PART IV ANALYSIS OF METEOROLOGY AND POLLUTANT CONCENTRATION DATA

To perform air pollution assessment precisely, meteorological condition and present status of pollutant level in the objective area are necessarily required. In this project, meteorological data such as wind direction and velocity, environmental concentration of objective pollutant (sulfur dioxides) were measured for one year as described in Part II.

In Part IV, statistical analysis of obtained data and the results of it, i.e., the meteorological features in the objective area, present status of SO_2 concentration, relation between meteorology and concentration are stated. These results are utilized for the estimation of future level of SO_2 concentration.

CHAPTER 1 ANALYSIS OF METEOROLOGICAL DATA

Atmospheric pollutants emitted from artificial sources such as factory stacks, ships, automobiles etc. are transported and dispersed by wind. Therefore, the meteorological conditions such as wind direction, wind velocity, turbulence intensity, solar radiation etc. are the controlling factors of diffusion phenomena.

In this project, wind velocity, wind direction, solar radiation, net flux radiation, air temperature have been measured hourly, at several sites in the objective area for one year. Those hourly data were analyzed statistically by computer and following results were obtained.

IV-1-1 Categorizing of Hourly Conditions by Seasons and Hours

The meteorological and source emission conditions vary by seasons and hours. For instance, rather small number of factories are active in night time. Even the estimation of pollutant concentration aims for long term averages, such as annual or seasonal, we cannot neglect the seasonal or hourly variations of sources and also diffusion characteristics.

However it is not realistic to consider every hour to hour variations of sources in the diffusion model, so the source conditions are categorized by seasons and hours. According to the statistical analysis of source conditions, meteorological conditions and concentration data, every hour of one year are classified into four groups by month and day or night as in Table IV-1-1.

Table IV-1-1 Seasonal and hourly classification

Hours \ Season	Southerly monsoon	Northerly monsoon
	April to October	November to May
Daytime	7:00 to 17:59	7:00 to 17:59
Nighttime	18:00 to 6:59	18:00 to 6:59

The analyzed results of monthly and hourly averages of wind velocity and wind direction, cluster analysis of SO_2, principal factor analysis of SO_2 and SO_2 emission rate are shown in Figs. IV-1-1 and IV-1-2. The figures suggest that a year is divisible into two seasons and day is also separable to two, and it certifies the validity of Table IV-1-1.

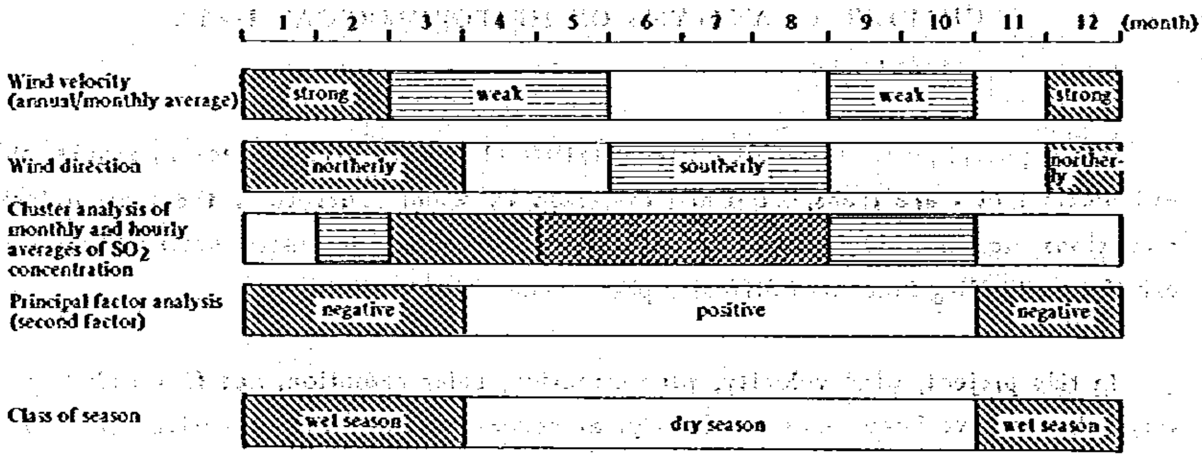


Fig. IV-1-1 Monthly variation of meteorological and SO_2 concentration factors

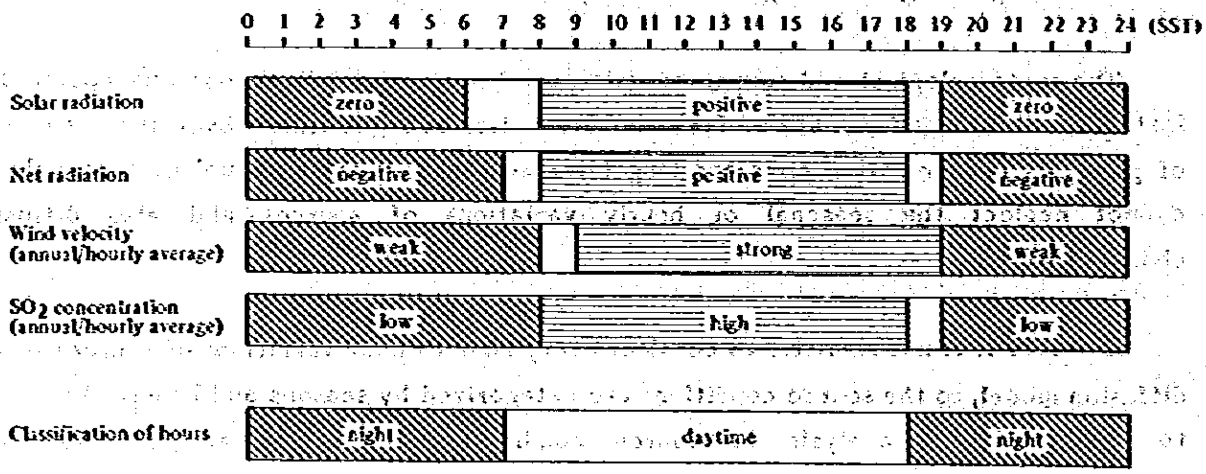


Fig. IV-1-2 Diurnal variation of meteorological and SO_2 concentration factors

IV-1-2 Monthly and Hourly Variations of Wind Velocity

Seasonal, monthly and hourly averages of wind velocity give important informations and ideas about the meteorological conditions in the objective area, such as sea breeze, topographic effect, diurnal variation etc. Table IV-1-2 shows the daytime and nighttime averages of wind velocity for each observation site for two seasons.

In the table, the height of the observation equipments are also shown. From the results, strong dependence of measuring height and structural condition on average wind velocity is clearly seen. The wind velocity is high for high places, and in terms of the seasonal averages, the wind velocity is generally higher in northerly monsoon than in Southerly monsoon.

Table IV-1-2 Average wind velocity for each season and day and night

Observation site	Height of the measurement (m)	Southerly monsoon			Northerly monsoon			Annual average		
		d	n	ave.	d	n	ave.	d	n	ave.
(1) N.U.S.	10	1.2	0.5	0.8	1.3	0.7	1.0	1.3	0.6	0.9
(2) J.T.C. HALL	29	2.9	1.9	2.4	3.2	2.5	2.8	3.0	2.2	2.5
(3) S.I.U.	10	0.6	0.4	0.5	1.1	0.7	0.9	0.8	0.5	0.7
(4) BOON LAY APARTMENT	51	3.1	1.9	2.4	2.5	1.7	2.1	2.8	1.8	2.3
(5) BUKIT TIMAH FIRE ST.	10	0.7	0.3	0.5	1.1	0.7	0.9	0.9	0.5	0.7
(6) CHANGI AIRPORT	6	3.0	1.8	2.4	3.0	1.8	2.3	3.0	1.8	2.3
(7) BEDOK POLICE STATION	13	1.4	0.8	1.1	2.3	1.5	1.9	1.7	1.1	1.4

(d and n mean daytime and nighttime, respectively.)

The monthly variations of wind velocity are shown in Fig. IV-1-3. Generally, the wind is relatively high from December to February and low through March to May and September to October. At MP-2, MP-4 and MP-6, where the anemometers were set at high place, the wind velocity is higher than other sites and relatively high wind is also observed in July and August.

With respect to the diurnal variations of wind velocity, it is relatively high in the daytime and low in nighttime. This tendency is clear in MP-2, MP-4 and MP-6 and is probably due to the daytime sea breeze and nighttime inversion (see Fig. IV-1-4).

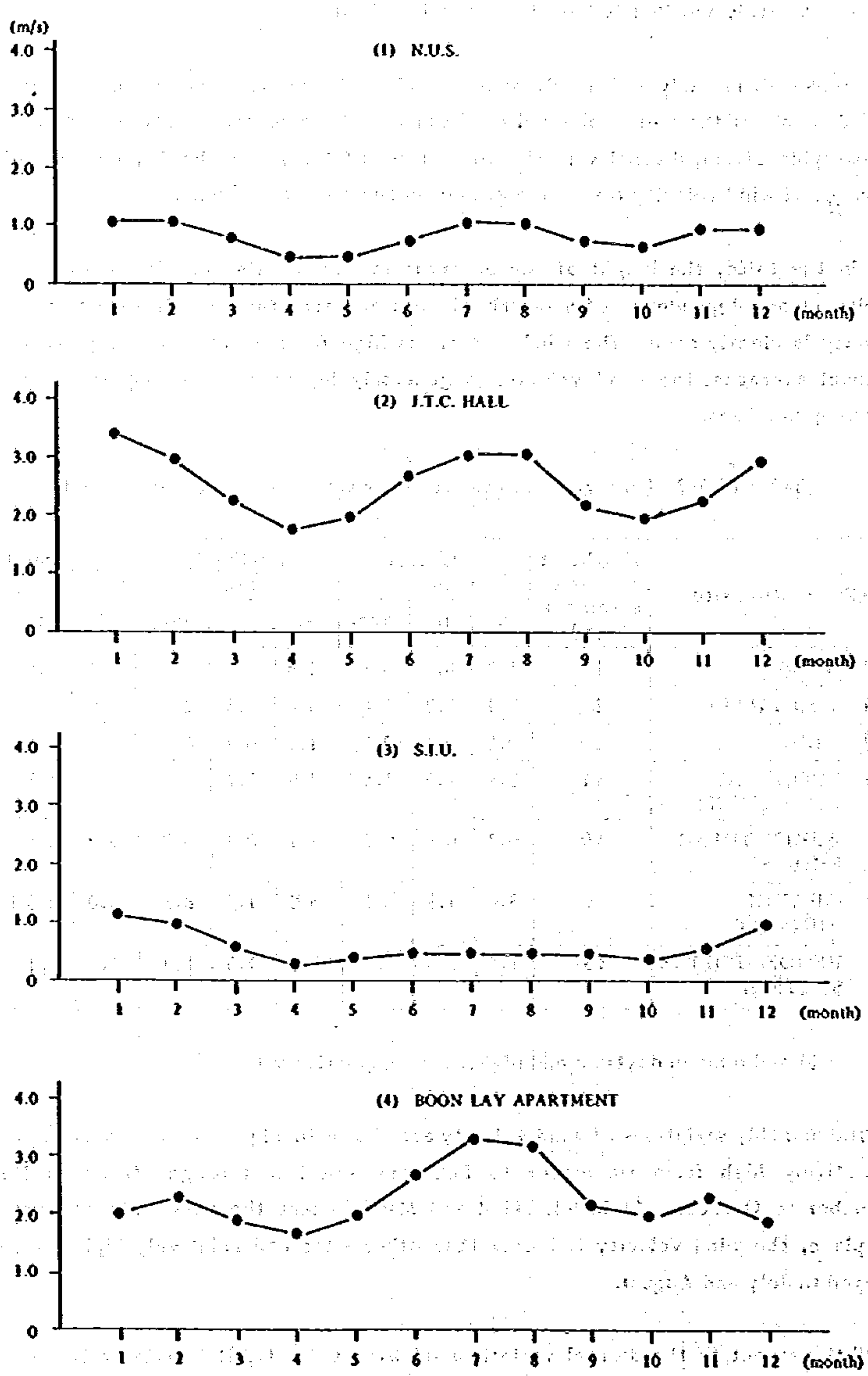


Fig. IV-1-3 Time series of average wind velocity for each observation site (a)

