the case for northerly flow regimes

(ii) initial northerly surge producing a trough across the Territory along the latitude of Tsing Yi Island with a vortex to the east of the island

Winds turning easterly 3 days after northerly surge:

(i) easterly flow prevailed over the eastern part of harbour but northerlies remained to the west and north probably due to effects of the Pearl Estuary

(ii) convergence between the two flow regimes led to the formation of a vortex in the Tuen Mun area

(iii) ridge flow over Lantau Island

(e) Extreme gusts at various stations

The complex topography and the built-up urban areas of Hong Kong cause the enormous complexities in the patterns of airflow which vary very sharply in both space and time. Variations in the stability of the boundary layer (or the lowest ½ km to 1 km of the atmosphere) also adds another dimension to the diversity of the flow patterns. It may therefore be interesting to compute peak gust velocities at other wind stations in Hong Kong and compare these values to those at Waglan Island.

Following the procedure described in Section 2(b), the Gumbel estimation of 50-year return period mean winds and gusts are computed for some other stations with a reasonable length of record in Hong Kong - Cheung Chau, Royal Observatory and Hong Kong International Airport. In order to avoid the changing degree of urbanization around the site, the Royal Observatory data considered is from 1951 to 1985 only, despite the availability of a much longer period of data. Table 5 shows the results.

Values of the return periods of mean winds are generally as expected. In the rural, better-exposed sites the 50-year return period mean winds are higher, 47.4 ms^{-1} and 46.8 ms^{-1} respectively for Waglan Island and Cheung Chau versus the urban, somewhat obstructed sites of Royal Observatory and Kai Tak, with values of 35.8 ms^{-1} and 38.2 ms^{-1} respectively. The results are almost similar for the gust speed, except that the Royal Observatory site exhibited a rather high value of 70.3 ms^{-1} compared to the Waglan Island value of 73.8 ms^{-1}. This may be attributed to the increase in gustiness factor at the Royal Observatory and the inclusion of high values of annual extreme gusts of 1962 and 1971 in the data set.

5. Concluding Remarks

The Code of Practice on Wind Effects in Hong Kong (1983) gave general guidance for using a 50-year return period gust for calculating the wind loading in the structural design of buildings in Hong Kong. The choice of observation of winds from the station Waglan Island to arrive at this estimate is judicious as the station enjoys a fair exposure to winds from all directions for a very long time. The mean winds and gust characteristics of the station is also generally unchanged through the year. The choice of a statistical function to describe the distribution of extreme winds seems to be good either using the Gumbel or the Weibull functions. With hindsight, however, the choice of 70.5 ms^{-1} value using the Gumbel method seems to be in order, considering also it is approximately in the middle ranges of various possible values obtained from different stations, for different time periods and using different statistical methodologies. The Code of Practice also suitably allows for the possibility of using experimental wind tunnel data with reference to local conditions so that in-situ information can be used in place of coefficients given in the Code. Obviously, a degree of judgement needs to be exercised in deciding a safe enough weather-design value that will not on the other hand entail over-designed engineering works.

Acknowledgements - Thanks are due to Dr. J. Chan for his help with case studies and to Dr. W.L. Chang for carrying out the Weibull analysis.

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	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Due to strong monsoon	8	12	21	11	2	10	1	0	33	79	22	54	253 (15.3%)
Due to tropical cyclone	0	0	0	0	46	132	232	221	320	361	67	0	1379 (83.6%)
Due to other weather phenomena	1	0	0	1	0	0	0	3	2	6	2	2	17
Due to all systems/phenomena	9	12	21	12	48	142	233	224	355	446	91	56	1649

48.6% (SEP–OCT)

84.9% (JUN–OCT)

Table 1 MONTHLY DISTRIBUTION OF MEAN HOURLY WINDS OF GALE FORCE OR ABOVE ($\geqslant$ 17.5 ms^{-1}) AT WAGLAN ISLAND (1953–85)

No of occasions mean recurrence value is equalled or exceeded	Probability over 50 years	Probability over 20 years
Not at all	0.36	0.67
At least once	0.64	0.33
Once only	0.37	0.27
At least twice	0.27	0.061
Twice only	0.19	0.053
At least three times	0.078	0.009
Three times only	0.061	0.007
At least four times	0.017	0.002

Table 2 PROBABILITY OF THE NUMBER OF OCCASIONS IN A 50-YEAR AND 20-YEAR PERIOD ON WHICH A METEOROLOGICAL EVENT IS LIKELY TO EQUAL OR EXCEED THE 50-YEAR MEAN RECURRENCE VALUE OF THAT EVENT

Country	Loading	Meteorological event	Mean recurrence period
U.K.	Wind	3-second gust at 10 m	Once in 50 years
France	Wind	0.92 of maximum gust recorded by standard anemometer	Normal loadings three times per 1000 days Extreme 1.75 x normal
U.S.A.	Wind	Fastest mile of wind	Once in 50 years
Canada	Snow	Max. ground snow depth + maximum 24 h rainfall for period when snow depths are greatest	Once in 30 years
U.S.A.	Snow	Max. annual weight of snow pack on ground expressed in depth of water	Not known
U.S.S.R.	Snow	Depth of snow and density of snow used to determine ground snow load	Approximately once in 10-15 years

Table 3 SOME SELECTED VALUES OF MEAN RECURRENCE PERIODS USED IN LOADING STUDIES IN VARIOUS COUNTRIES (Page (1976))

Maximum hourly mean wind speed (ms^{-1})	Maximum gust speed (ms^{-1})	Distribution	Data period	Previous reference
47.4	73.8	Gumbel	1953-85	Climatology Section, Royal Observatory (unpublished)
47.7	66.8	Weibull	1953-85	
51.5	77.2	Gumbel	1953-69	Lun (1970)
44.3	70.5	Gumbel	1953-74	Chan (1975)

Table 4 ESTIMATED 50-YEAR RETURN PERIODS FOR WINDS AT WAGLAN ISLAND

Station	Maximum hourly mean wind speed (ms^{-1})	Maximum gust speed (ms^{-1})	Data period
Waglan Island	47.4	73.8	1953–85
Cheung Chau	46.8	70.3	1968–85
Royal Observatory	35.8	71.8	1951–85
Kai Tak	38.2	65.6	1968–85

Table 5 ESTIMATED 50-YEAR RETURN PERIODS FOR WINDS IN VARIOUS STATIONS IN HONG KONG USING THE GUMBEL DISTRIBUTION

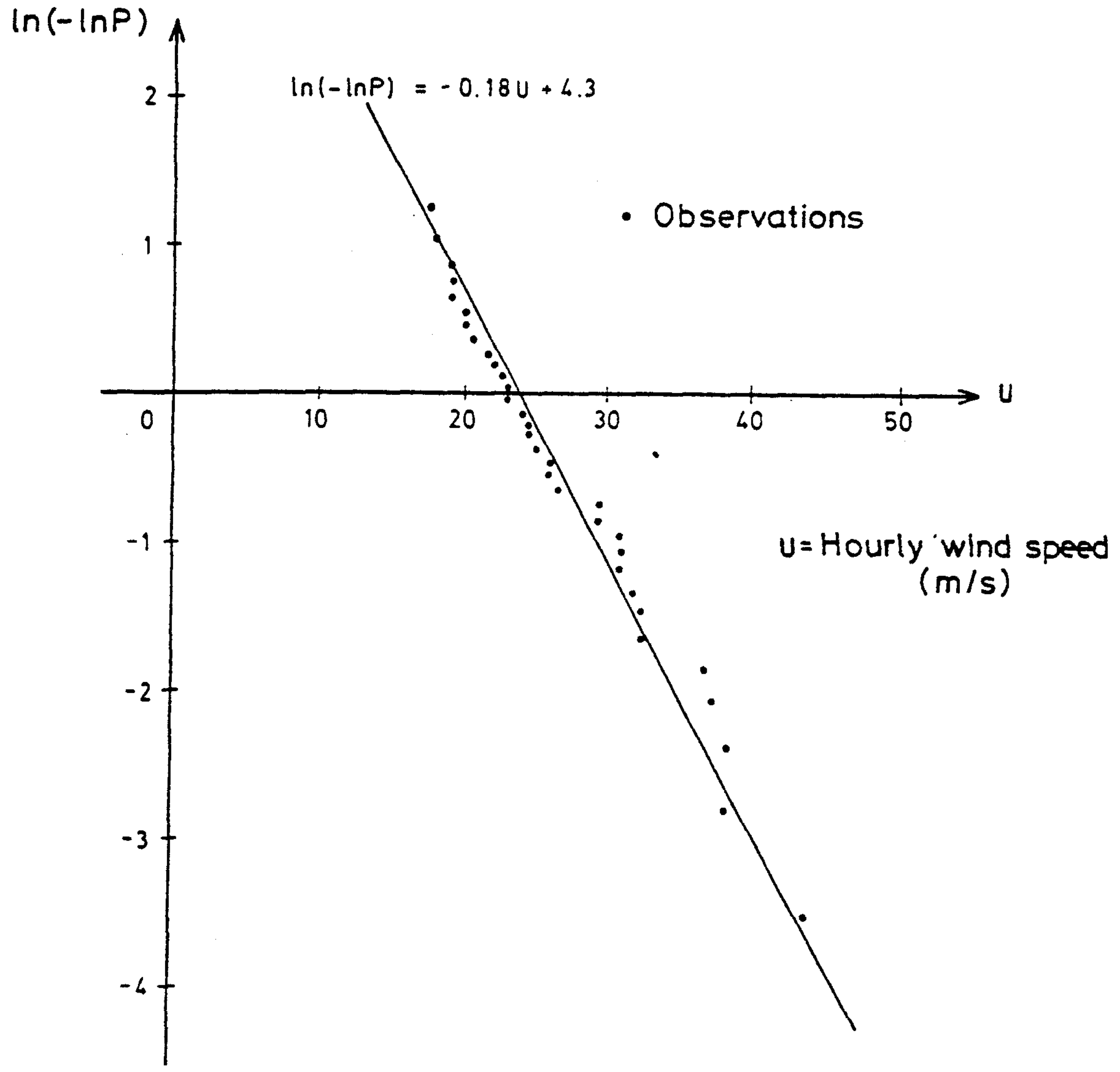

Figure 1(a) THE GUMBEL DISTRIBUTION FITTED TO ANNUAL MAXIMUM HOURLY WIND SPEEDS RECORDED AT WAGLAN ISLAND (1953–85)