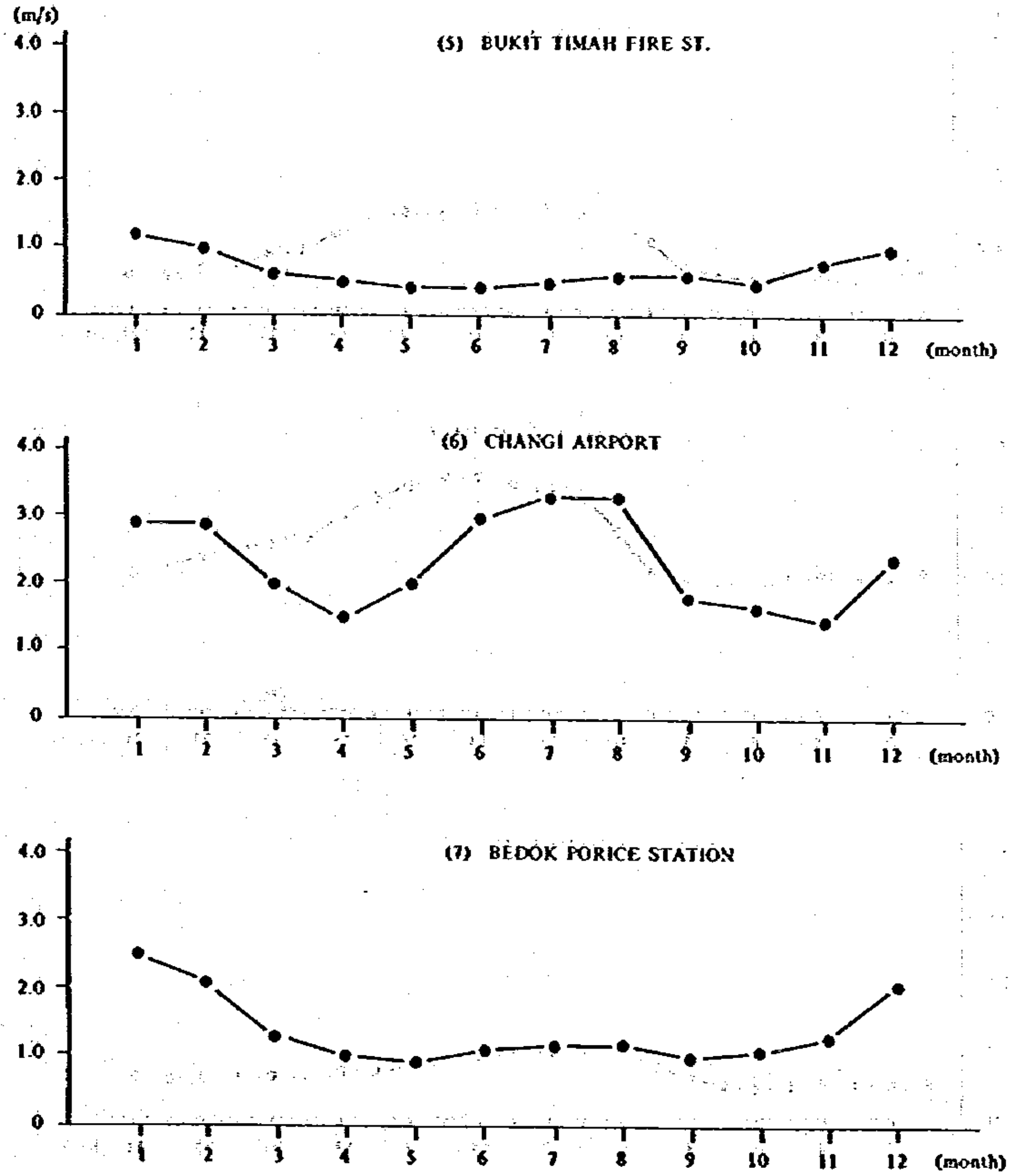


Fig. IV-1-3 Time series of average wind velocity for each observation site (b)

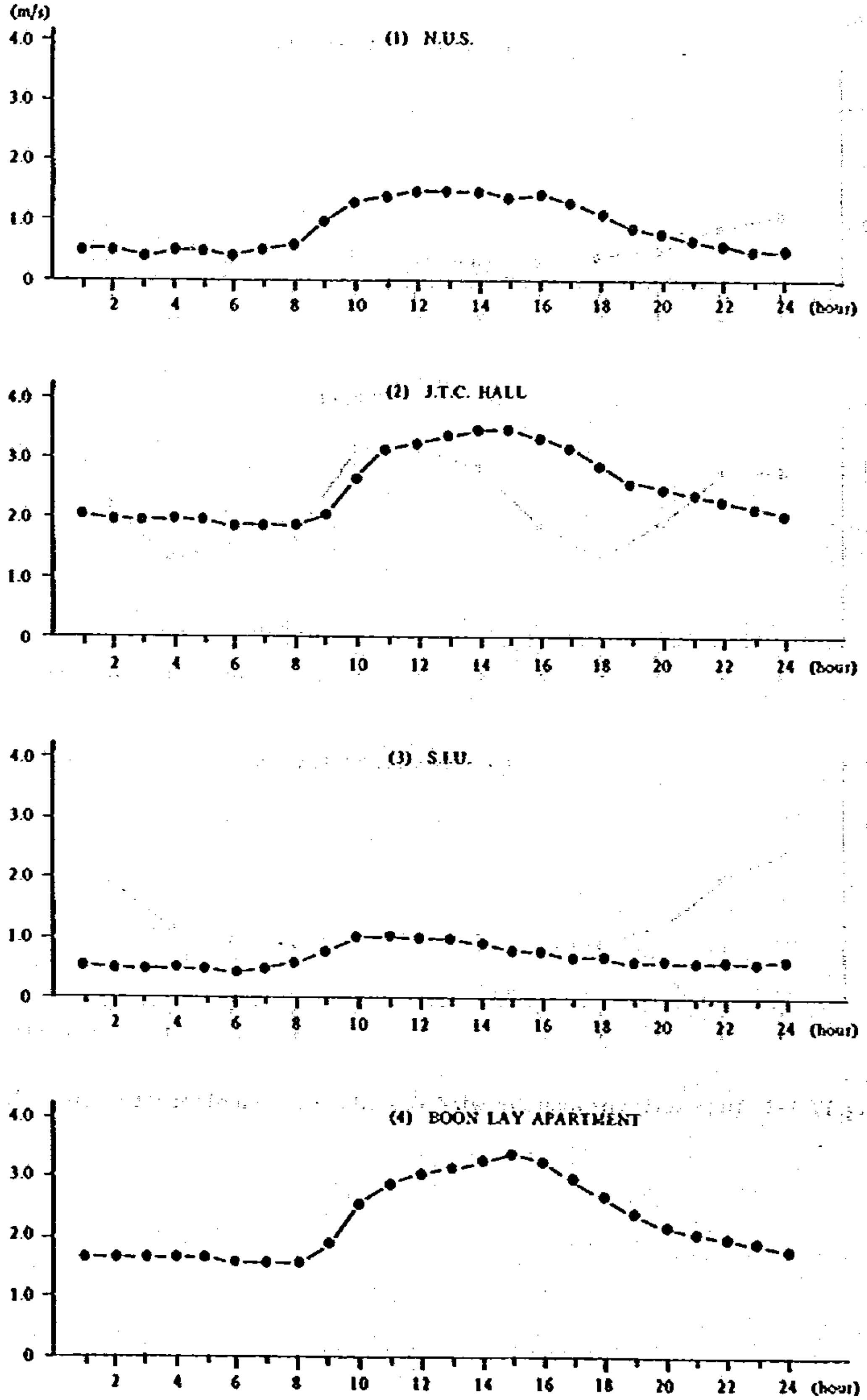


Fig. IV-1-4 Annually averaged diurnal variation of wind velocity (a)

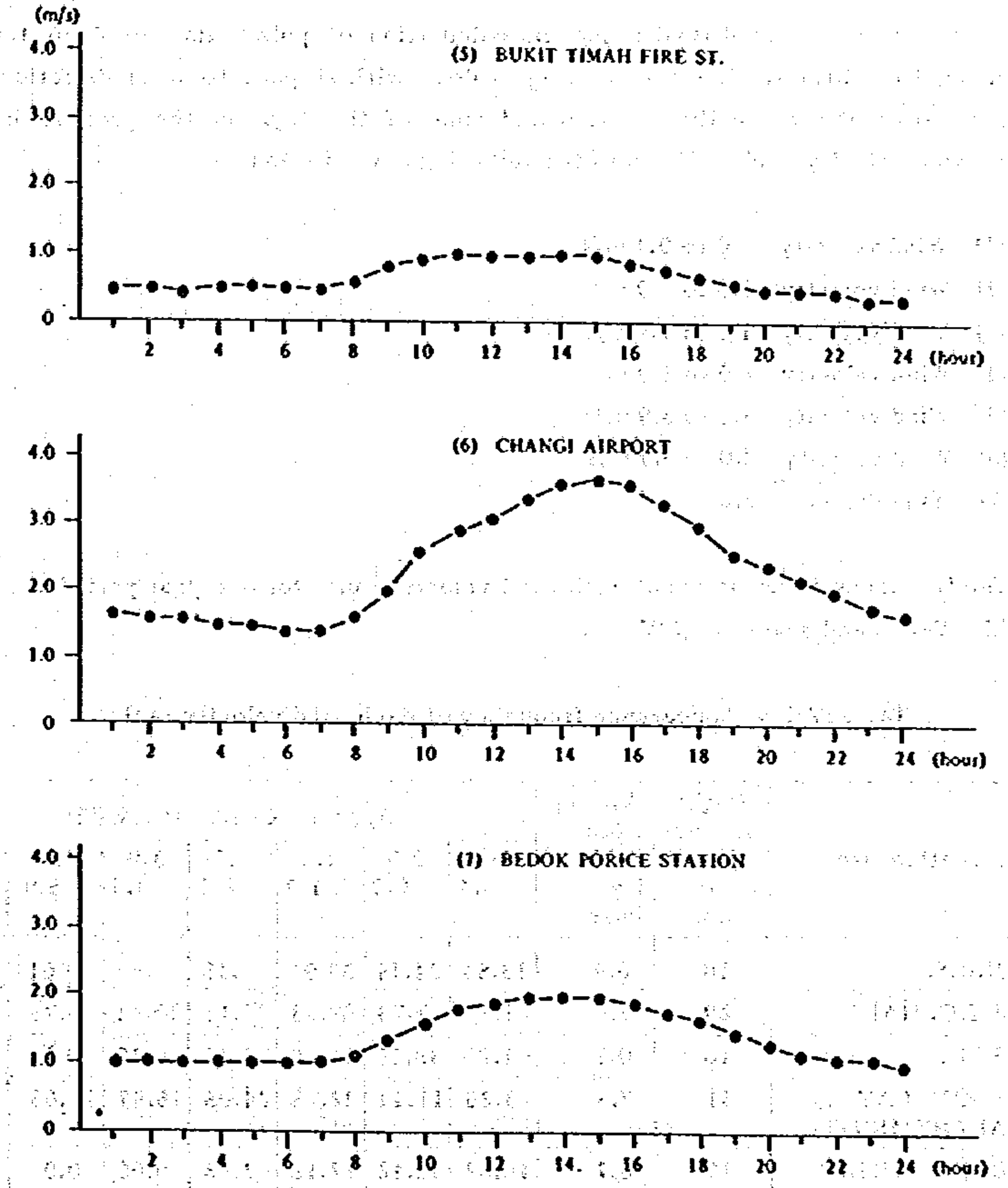


Fig. IV-1-4 Annually averaged diurnal variation of wind velocity (b)

IV-1-3 Frequency Distribution of Wind Velocity

In the atmospheric diffusion model, calculation of pollutants are done for each categorized conditions. The categorizing is done with respect to wind direction, wind velocity, atmospheric stability, season and time of the day. In the present diffusion model, wind velocity is classified into the following seven ranks:

(1) Wind velocity 0 to 0.4 m/s
(2) Wind velocity 0.5 to 0.9 m/s
(3) Wind velocity 1.0 to 1.9 m/s
(4) Wind velocity 2.0 to 2.9 m/s
(5) Wind velocity 3.0 to 3.9 m/s
(6) Wind velocity 4.0 to 5.9 m/s
(7) Wind velocity 6.0

The frequency distributions of each wind velocity ranks for one year period are shown in Table IV-1-3, and also in Fig. IV-1-5.

Table IV-1-3 Appearance frequency of each wind velocity ranks

Observation site	Height of measurement (m)	Average wind velocity (m/s)	Appearance frequency (%)						
			0-0.4	0.5-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-5.9	6.0-
(1) N.U.S.	10	0.9	33.84	24.19	33.91	7.48	0.57	0.01	0.0
(2) J.T.C. HALL	29	2.6	1.71	7.73	29.33	25.17	20.24	14.75	1.07
(3) S.I.U.	10	0.7	41.20	38.15	16.90	3.45	0.30	0.0	0.0
(4) BOON LAY APARTMENT	51	2.3	3.25	11.44	32.78	24.08	15.97	11.68	0.8
(5) BUKIT TIMAH FIRE ST.	10	0.7	40.82	34.42	22.12	2.58	0.06	0.0	0.0
(6) CHANGI AIRPORT	6	2.3	4.13	18.34	25.73	17.77	17.06	15.86	1.11
(7) BEDOK POLICE STATION	13	1.4	8.97	28.19	41.30	14.76	5.34	1.44	0.0

At the stations MP-1, MP-3 and MP-5, frequency of the rank (1) (wind velocity ranges 0 to 0.4 m/s) is more than 30 percent and far higher than other stations. This is probably attributable to the low measuring height, buildings and trees around the stations. Excluding those three stations, the frequency of the wind velocity rank (3) (1.0 to 1.9 m/s) is the highest and reaches to 26 to 41 percents.