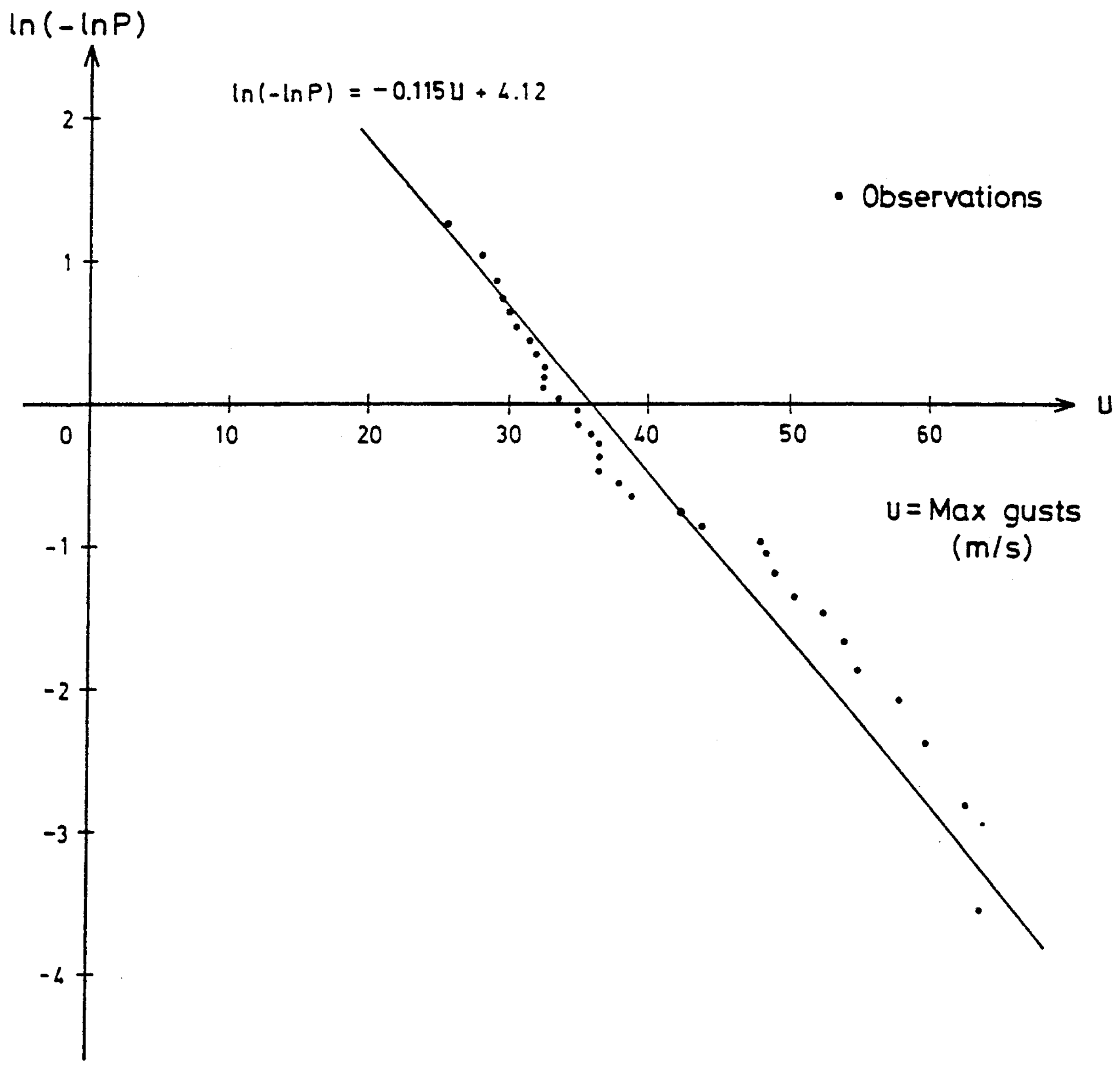

Figure 1(b) THE GUMBEL DISTRIBUTION FITTED TO MAXIMUM GUSTS RECORDED AT WAGLAN ISLAND (1953–85)

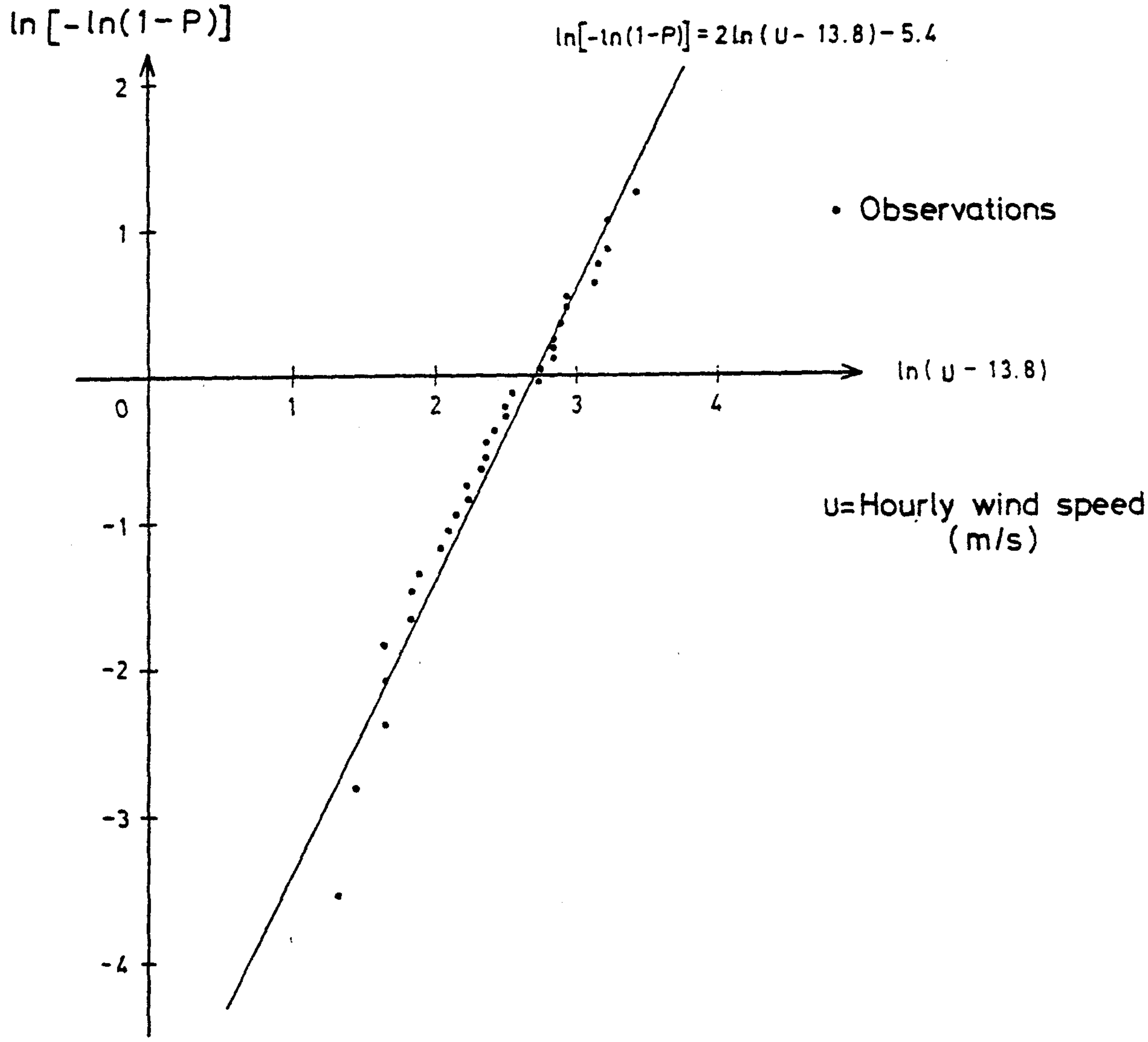

Figure 2(a) THE 3-PARAMETER WEIBULL DISTRIBUTION FITTED TO ANNUAL MAXIMUM HOURLY WIND SPEEDS RECORDED AT WAGLAN ISLAND (1953-85)