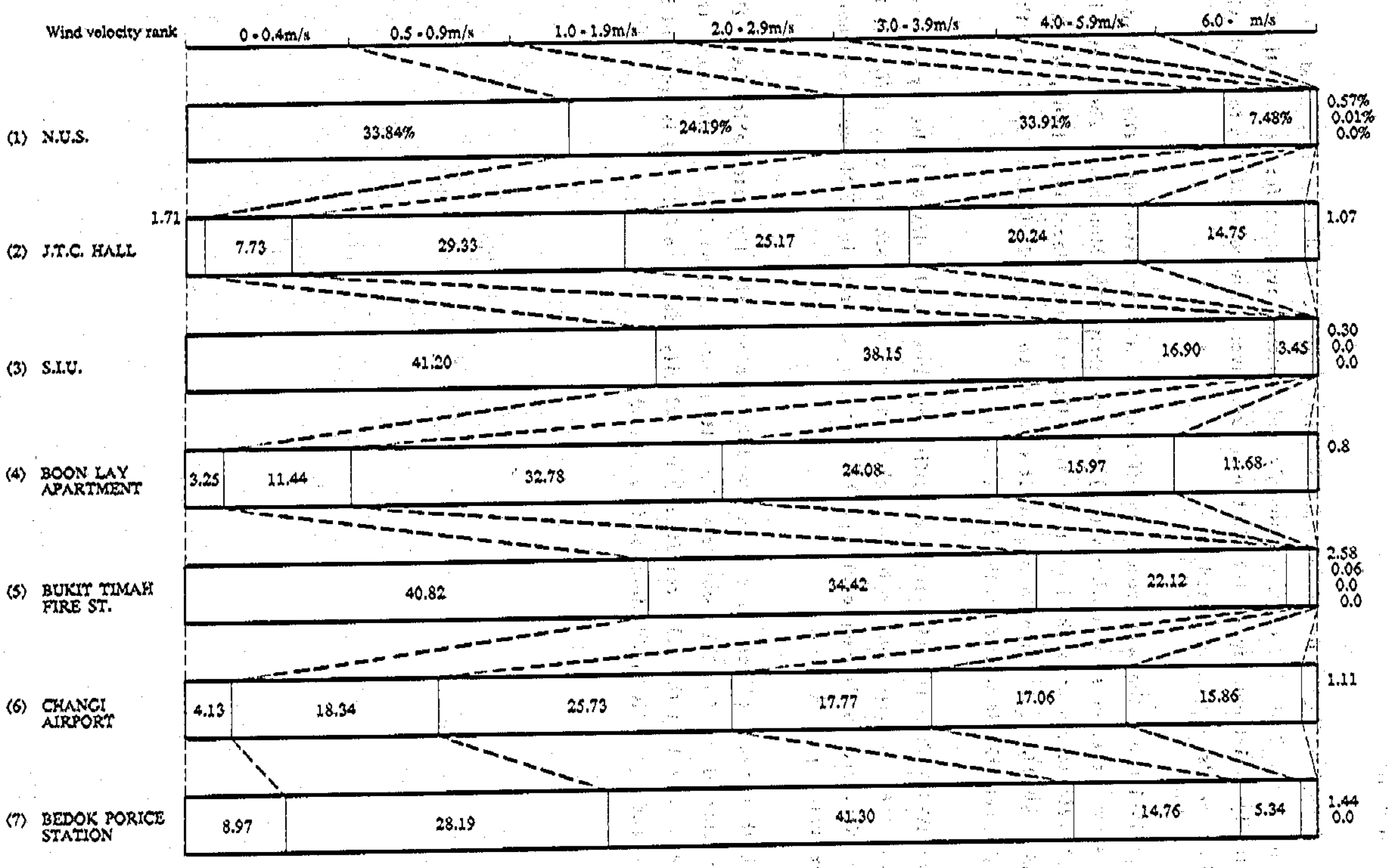


Fig. IV-1-5 Bar charts of the appearance frequency of wind velocity ranks

IV-1-4 Wind Rose

As a way of display of the appearance frequency of wind direction, wind rose is commonly used. The wind roses of monthly and seasonal averages for each station are shown in Fig. IV-1-6 and Fig. IV-1-7. In the figures, average wind velocities for each wind directions are also shown by dotted lines.

Figs. IV-1-6 are the wind roses of different months and stations. The wind roses clearly show the effects of southerly (SW) and northerly (NE) Monsoons. The prevailing wind in NE Monsoon season which continues from December to March is northerly (NNW to NE) and in SW Monsoon (June to August) it changes to southerly (SSE to S). In another months, no remarkable wind direction is detected.

Figs. IV-1-7 show the wind roses classified by time of the day and also by seasons. Since two seasons correspond to NE and SW Monsoon, wind roses are very different by seasons. Northerly winds are prevailing in NE Monsoon, whereas in SW Monsoon, southerly winds are rather predominant.

In both seasons, effects of sea and land breeze are slightly detectable, i.e., the daytime southerly wind in NE Monsoon and nighttime northerly wind in SW Monsoon. The figures also show that the calm condition (wind velocity less than 0.4 m/s) is frequent in nighttime and especially in SW-Monsoon (dry season).

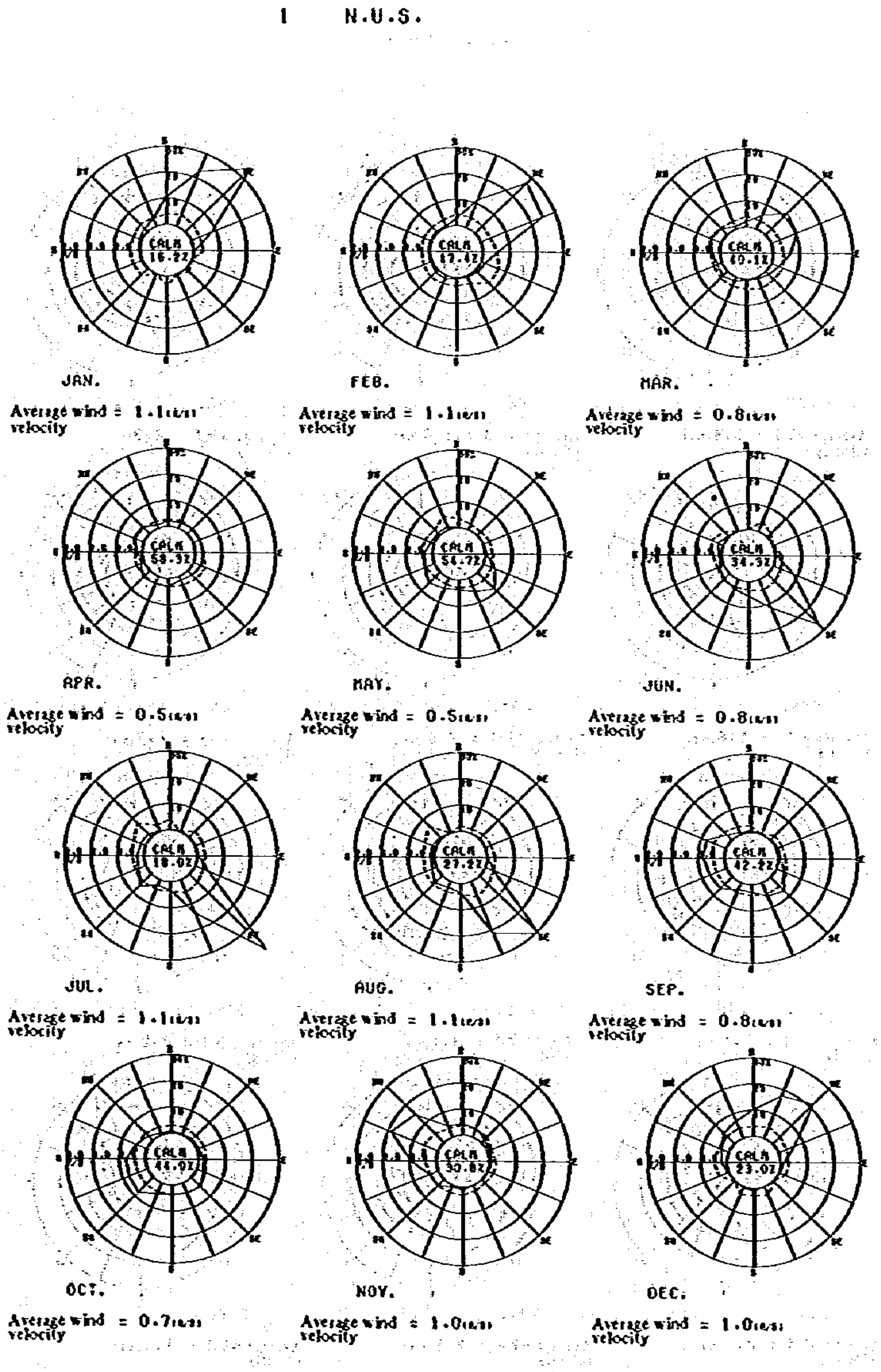


Fig. IV-1-6 Wind roses of each month (a)

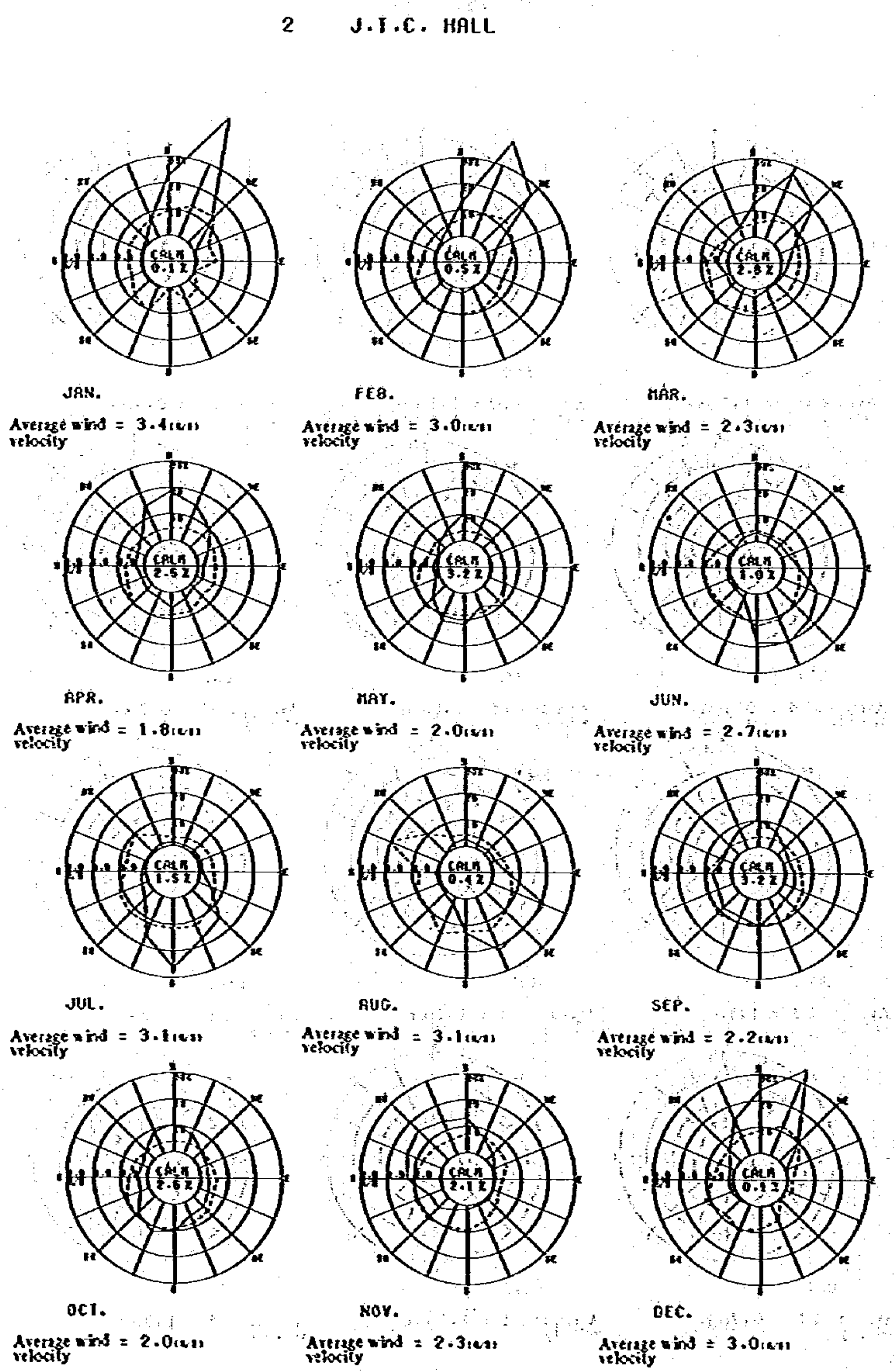


Fig. IV-1-6 Wind roses of each month (b)

3 S.I.U.

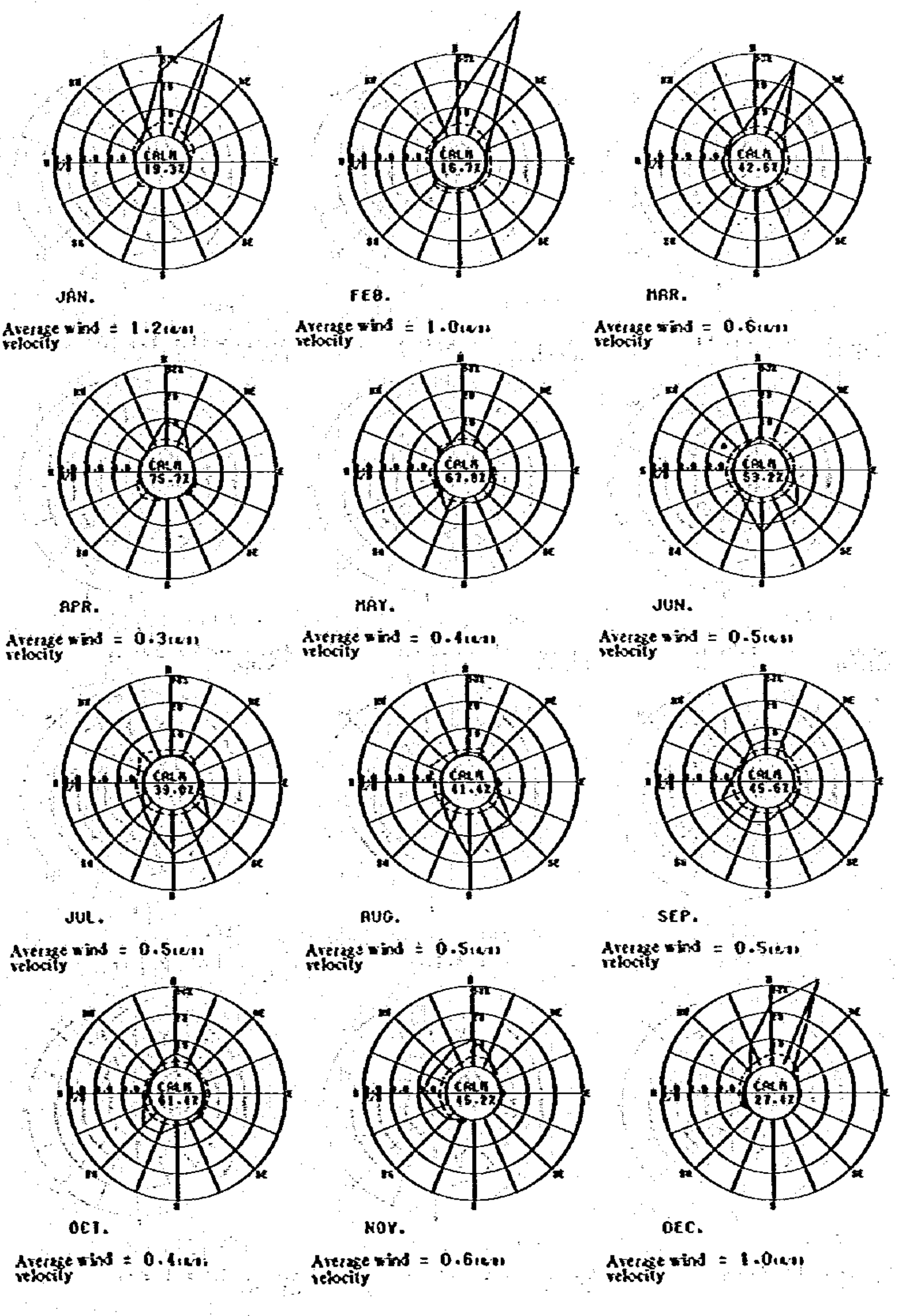


Fig. IV-1-6' Wind roses of each month (c)

4 BOON LAY APARTMENT

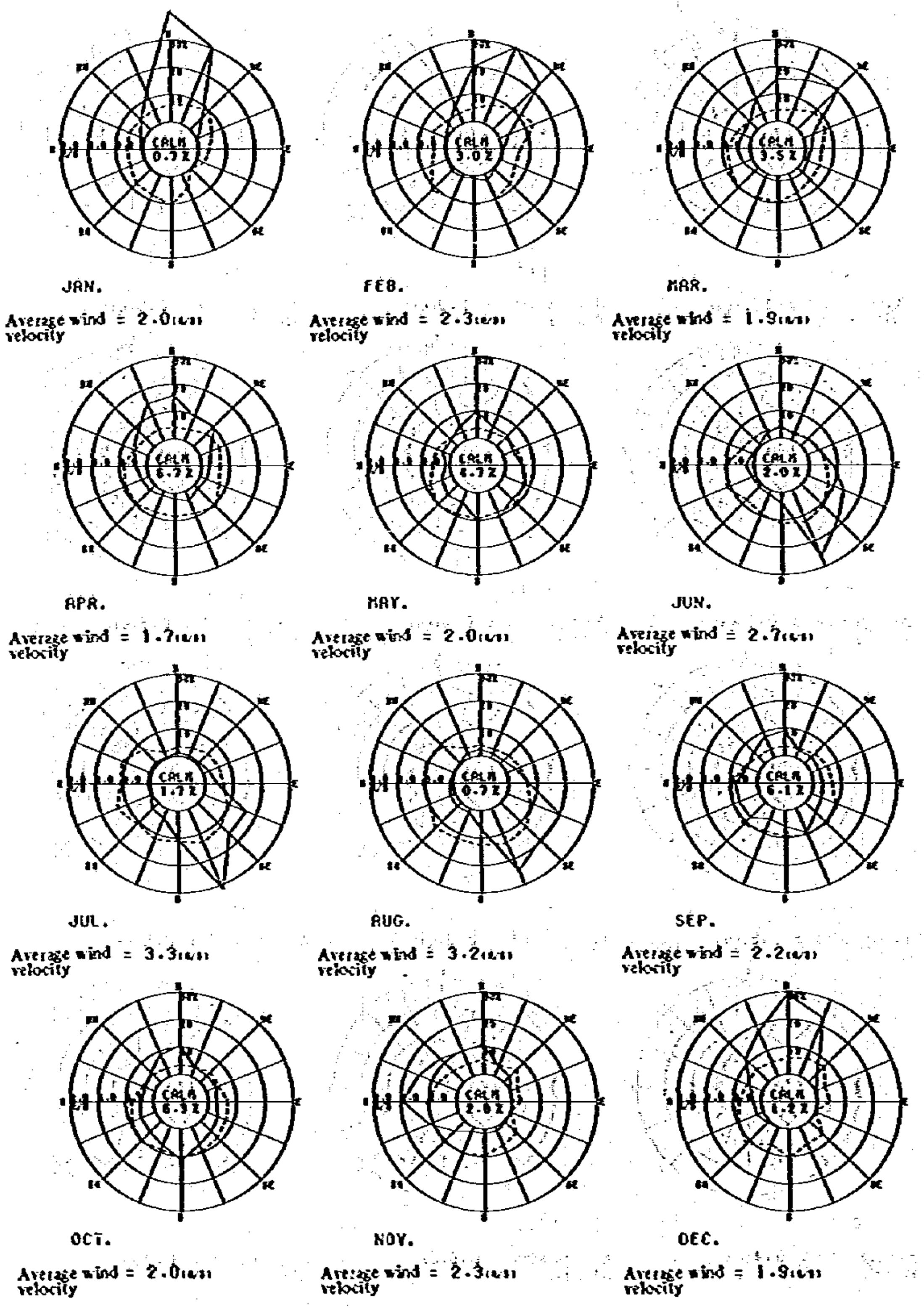


Fig. IV-1-6 Wind roses of each month (d)

5 BUKIT TIMAH FIRE ST.

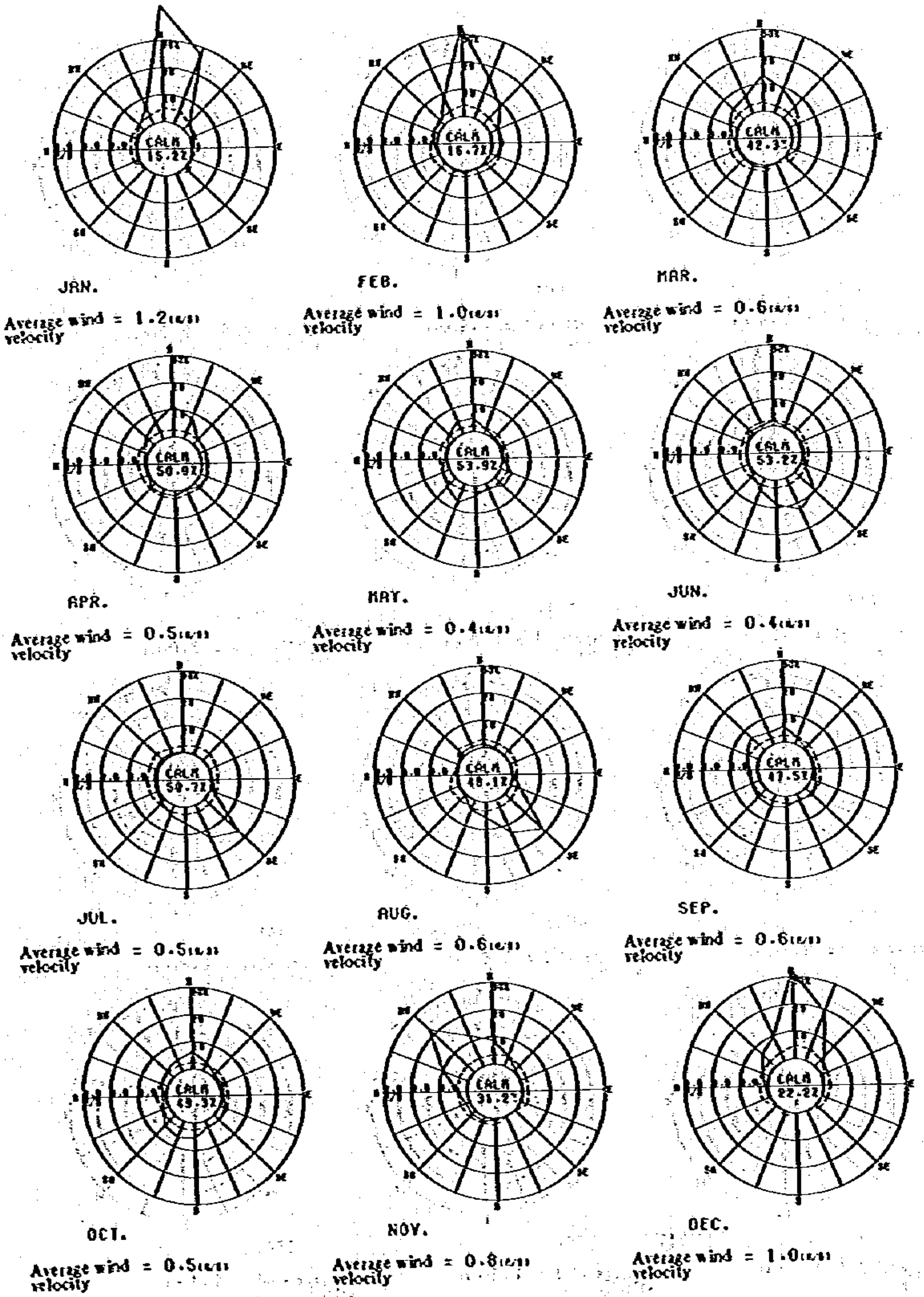


Fig. IV-1-6 Wind roses of each month (e)

6 CHANGI AIRPORT

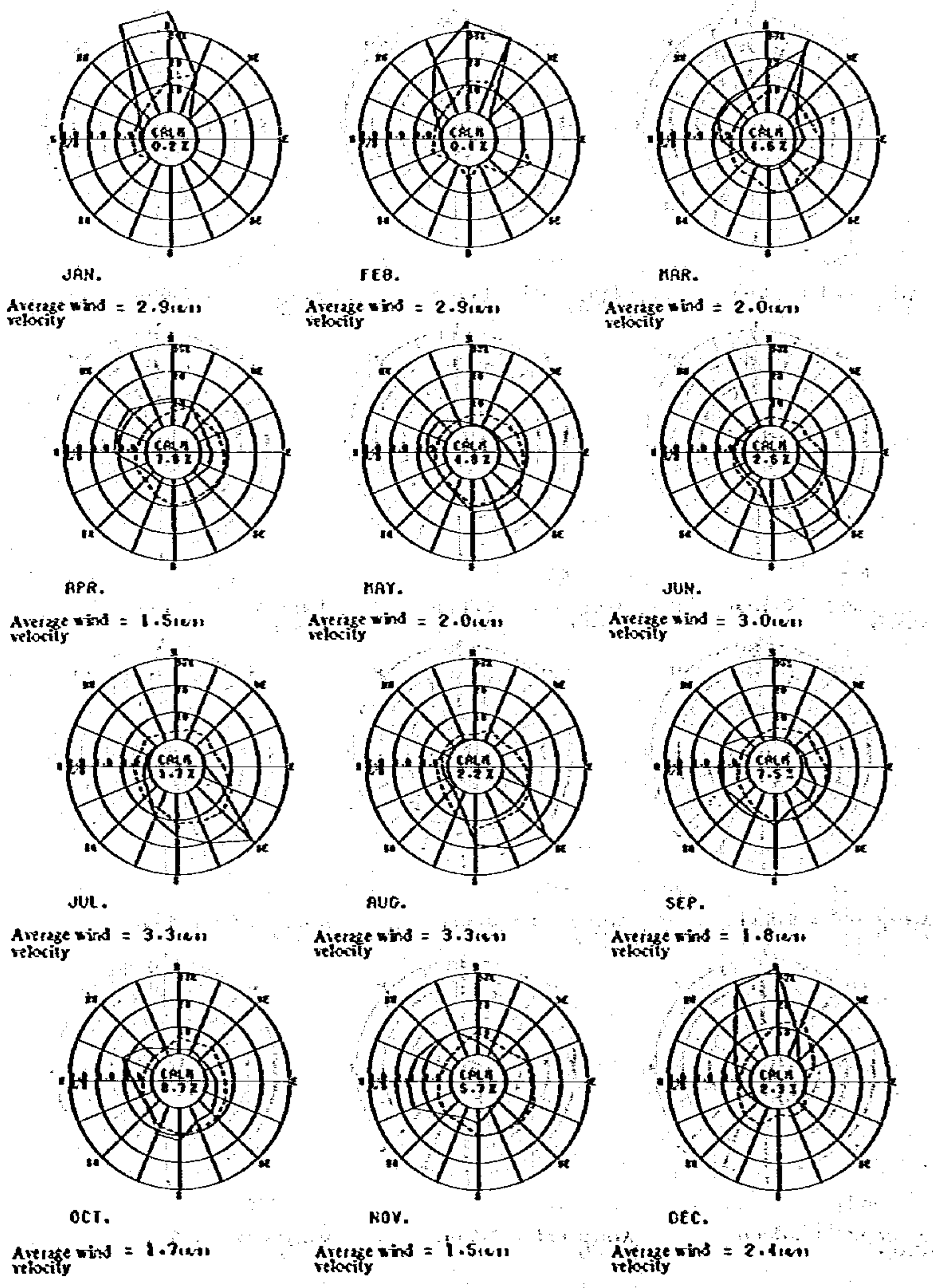


Fig. IV-1-6 Wind roses of each month (f)