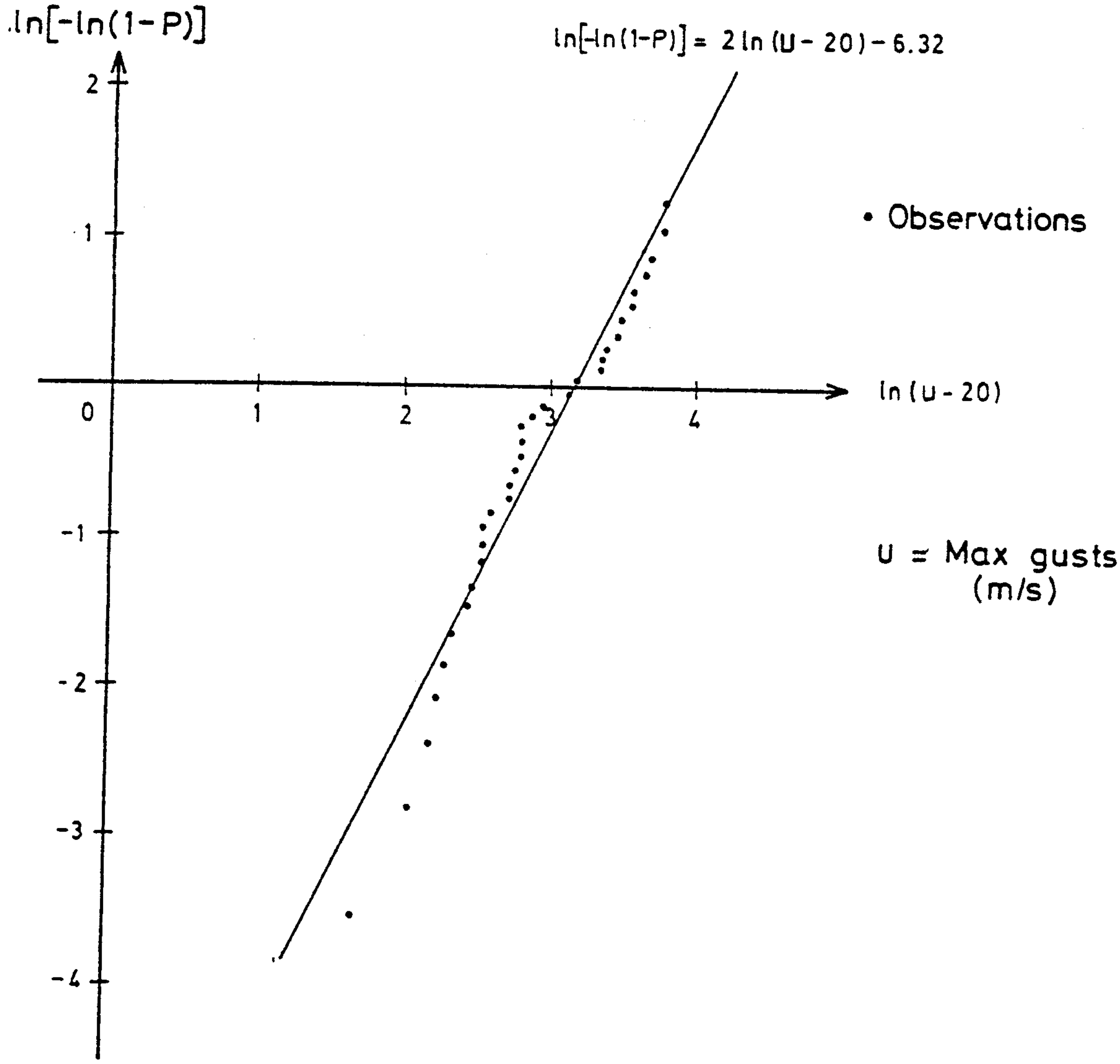

Figure 2(b) THE 3-PARAMETER WEIBULL DISTRIBUTION FITTED TO MAXIMUM GUSTS RECORDED AT WAGLAN ISLAND (1953–85)

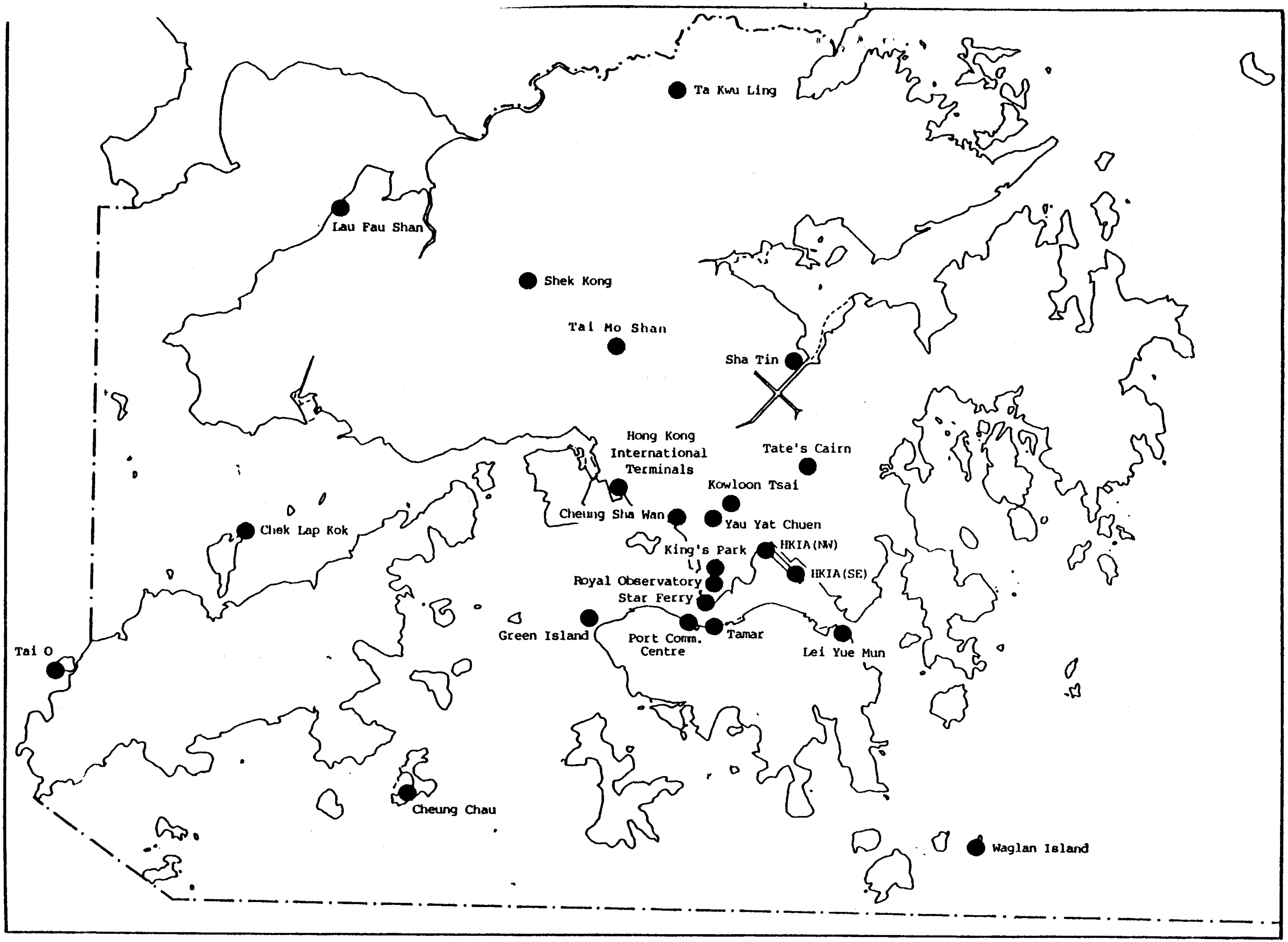

Figure 3: DISTRIBUTION OF WIND STATIONS IN HONG KONG.