7 BEDOK POLICE STATION

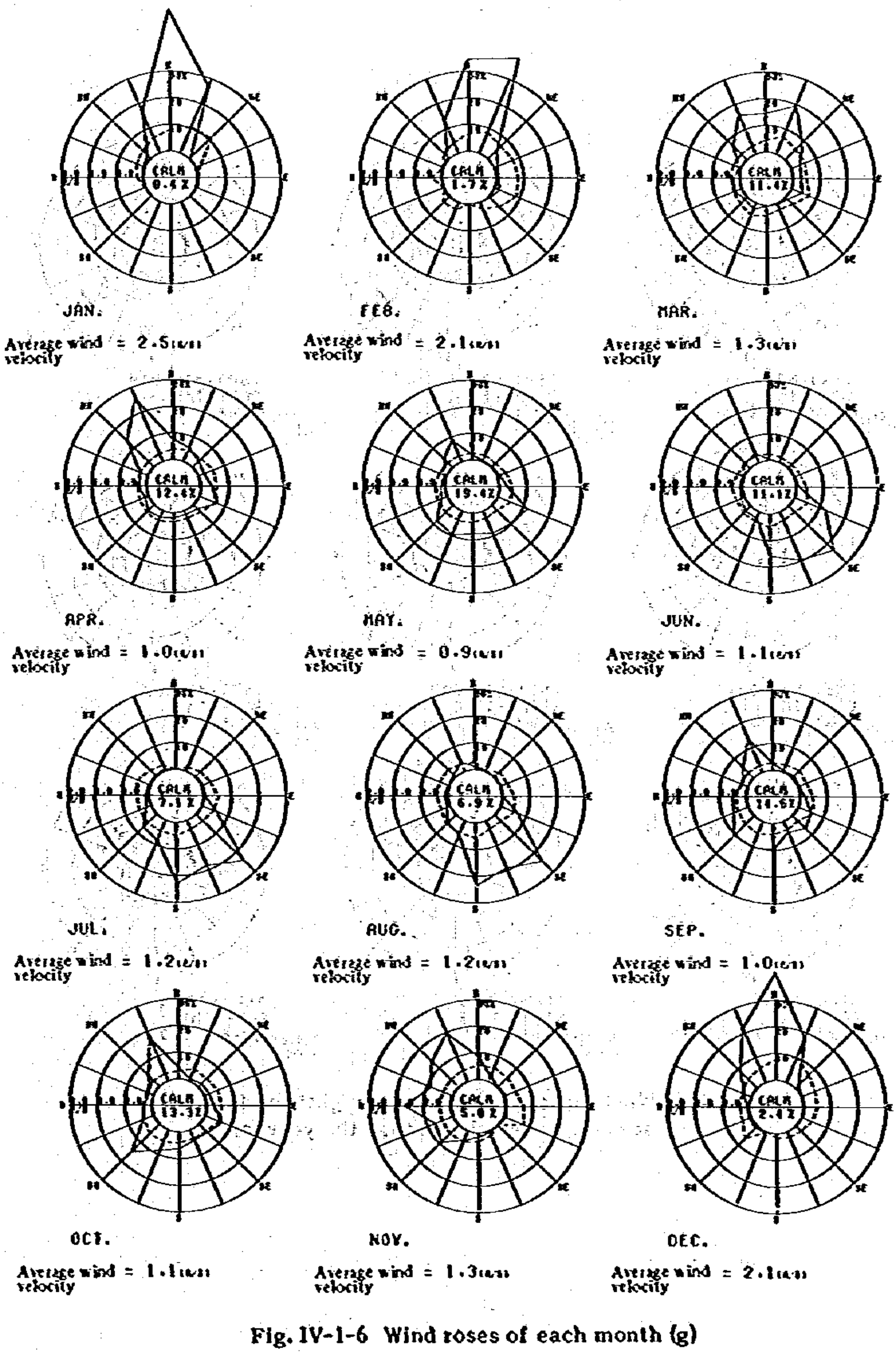


Fig. IV-1-6 Wind roses of each month (g)

1 N.U.S.

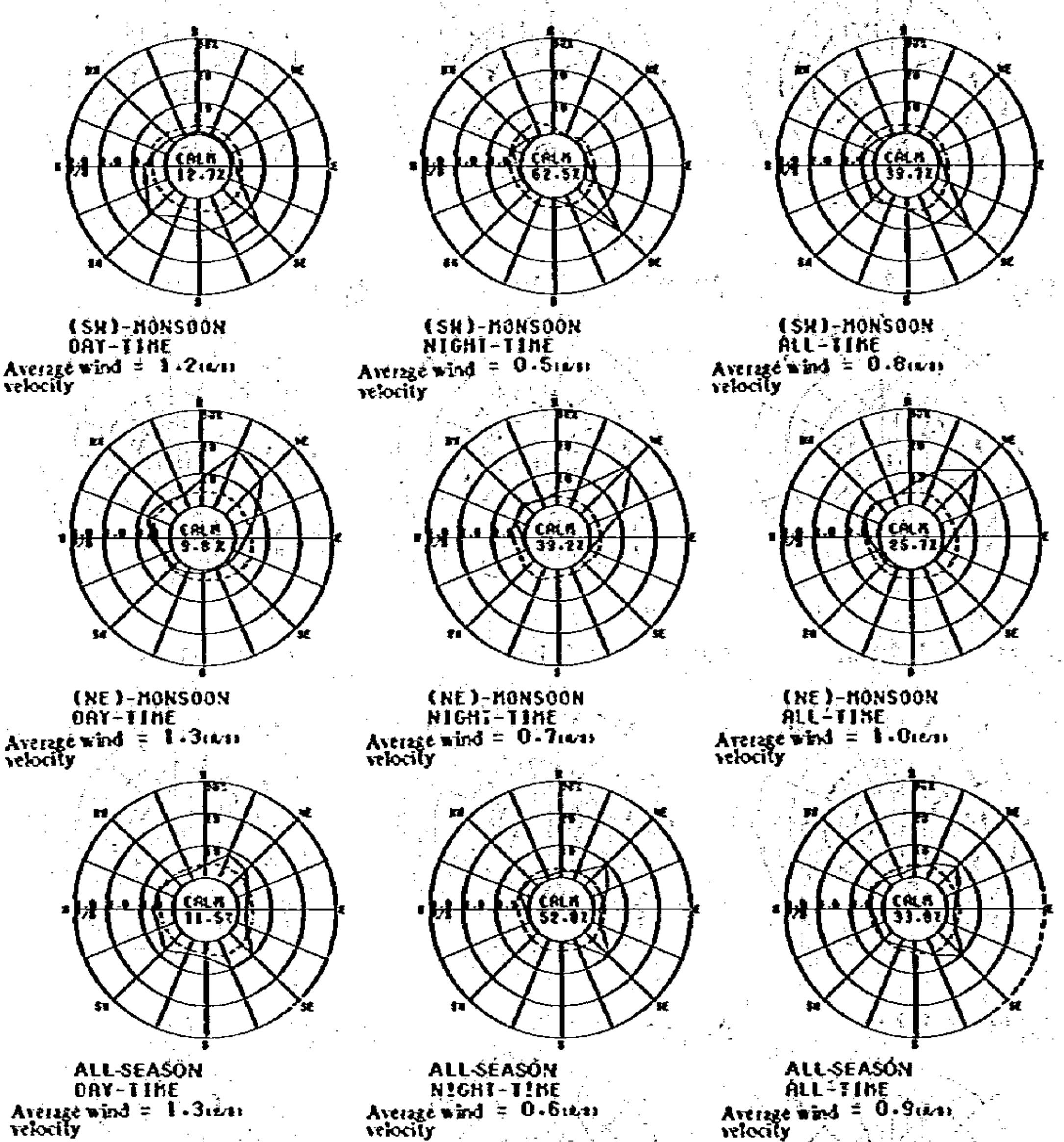


Fig. IV-1-7 Wind roses of daytime and nighttime for two seasons and whole through the year (a)

2 J.T.C. HALL

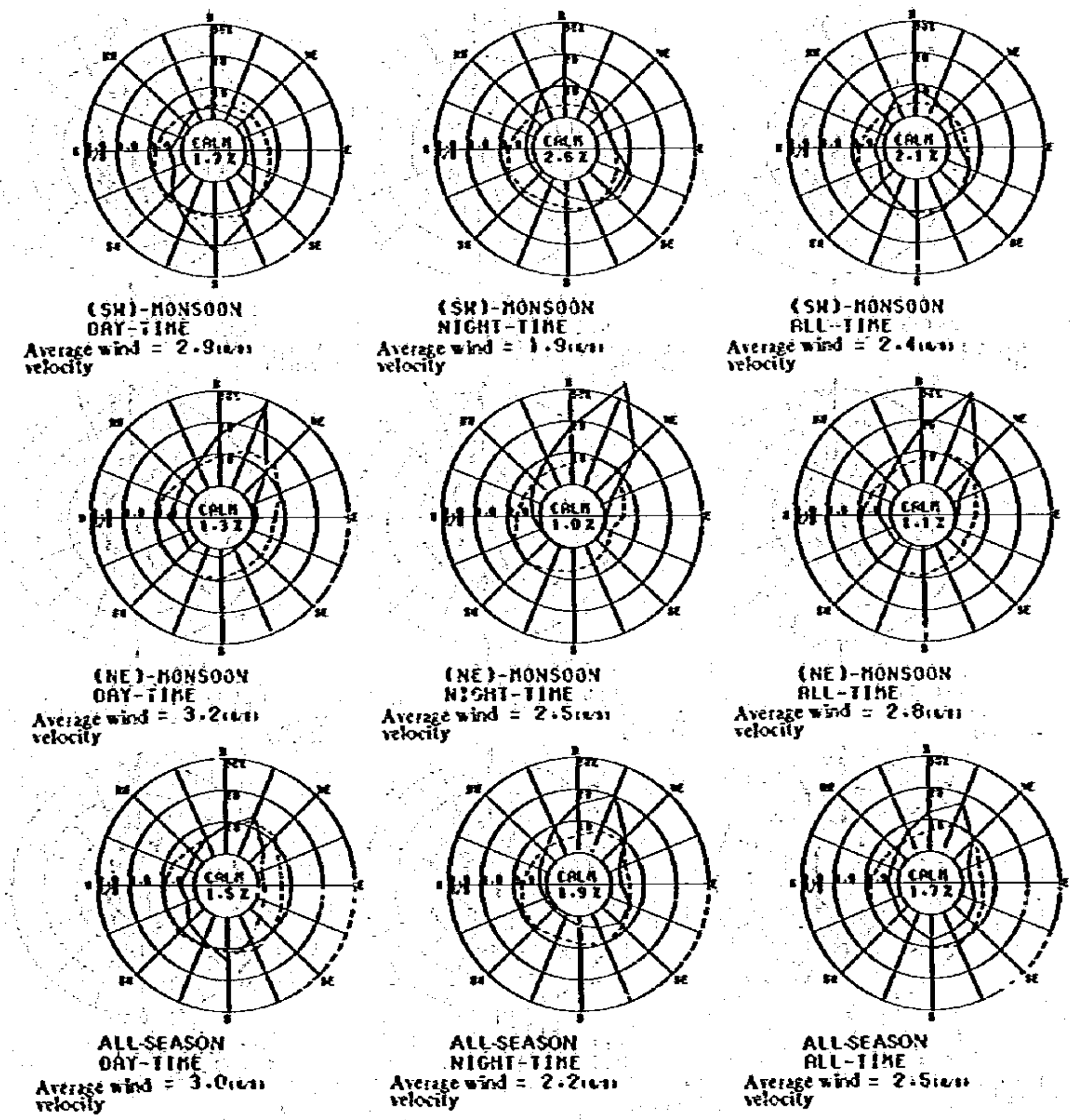


Fig. IV-1-7 Wind roses of daytime and nighttime for two seasons and whole through the year (b)

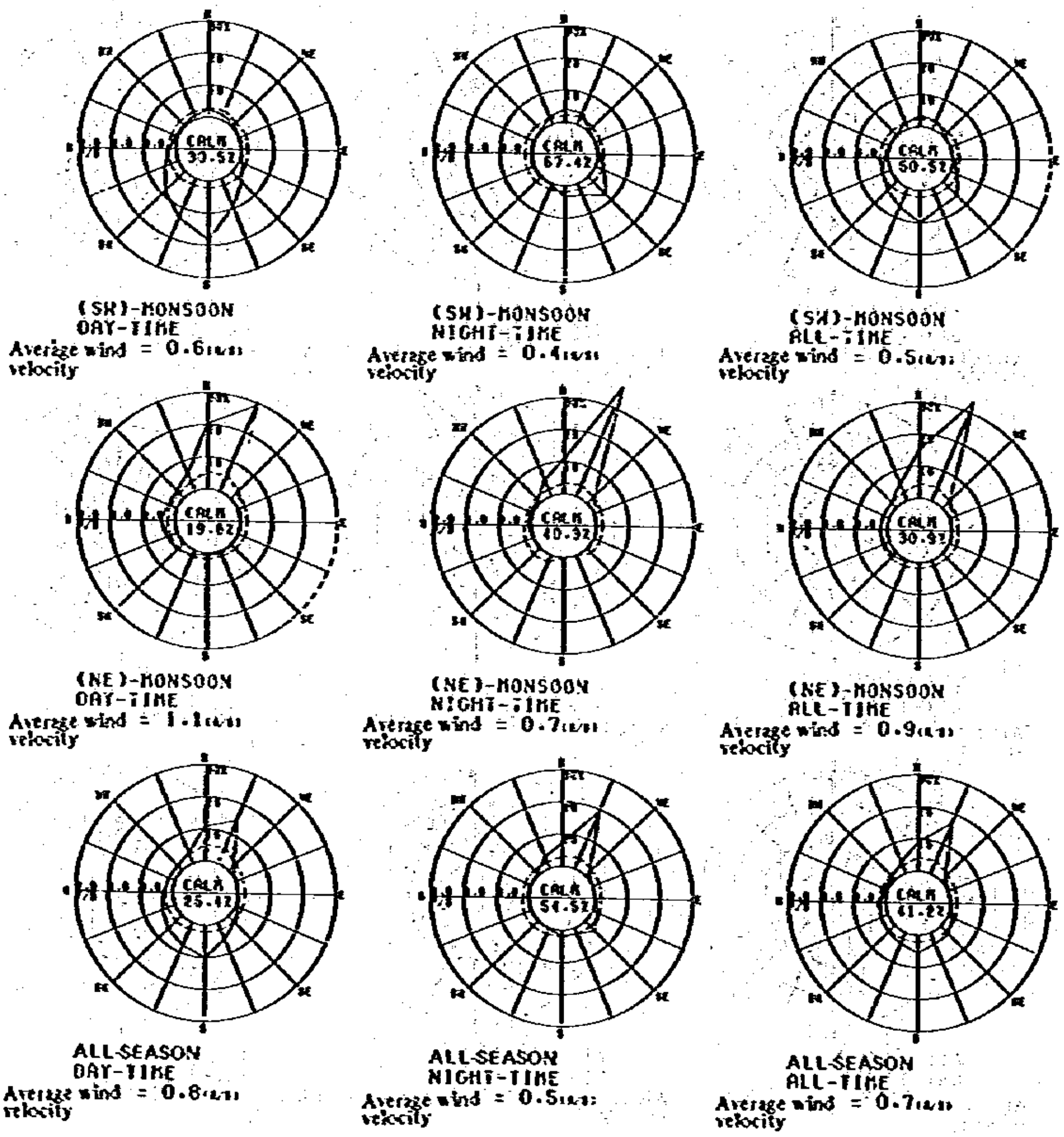


Fig. IV-1-7 Wind roses of daytime and nighttime for two seasons and whole through the year (c)