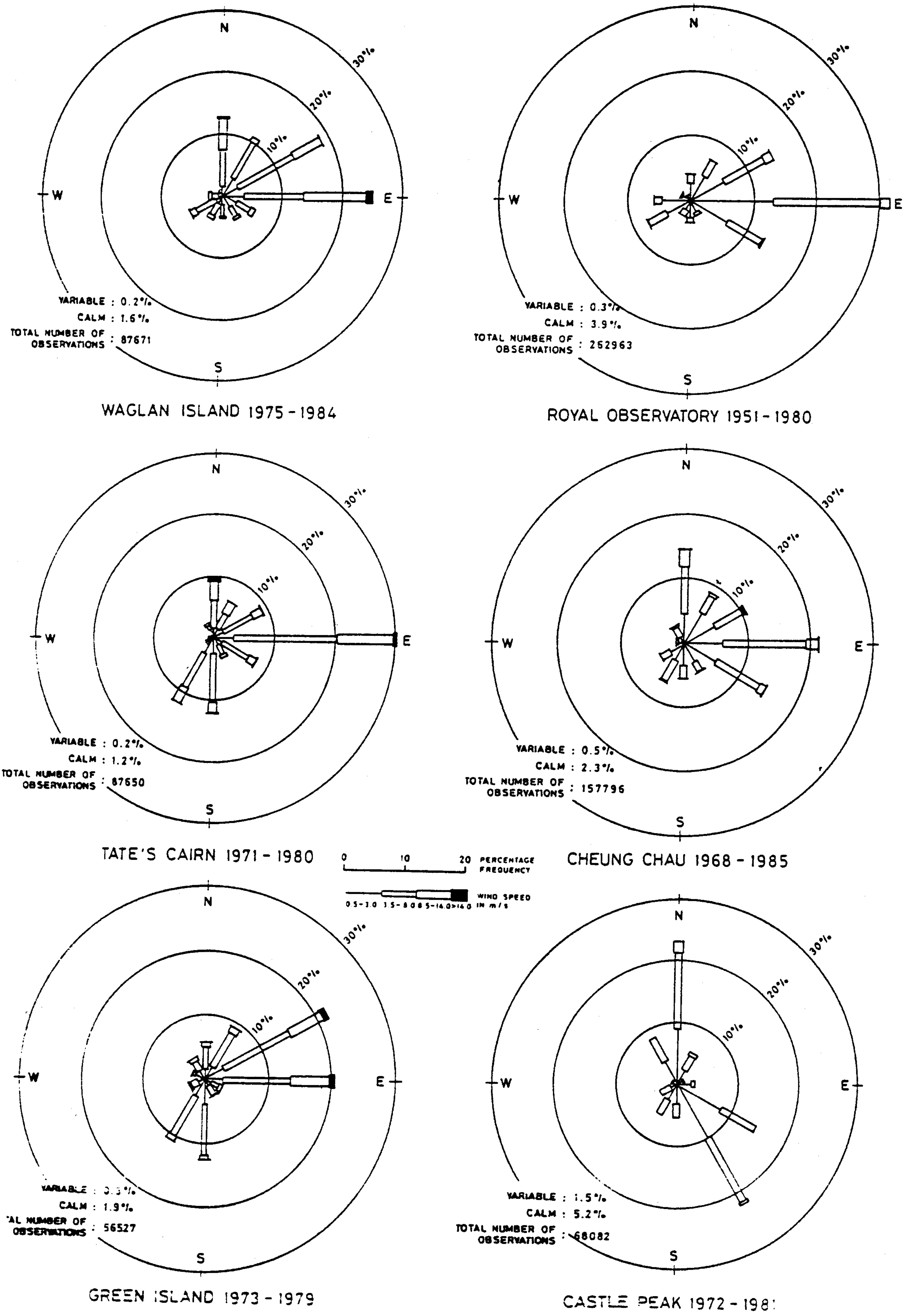

Figure 4: ANNUAL WIND ROSE OF SOME STATIONS IN HONG KONG.

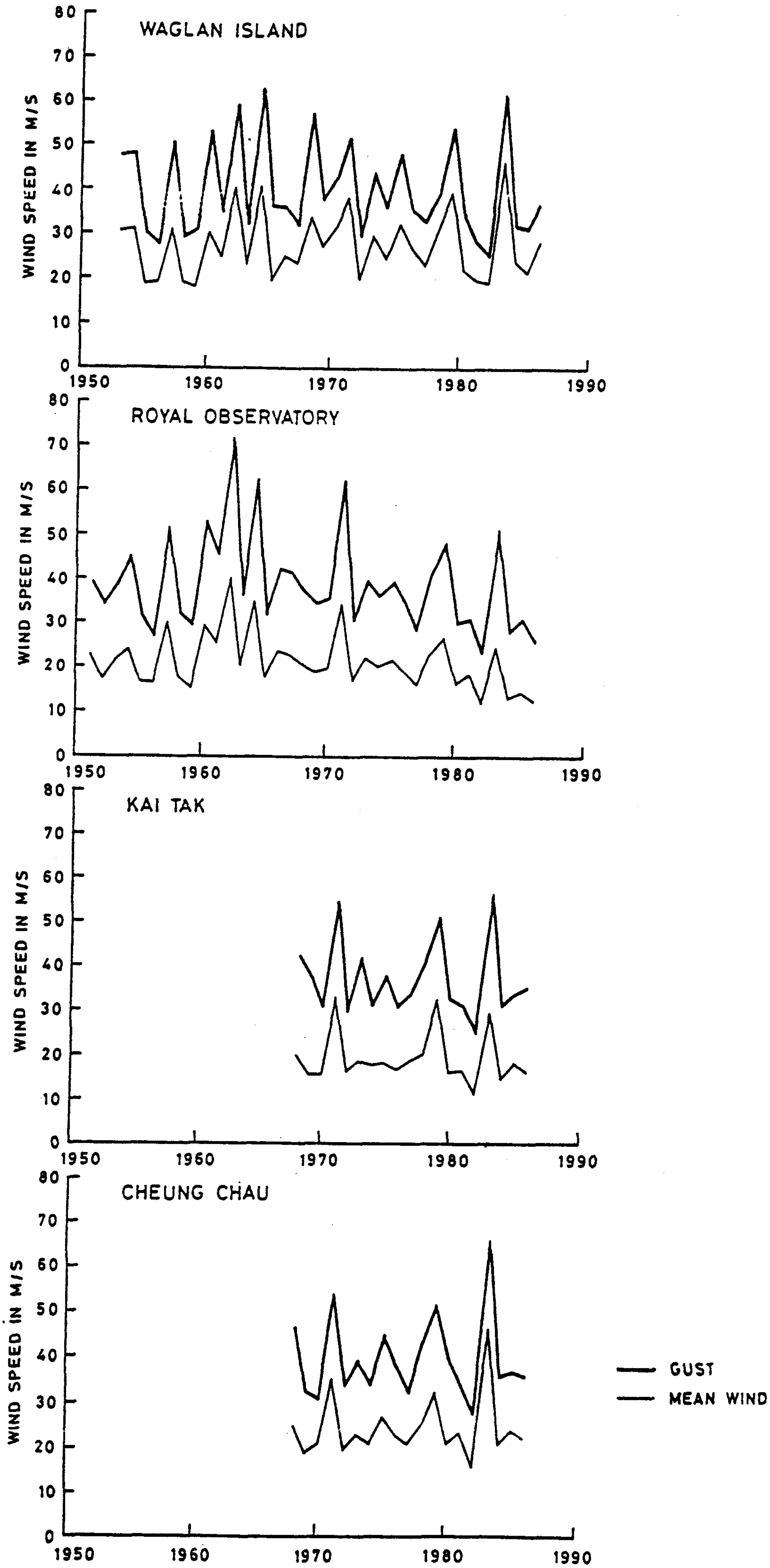

Figure 5: MAXIMUM HOURLY MEAN WIND AND GUST OF SOME STATIONS IN HONG KONG.

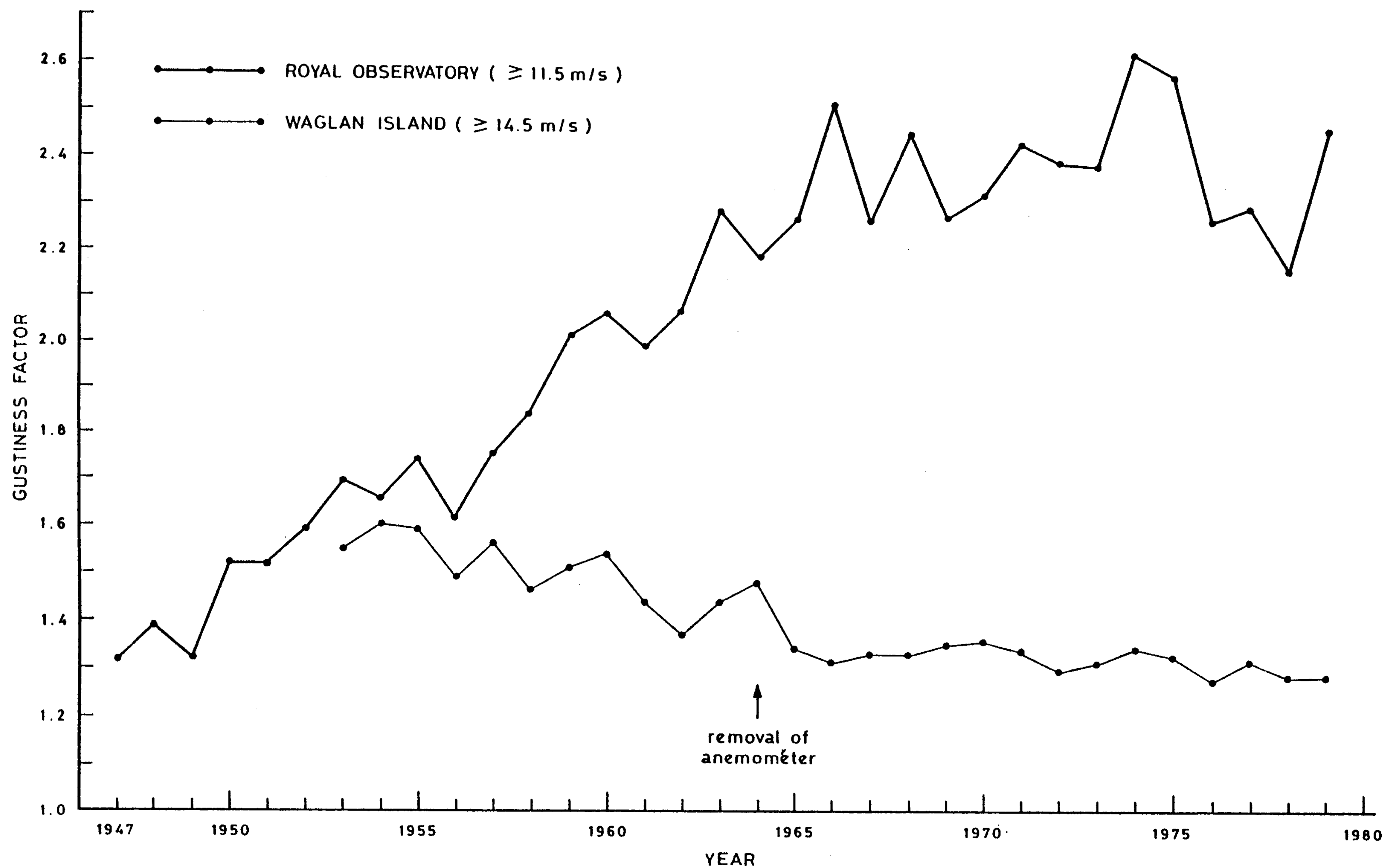

Figure 6: ANNUAL MEAN GUSTINESS FACTORS IN STRONG WINDS. (POON (1984))