4 BOON LAY APARTMENT

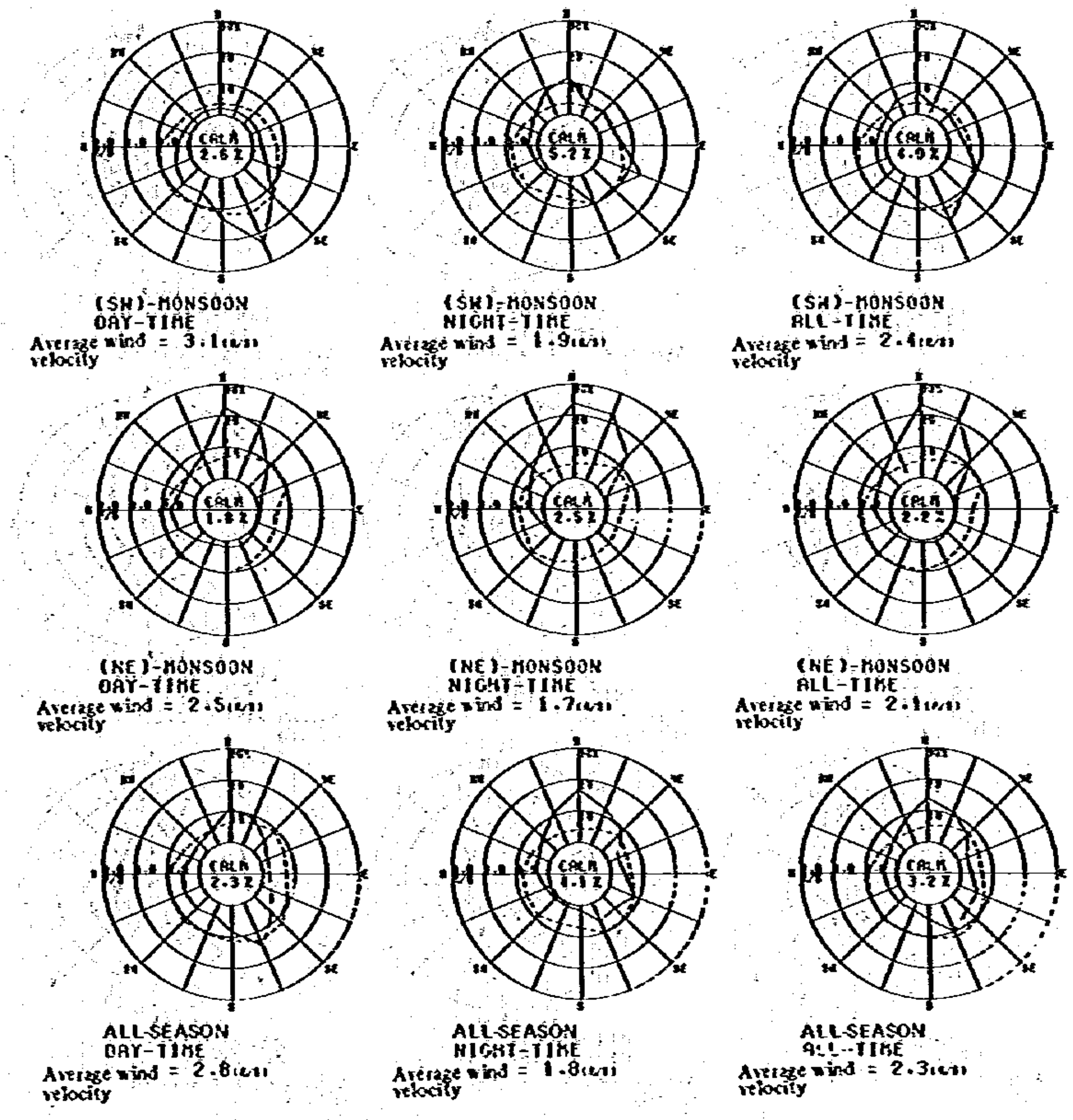


Fig. IV-1-7 Wind roses of daytime and nighttime for two seasons and whole through the year (d)

5 BUKIT TIMAH FIRE ST.

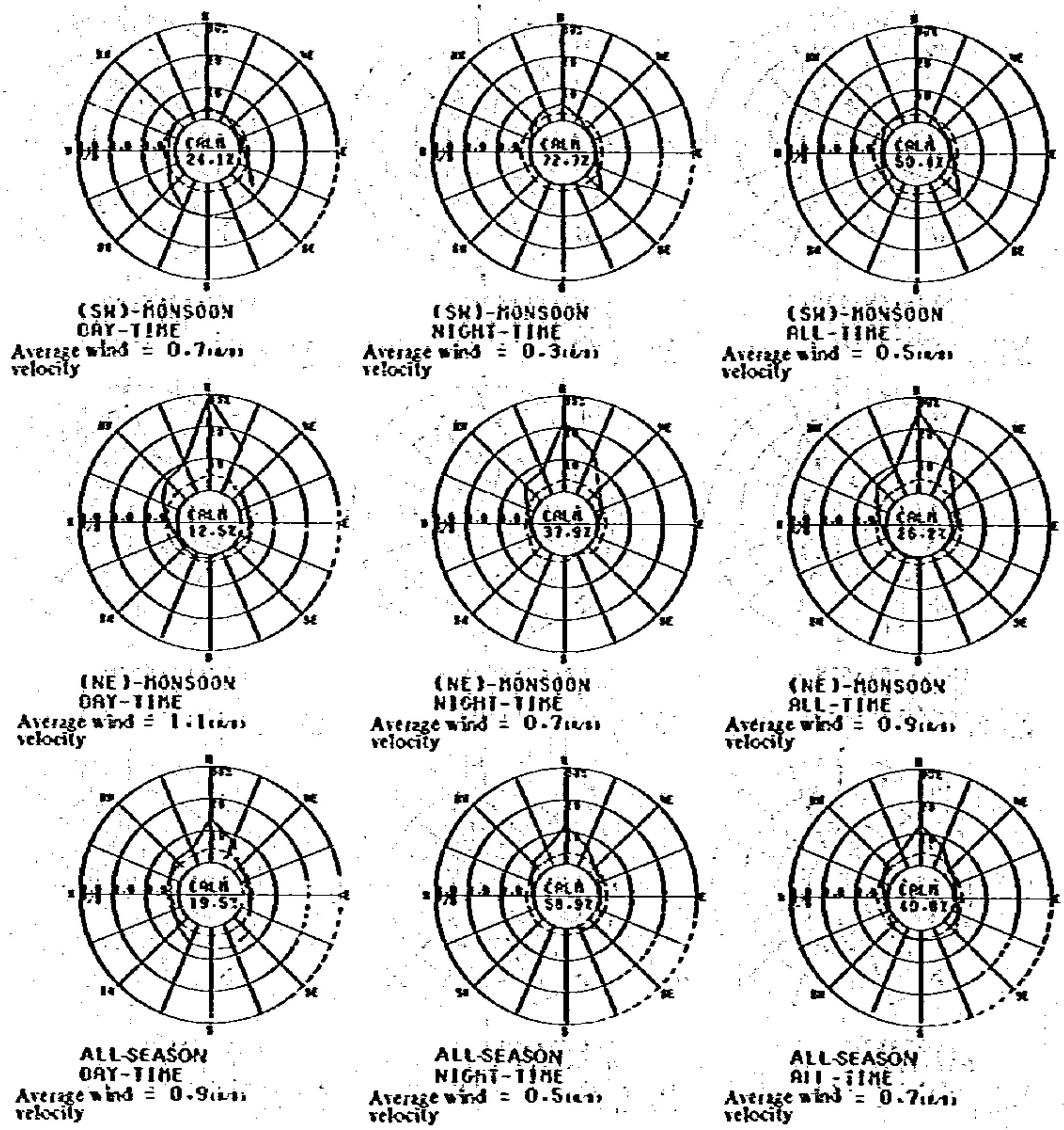


Fig. IV-1-7 Wind roses of daytime and nighttime for two seasons and whole through the year (e)

6 CHANGI AIRPORT

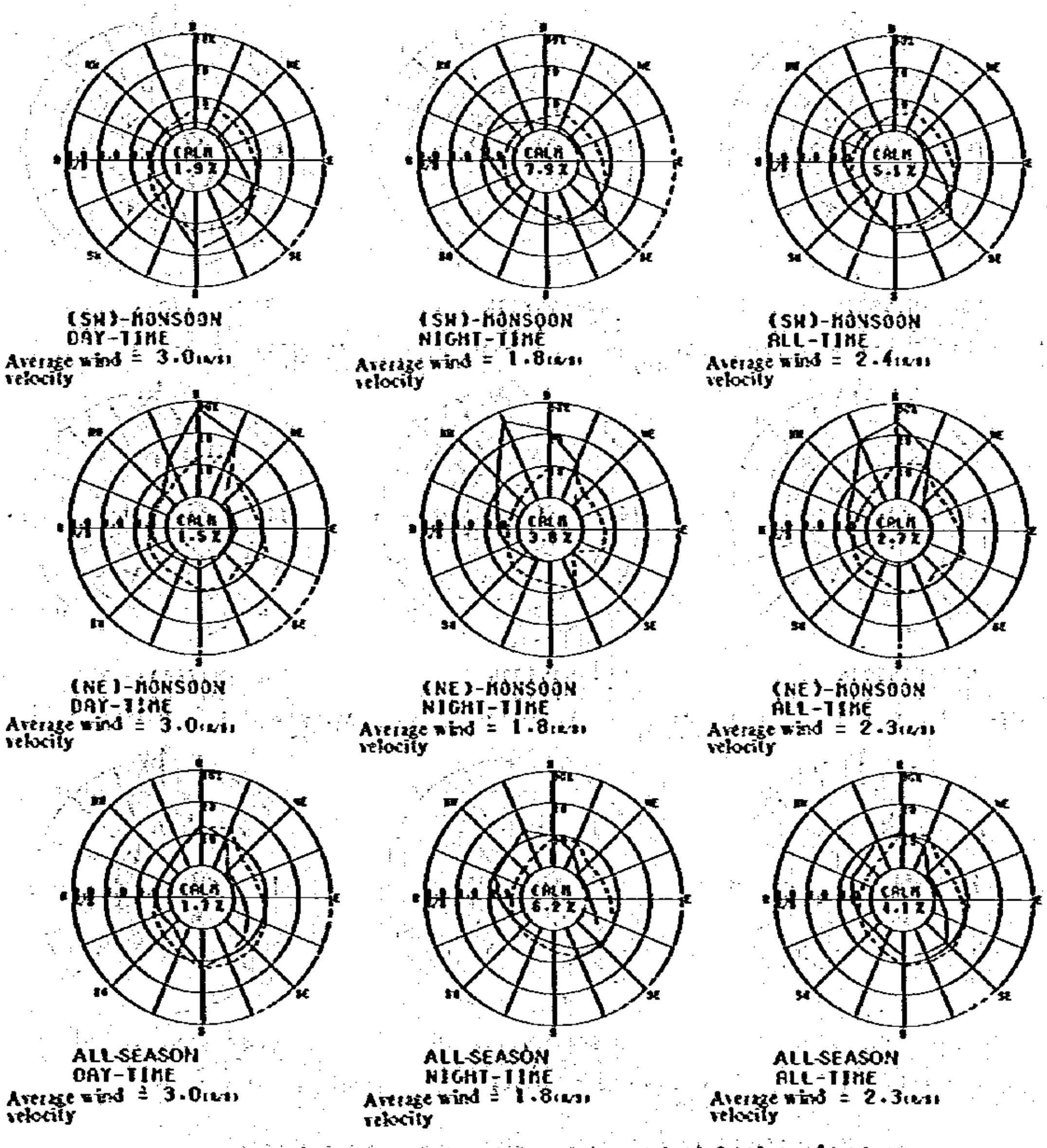


Fig. IV-1-7 Wind roses of daytime and nighttime for two seasons and whole through the year (f)

7 BEDOK POLICE STATION

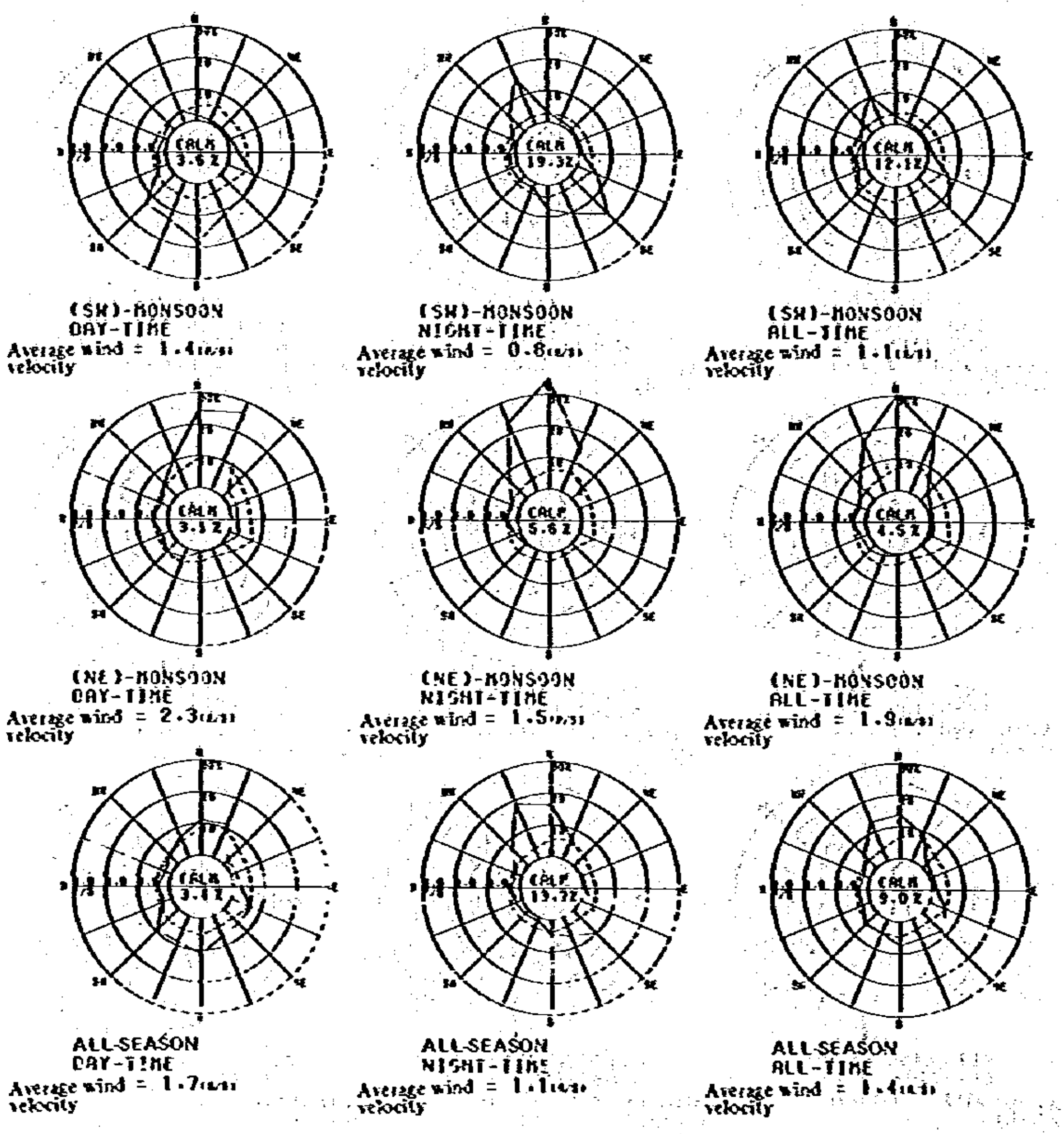


Fig. IV-1-7 Wind roses of daytime and nighttime for two seasons and whole through the year (g)