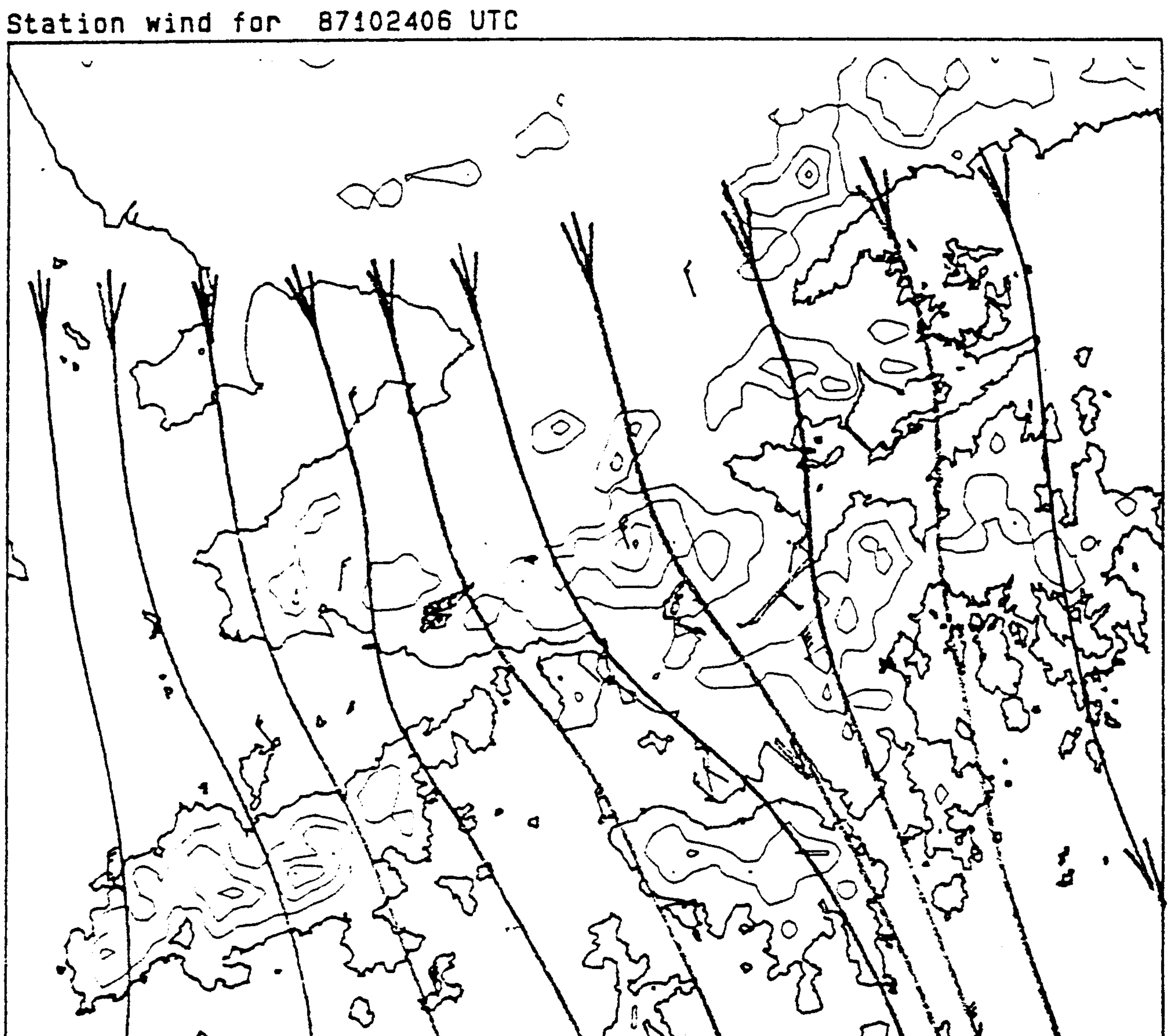

Figure 7(a) WIND FLOW OVER HONG KONG - STRONG NORTH TO NORTHWESTERLY. (CONTOURS OF TERRAIN IN 200 m INTERVALS. A FULL WIND BARB DENOTES 5 ms^{-1}).

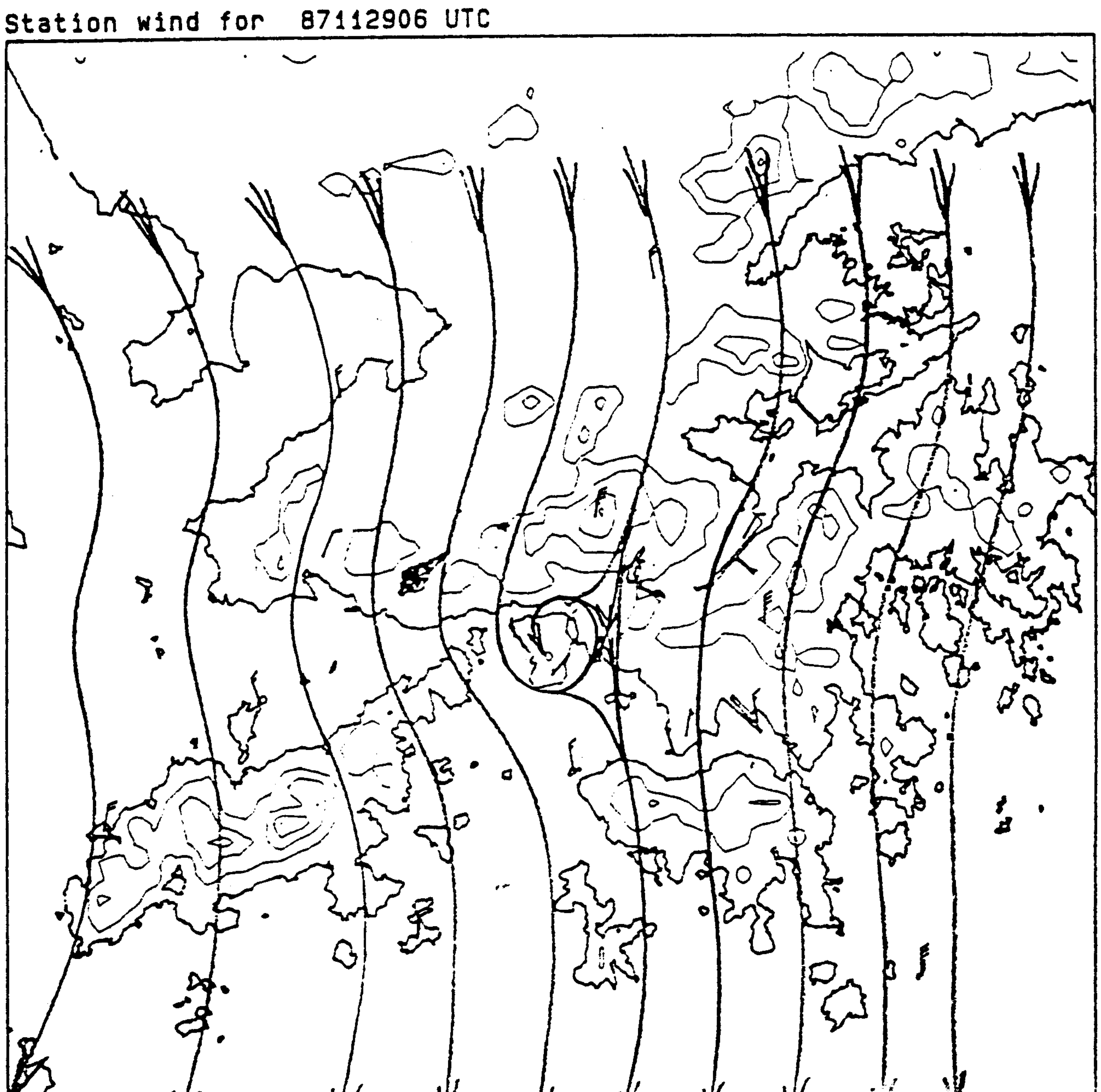

Figure 7(b) WIND FLOW OVER HONG KONG - INTENSE NORTHERLY SURGE

Station wind for 86082012 UTC

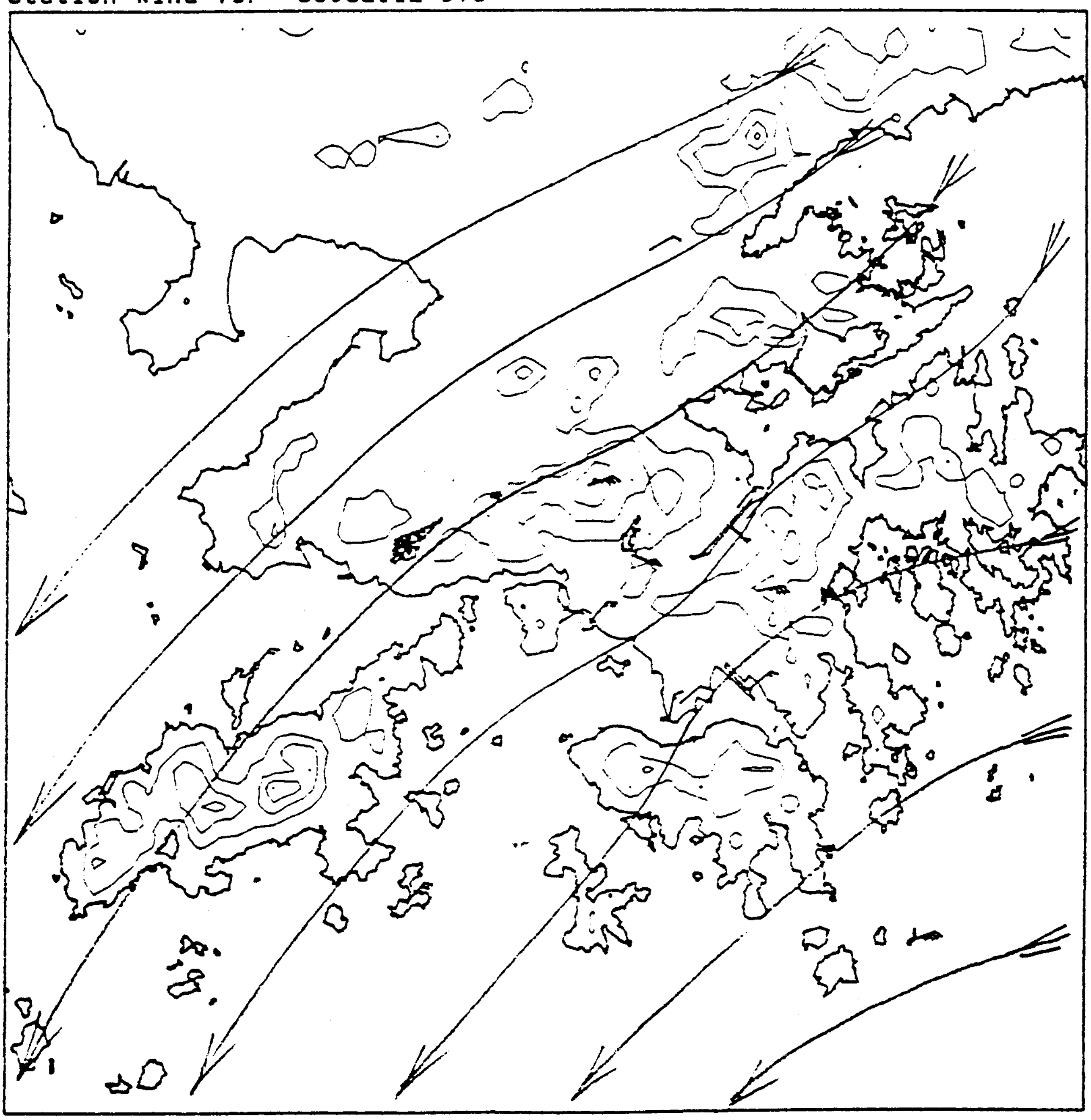

Figure 7(c) WIND FLOW OVER HONG KONG - STRONG NORTHEASTERLY

Station wind for 8711 900 UTC

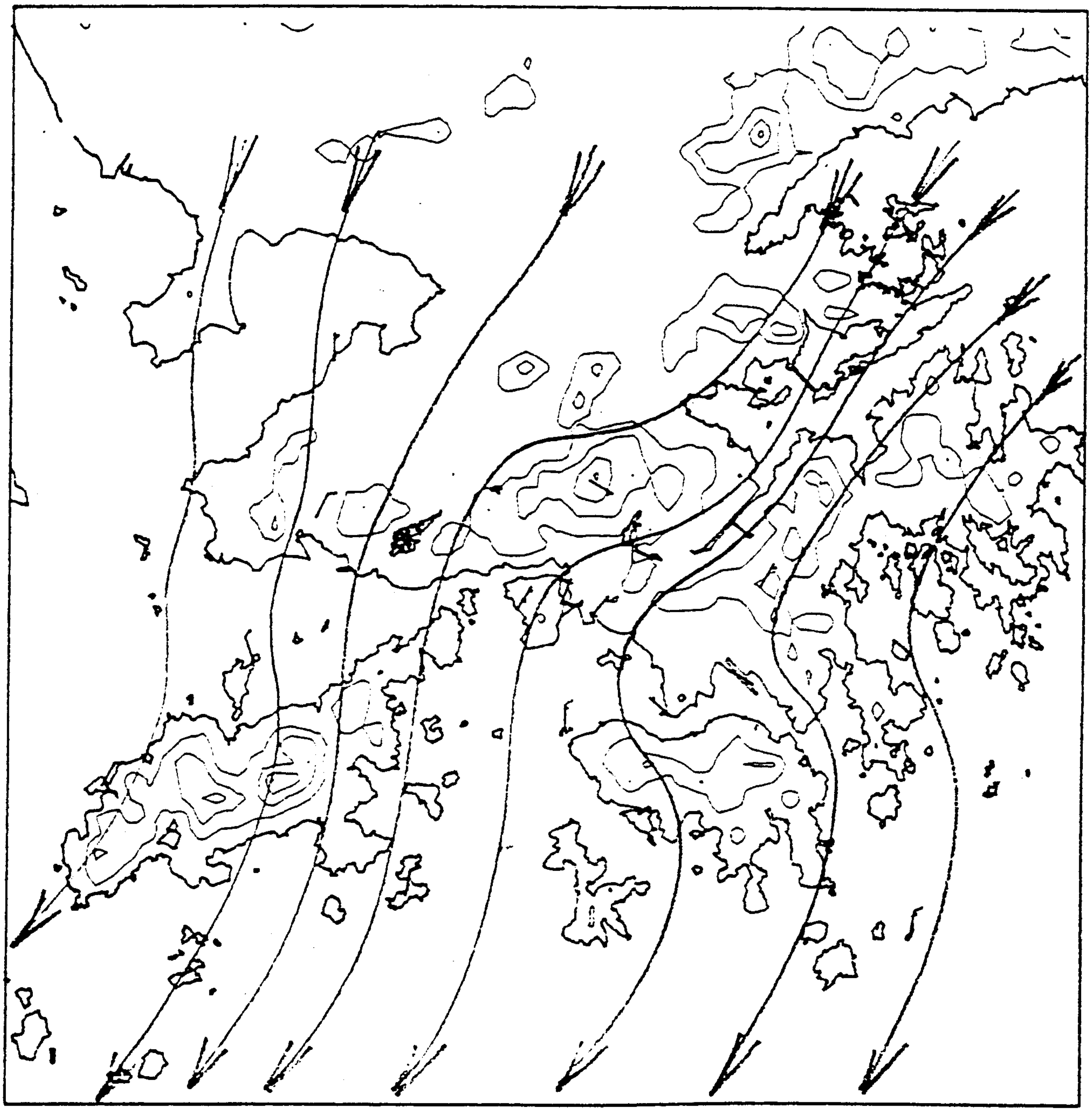