IV-1-5 Cross Correlation of Wind Vectors of Different Stations

To apply a diffusion model to an objective area, it is required to fix a model of dispersion field. That includes the models of wind rose, wind velocity ranks and atmospheric stability.

To make a wind field model, a typical wind rose for the objective area should be selected. One of the best way to do this is to take cross correlations of wind vectors of every hours for every stations. Then the most representative station of the area in meteorological view point is selected as the station of which the wind vectors correlated highly with another station. And also the ideas of regional blocks from meteorological view point are obtained.

(1) Cross correlation of wind vectors for different stations

The cross correlations of wind vectors of every hours are calculated by the following procedures:

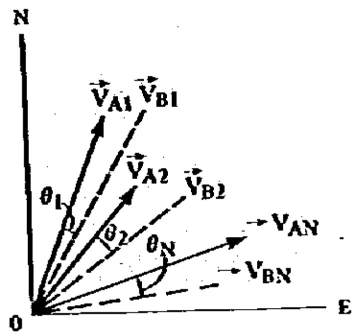


Fig. IV-1-8 Wind vectors between station A and station B

We consider stations A and B, and denote the wind vectors of station A at time i by $\vec{V}_{Ai}$ and for station B, $\vec{V}_{Bi}$ as in Fig. IV-1-8. (i = 1, 2, ... N).

Next we calculate the angle of the two wind vectors $\vec{V}_{Ai}$ and $\vec{V}_{Bi}$ for each time series, and denote it by θi. Then, the cross correlation of wind vectors for station A and B is given by

$$r(A, B) \fallingdotseq \frac{\sum_{i} \vec{V}_{Ai}\ \vec{V}_{Bi}\ \cos\theta i}{\sum \vec{V}_{Ai}\ \vec{V}_{Bi}} \qquad \text{Equation IV-1-1}$$

Where $\vec{V}_{Ai}$ and $\vec{V}_{Bi}$ are the wind velocity at time i and at station A and B, respectively.

The calculated cross correlations for all stations are shown in Table IV-1-4. The Table IV-1-5 shows the number of hourly wind data effectively used. The wind data are effectively used if wind data exist for two objective stations and the wind velocity at both stations are higher than 0.5 m/s.

From the results, it is clear that the correlations are high for MP-1 to MP-5; all of them are the stations located in western part of Singapore. And it is also high between MP-6 and MP-7, both of two located east. There are several methods to divide stations into a few groups, but in this research, we applied cross correlation method, cluster analysis and principal component analysis.

Observation site

(1) N.U.S.
(2) J.T.C. HALL
(3) S.I.U.
(4) BOON LAY APARTMENT
(5) BUKIT TIMAH FIRE ST.
(6) CHANGI AIRPORT
(7) BEDOK POLICE STATION

Table IV-1-4 Cross correlations of wind vectors for different stations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	1.000	0.896	0.883	0.857	0.851	0.716	0.790
(2)	0.896	1.000	0.955	0.940	0.871	0.796	0.858
(3)	0.883	0.955	1.000	0.932	0.909	0.847	0.901
(4)	0.857	0.940	0.932	1.000	0.840	0.809	0.841
(5)	0.851	0.871	0.909	0.840	1.000	0.765	0.828
(6)	0.716	0.796	0.847	0.809	0.765	1.000	0.924
(7)	0.790	0.858	0.901	0.841	0.828	0.924	1.000

Table IV-1-5 Number of data of hourly wind vectors used to calculate cross correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1)	5669.	5306.	3584.	5561.	4026.	5414.	5331.
(2)	5306.	8174.	4064.	7849.	4710.	7625.	7235.
(3)	3584.	4064.	4311.	4267.	3252.	4119.	4054.
(4)	5561.	7849.	4267.	8348.	4840.	7830.	7439.
(5)	4026.	4710.	3252.	4840.	4936.	4685.	4633.
(6)	5414.	7625.	4119.	7830.	4685.	8191.	7319.
(7)	5331.	7235.	4054.	7439.	4633.	7319.	7723.

(2) Cluster analysis based on cross correlation of wind vectors

The cluster analysis is an analytical method to classify a set of variables into several clusters. It is commonly used in biology and natural history in order to classify samples. In this study, observational stations are classified by Furthest Neighbour Method in which cross correlations are used as the measure of the distance. The algorithm is as follows:

(a) First we define d_{ij} as the measure of the neighbouring factor between stations i and j as follows:

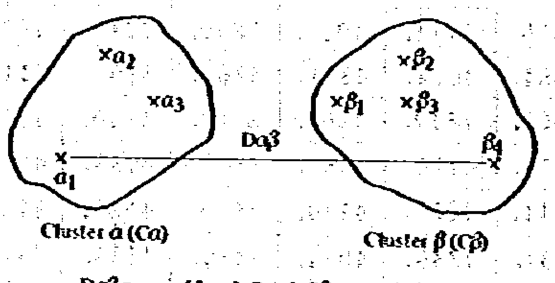
$$d_{ij} = (1 - r_{ij})$$

where r_{ij} is the cross correlation.

(b) Using the initial measures of distance defined above, clustering is started and the neighbouring two stations are grouped. These groups are new clusters.

(c) The measures of distance are again calculated between new clusters. And clustering is again done for the newly calculated measures. These procedures are repeated until all samples are gathered into one cluster.

For the renewal of distance between new clusters, several methods are proposed. In this research, the Furthest Neighbouring method in which the furthest distance of the clusters are used, is applied (Fig. IV-1-9).



Dαβ : Distance between clusters α and β

Fig. IV-1-9 Distance between cluster α and β.

The results of the cluster analysis is shown in Fig. IV-1-10. From the figure it is clear that the measuring stations are classified into two groups with correlation coefficient of 0.8. The first group is MP-1 to MP-5. These are the stations located west of Singapore and another is the eastward stations. It implies that the wind field is different in west of Singapore from the east.

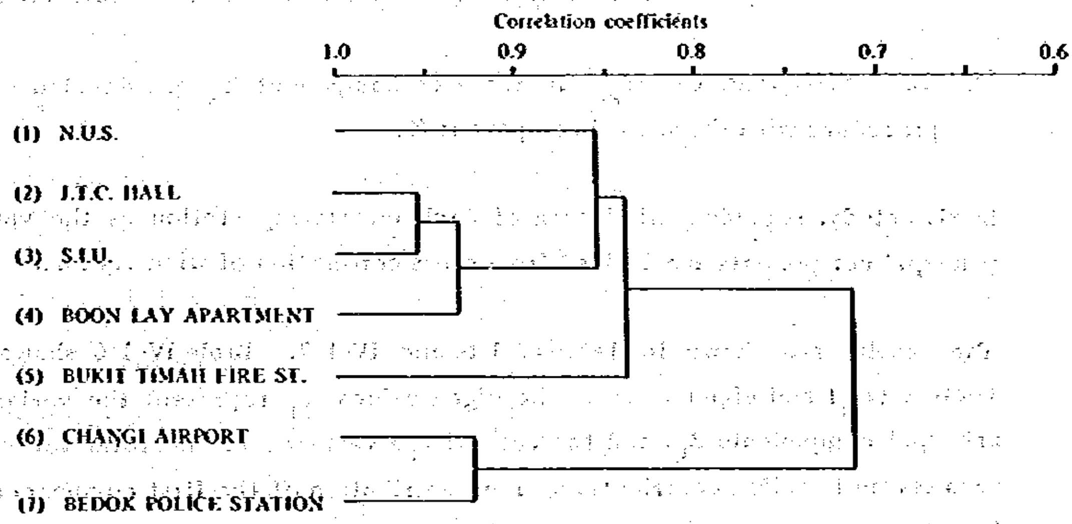


Fig. IV-1-10 Results of clustering and correlation coefficients

(3) Principal component analysis based on cross correlation analysis

The principal component analysis is a method in which variables $x_1, x_2, x_3 \ldots x_p$ are summed up to mutually independent components.

In the principal component analysis, principal components Z_k are represented by weighed averages of variables as follows:

$$
\left.
\begin{aligned}
z_1 &= \ell_{11}x_1 + \ell_{12}x_2 + \cdots + \ell_{1p}x_p = \sum_{i=1}^{p} \ell_{1i}x_i \\
z_2 &= \ell_{21}x_1 + \ell_{22}x_2 + \cdots + \ell_{2p}x_p = \sum_{i=1}^{p} \ell_{2i}x_i \\
&\cdots\cdots \\
z_k &= \ell_{k1}x_1 + \ell_{k2}x_2 + \cdots + \ell_{kp}x_p = \sum_{i=1}^{p} \ell_{ki}x_i \\
z_m &= \ell_{m1}x_1 + \ell_{m2}x_2 + \cdots + \ell_{mp}x_p = \sum_{i=1}^{p} \ell_{mi}x_i
\end{aligned}
\right\} \quad \text{Equation IV-1-2}
$$

where,

$$\ell_{k1}^2 + \ell_{k2}^2 + \cdots + \ell_{kp}^2 = \sum_{i=1}^{p} \ell_{ki}^2 = 1 \quad (k = 1, 2, \cdots, m) \qquad \text{Equation IV-1-3}$$

Coefficients ℓ_{ki} are decided as to satisfy following conditions :

(a) In the first principal component Z_1, the coefficients $\{\ell_{1i}\}$ $(i = 1, 2, ...p)$ are settled as the variance of Z_0 takes the maximum.

(b) The coefficients of $\{\ell_{2i}\}$ in the second component Z_2 are decided as the variance of Z_2 takes the maximum under the condition of no correlation with Z_1.

(c) The coefficients of $\{\ell_{ki}\}$ in the k th component Z_k are decided by the same procedure with the second component Z_2.

In this study, regarding wind data of each monitoring station as the variables, the principal components are derived from cross correlation of wind vectors.

The results are shown in Table IV-1-6 and IV-1-7. Table IV-1-6 shows the eigen vectors (ℓ_{ki}) and eigen values. The eigen values λ_k represent the variances of the principal components Z_k, and the rate of the variance to the total variance (in this case seven) is called contribution. The contribution of the first component Z_1 is 0.88 ($\lambda_1/7$) and it means that 88 percent of informations included in variables is contained in Z_1. The eigen vectors of the first component are about 0.15 for all stations and only slight differences are detected.

The contribution of second principal component is 0.05 (0.381/7), and the summed contribution of the first and second principal components becomes 0.93. This means that 93 percent of total informations is explained by the two components.

Factor loading $r(Z_k, x_i)$ is equal to the cross correlations of variables x_i, and expressed by the equation

$$r(Z_k, x_i) = \sqrt{\lambda_k}\ \ell_{ki} .$$

Fig. IV-1-11 shows the distributions of factor loadings of the first and second components, the first components are as high as 0.89 to 0.98 for every stations and seem to express the effect of general air flow system.

On the other hand, the second principal components are changeable with stations i.e., positive for MP-1 to MP-5 and negative for MP-6 and MP-7, and those components seem to express the effect of local flow system.

From these remarks we can divide the monitoring stations into two groups, the group of MP-1 to MP-5, and MP-6 to MP-7, these grouping is consistent with the results of cluster analysis.