Figure 7(d)(i) WIND FLOW OVER HONG KONG - WEAK NORTHERLY

Station wind for 8711 906 UTC

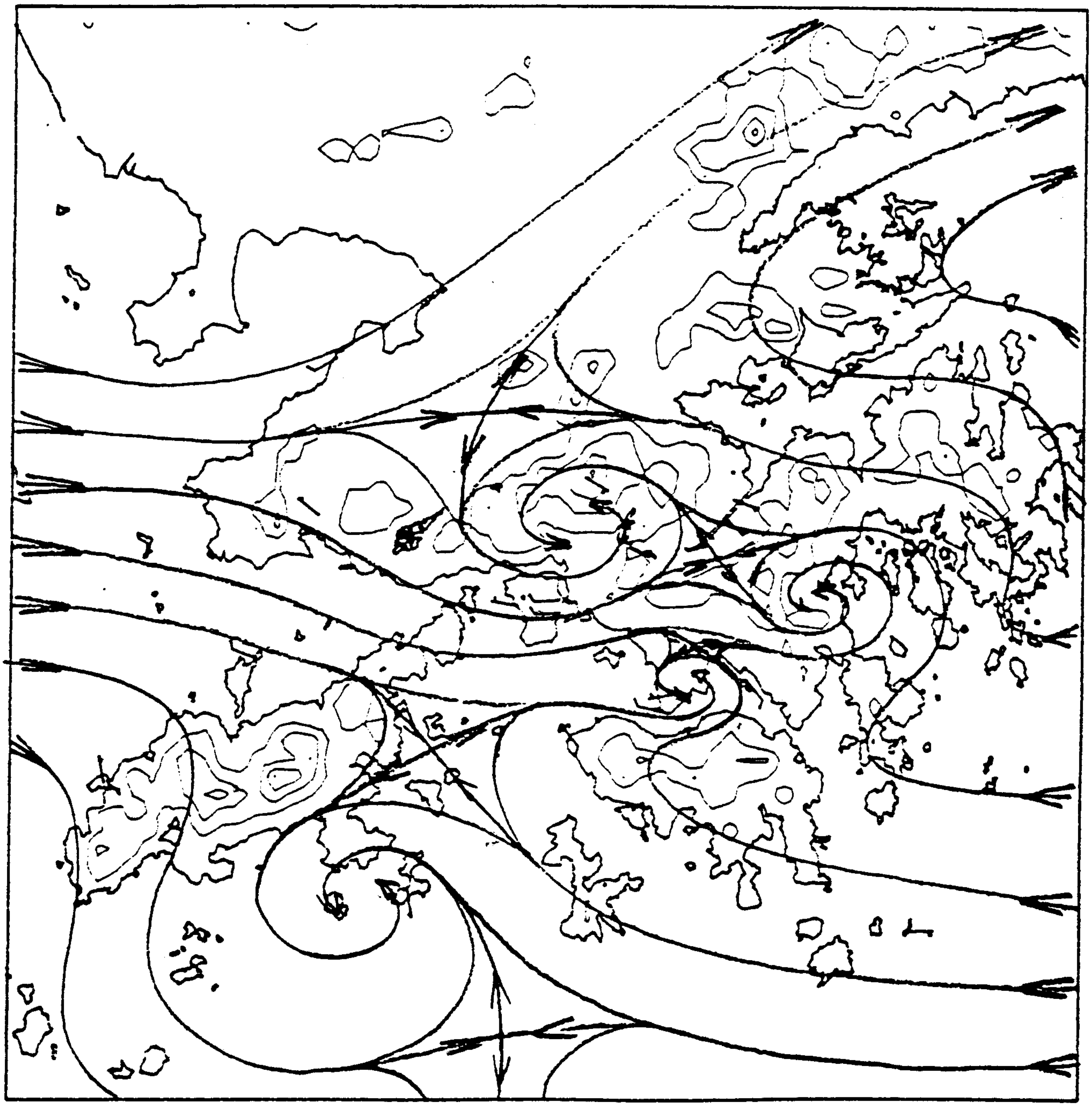

Figure 7(d)(ii) WIND FLOW OVER HONG KONG - WEAK NORTHERLY

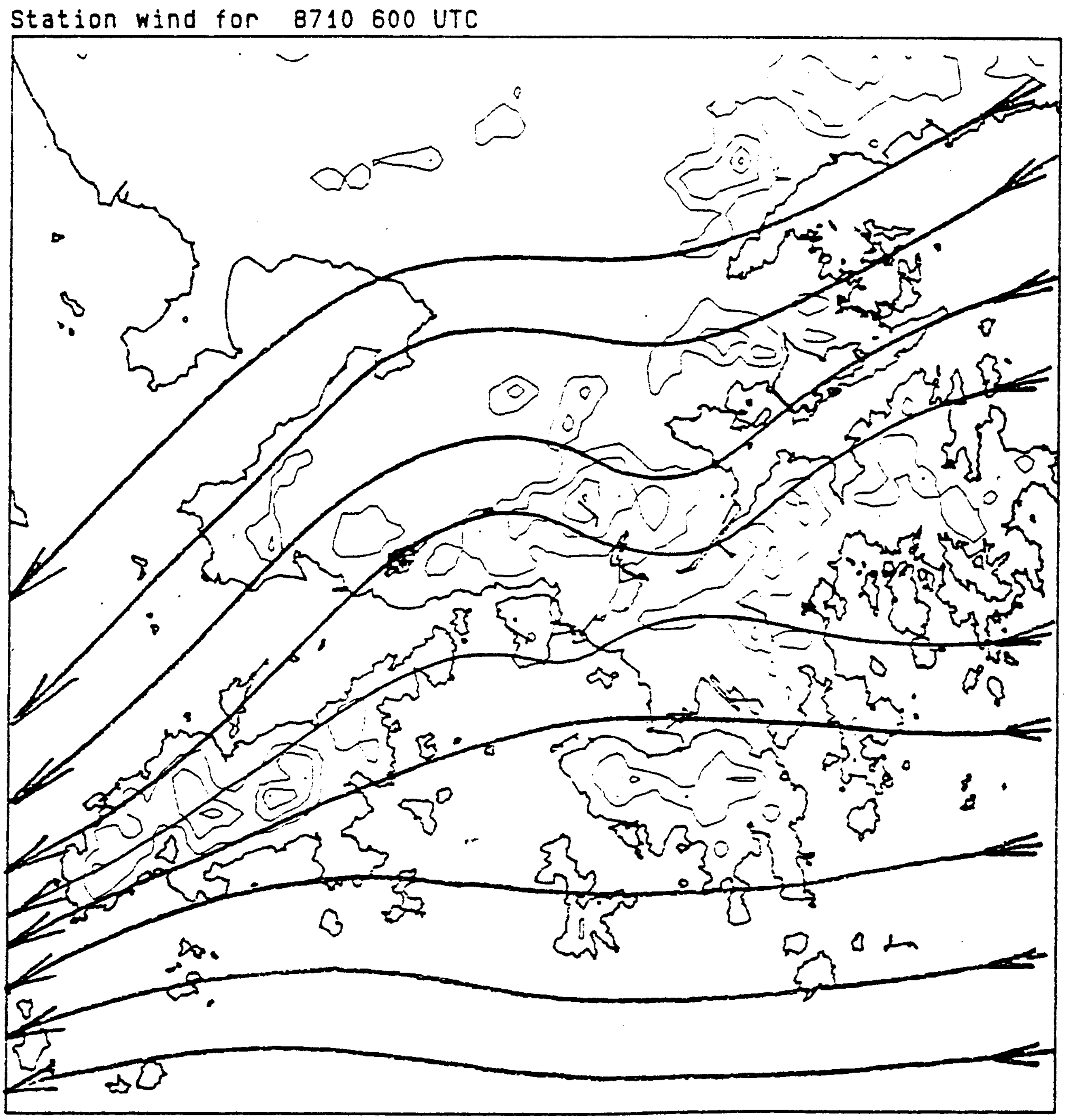

Figure 7(e)(i) WIND FLOW OVER HONG KONG - WEAK EASTERLY

Station wind for 8710 606 UTC

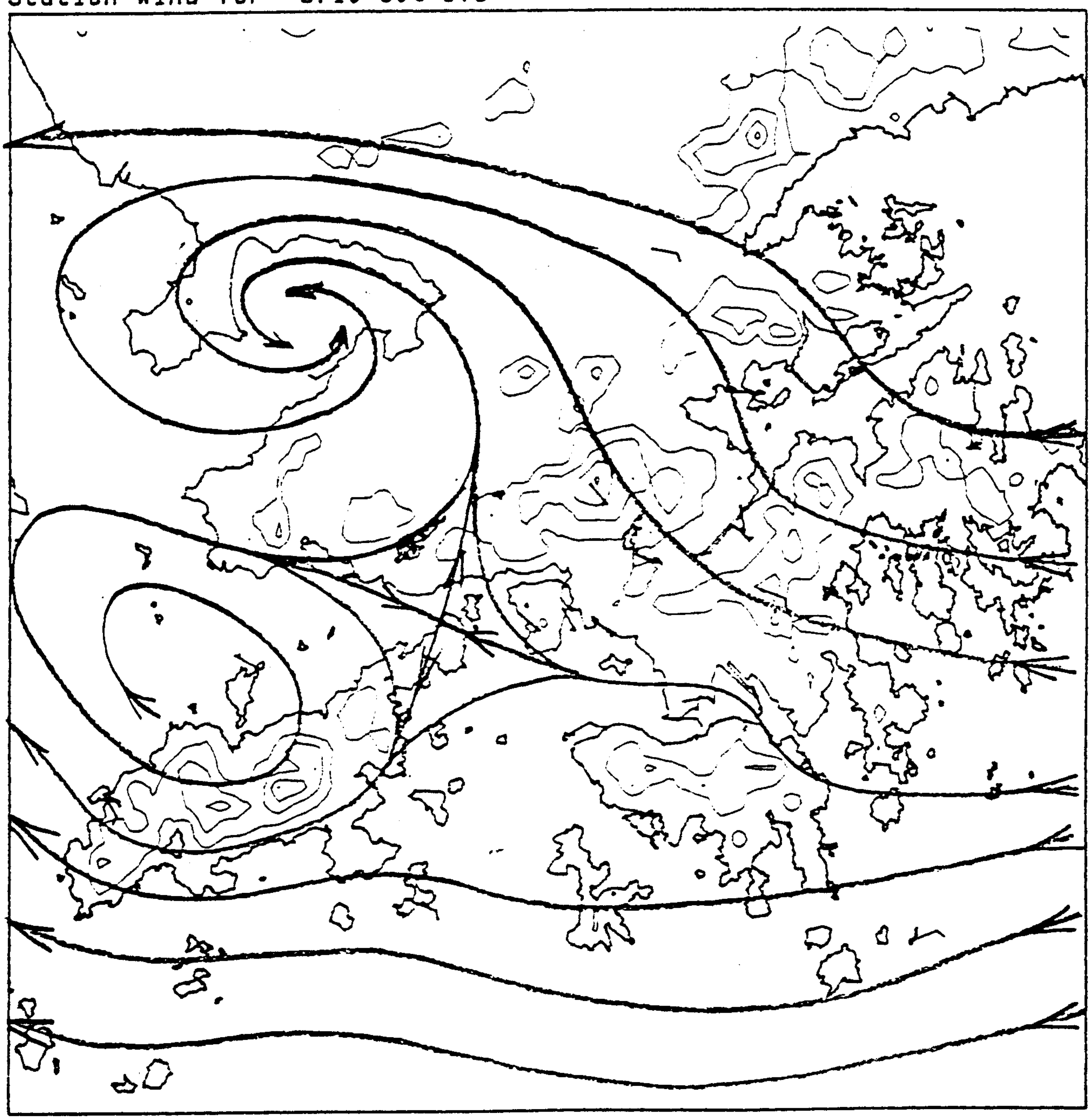

Figure 7(e)(ii) WIND FLOW OVER HONG KONG - WEAK EASTERLY

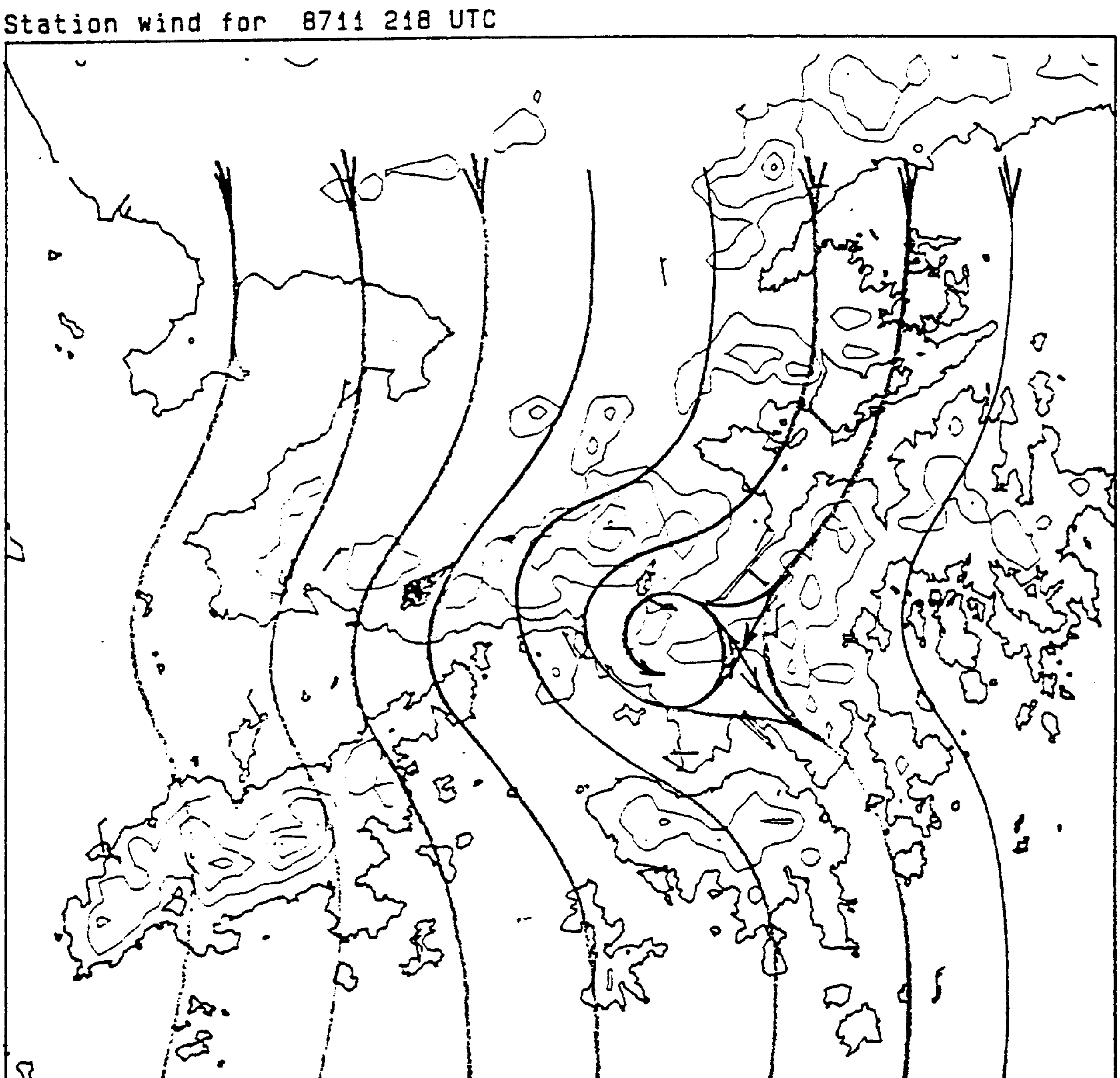

Figure 7(f)(i) WIND FLOW OVER HONG KONG - WEAK NORTHERLY FOLLOWED BY EASTERLY

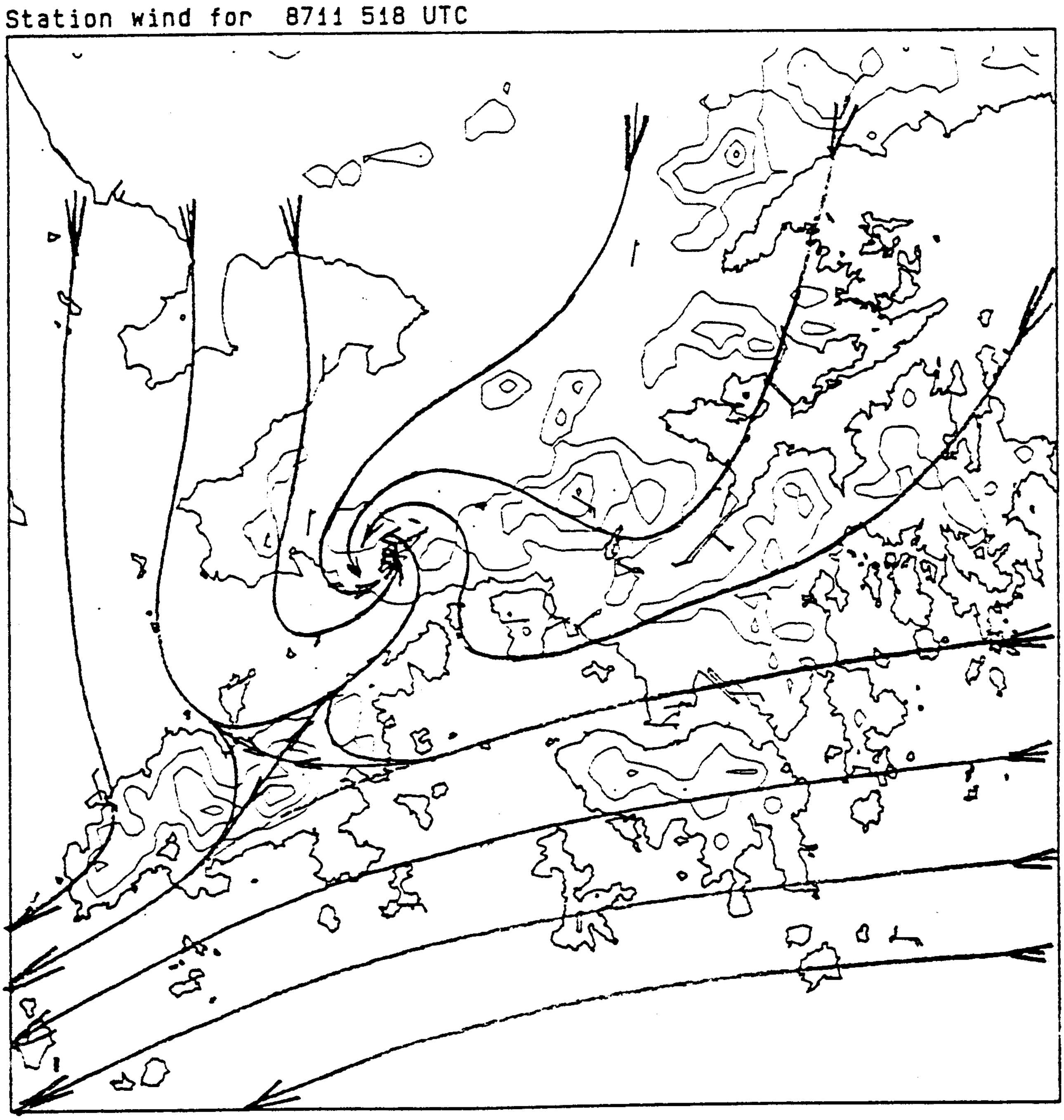

Figure 7(f)(ii) WIND FLOW OVER HONG KONG - WEAK NORTHERLY FOLLOWED BY EASTERLY