Table IV-1-6 Eigen vectors and eigen values

Principal components	Z_1	Z_2	Z_3	Z_4
(1) N.U.S.	0.14857	-0.74192	0.11381	2.14434
(2) J.T.C. HALL	0.15671	-0.36463	-0.73734	-0.37820
(3) S.I.U.	0.15941	-0.10827	-0.06866	-0.57795
(4) BOON LAY APARTMENT	0.15427	-0.22775	-1.29710	-0.94691
(5) BUKIT TIMAH FIRE ST.	0.15031	-0.34519	1.83157	-1.04569
(6) CHANGE AIRPORT	0.14493	1.10303	-0.05241	0.38824
(7) BEDOK POLICE STATION	0.15212	0.73486	0.27594	0.52469
Eigen value (λ_k)	6.151	0.381	0.176	0.133

Table IV-1-7 Loading factors

Principal components	Z_1	Z_2	Z_3	Z_4
(1) N.U.S.	0.914	-0.283	0.020	0.286
(2) J.T.C. HALL	0.964	-0.139	-0.130	-0.050
(3) S.I.U.	0.980	-0.041	-0.012	-0.077
(4) BOON LAY APARTMENT	0.949	-0.087	-0.228	-0.126
(5) BUKIT TIMAH FIRE ST.	0.925	-0.132	0.323	-0.140
(6) CHANGE AIRPORT	0.891	0.421	-0.009	0.052
(7) BEDOK POLICE STATION	0.936	0.280	0.049	0.070

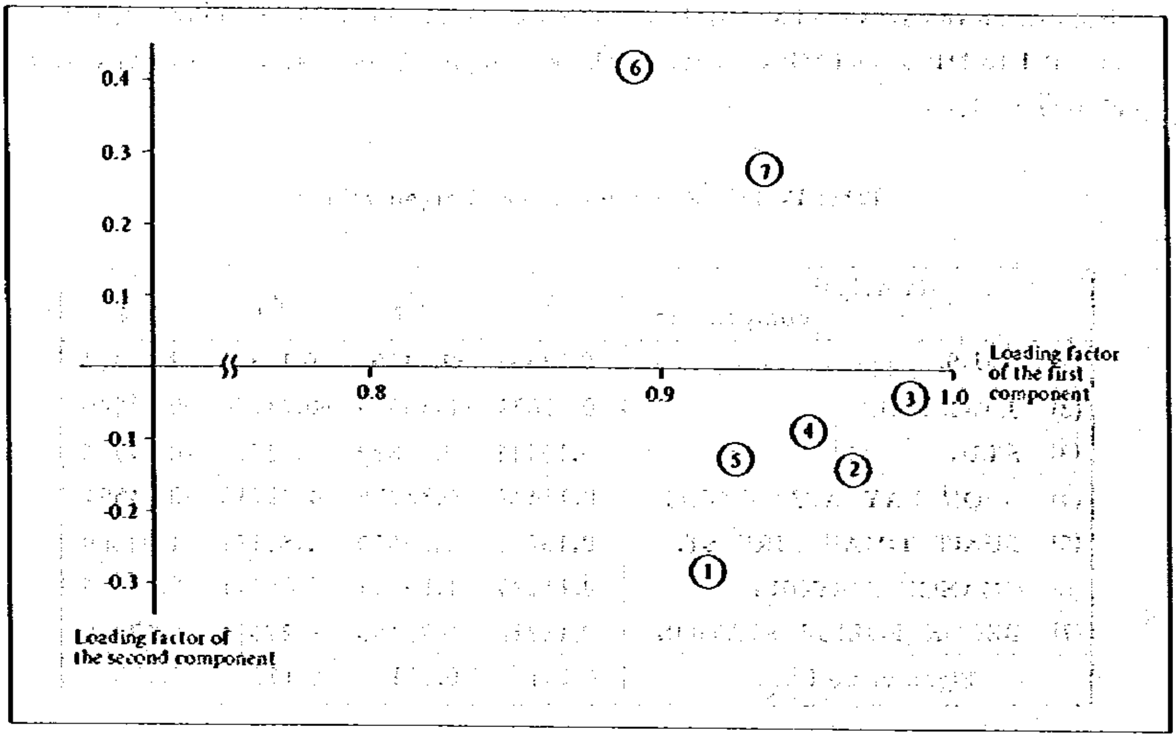


Fig. IV-1-11 Result of principal component analysis

IV-1-6 Vertical Profiles of Wind Velocity by Pilot Balloon Observations

The airflow layer where the effect of ground surface is predominant, is called atmospheric boundary layer. In the atmospheric boundary layer, the wind velocity increases with height because of drag forces due to surface roughness.

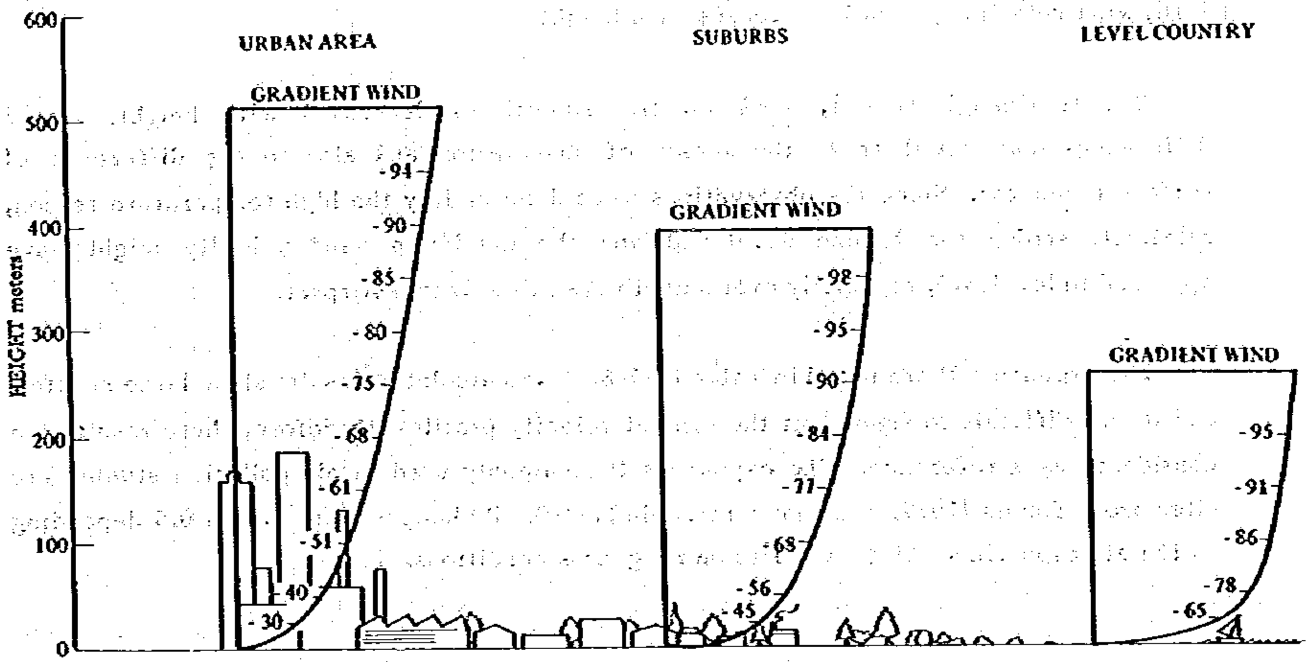


Fig. IV-1-12 Examples of variation of wind with height over different size roughness elements (figures are percentages of gradient wind); (from Davenport, 1963)

The velocity profile varies with surface roughness and atmospheric stability. For the prosecution of reliable air pollution simulation, we are required to know the characteristics of velocity profiles in the objective area.

Generally, the velocity profiles are represented by log law or power law, and power law is rather common than log law in air pollution studies. The power law exponents P were calculated for the pilot balloon observation data obtained at JTC Hall and Changi Airport. The power law is as follows:

$$U(Z) = U(Z_s)\,(Z/Z_s)^P \qquad \text{Equation IV-1-4}$$

where; $U(Z)$ is the wind velocity at height Z,
$U(Z_s)$ is the wind velocity at height Z_s,
P is the exponent.

The wind velocity data at 100, 200 and 300 meters high are used for estimation of P. The P_s are calculated by least square method.

In Figs. IV-1-13, the velocity profiles by pilot balloon observations are shown for JTC Hall and Changi Airport. Because of the large scattering of the plotts by height and also by time, it is relatively difficult to clarify the general characteristics, except that at JTC Hall, wind velocity generally increases with height.

But at Changi Airport, wind velocity sometimes decreased with height. Those differences may attribute to the season of observation and also to the difference of surface roughness. Since the observations were done in July the high temperature season, relatively strong sea breeze developed and the maximum wind velocity might have appeared in low level, especially over smooth area like Changi Airport.

The exponents P are listed in Table IV-1-8. The calculated results show large scatter, and it was difficult to figure out the typical velocity profiles, therefore, these results are considered as a reference. The exponents P commonly used in air pollution studies are cited from Touma (1977) and shown in Table IV-1-9. P changes from 0.1 to 0.5 depending on the atmospheric stability and also on roughness conditions.

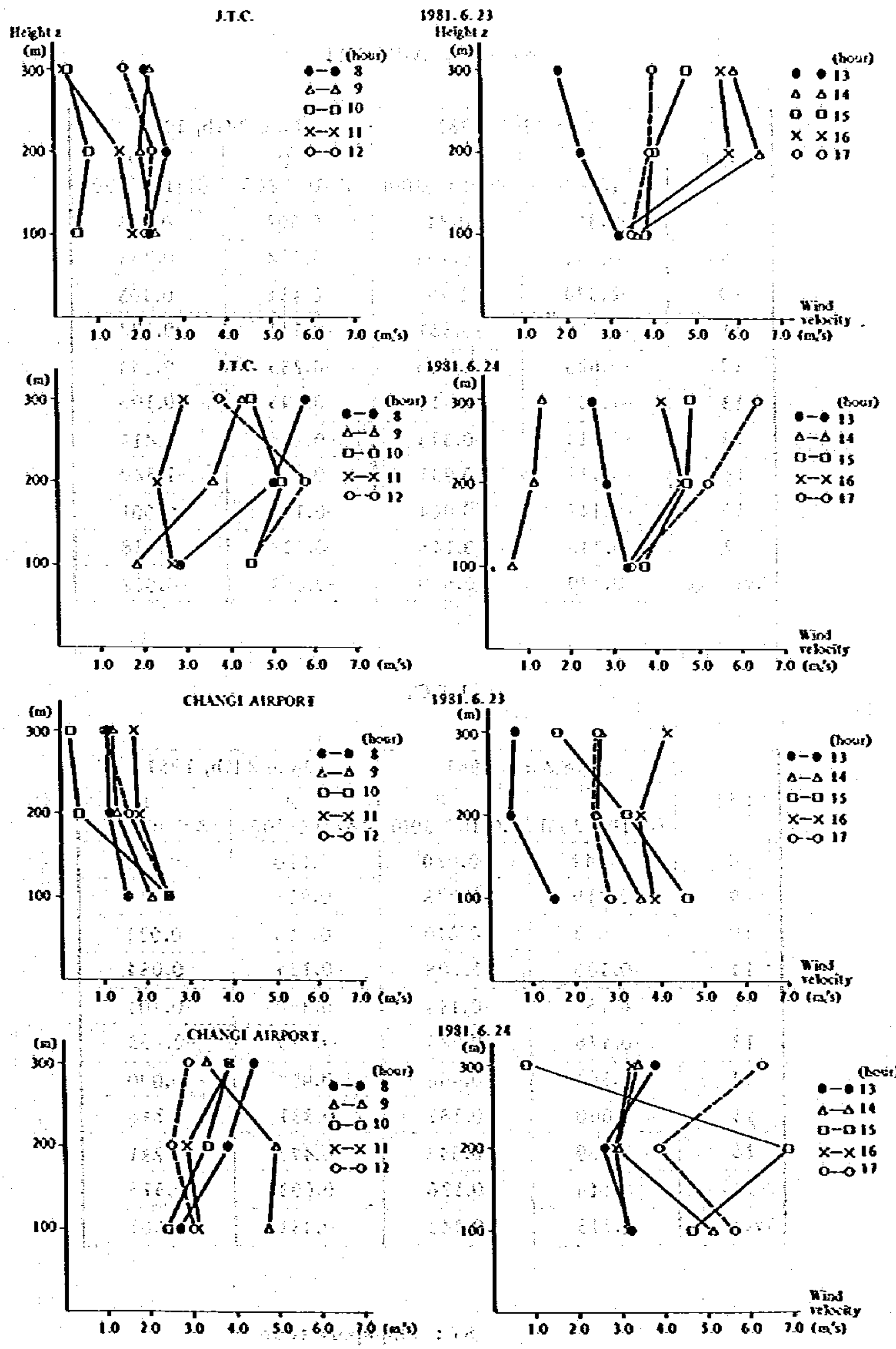


Fig. IV-1-13 Velocity profiles by pilot balloon observations

Table IV-1-8 Exponent P calculated by the pilot balloon data

CHANGI AIRPORT

SST	June 23rd, 1981		June 24th, 1981	
	P (Z=100-200)	P (Z=100-300)	P (Z=100-200)	P (Z=100-300)
8	-0.367	-0.242	0.502	0.463
9	-0.681	-0.493	0.062	-0.282
10	-2.574	-2.494	0.434	0.405
11	-0.435	-0.367	-0.147	0.172
12	-0.623	-0.855	-0.255	-0.043
13	-1.657	-0.919	-0.295	0.105
14	-0.514	-0.313	-0.835	-0.419
15	-0.548	-0.931	0.574	-1.320
16	-0.142	0.064	-0.146	-0.001
17	-0.246	-0.145	-0.522	0.038
Average	-0.779	-0.670	-0.063	-0.088

J.T.C.

SST	June 23rd, 1981		June 24th, 1981	
	P (Z=100-200)	P (Z=100-300)	P (Z=100-200)	P (Z=100-300)
8	0.249	-0.020	0.820	0.668
9	-0.219	-0.078	0.988	0.810
10	0.803	-0.240	0.212	0.021
11	-0.306	-1.708	-0.154	0.084
12	0.152	-0.199	0.360	-0.101
13	-0.476	-0.529	-0.249	-0.253
14	0.864	0.498	0.957	0.090
15	0.060	0.181	0.331	0.248
16	0.859	0.542	0.471	0.231
17	0.140	0.126	0.603	0.575
Average	0.213	-0.143	0.434	0.307

ST : Singapore time

Table IV-1-9 The typical values of exponent P for different sites and stabilities

Pasquill stability	a Missouri 1973-74	a Missouri 1974-75	a Kansas 1973-74	a Kansas 1974-75	a Iowa 1973-74	a Texas 1973-74	a Michigan 1975-76	b Missouri 1973-74
A	0.103	0.099	0.124	0.091	0.104	0.120	0.109	0.111
B	0.079	0.092	0.145	0.103	0.101	0.123	0.085	0.119
C	0.082	0.080	0.152	0.122	0.114	0.128	0.078	0.104
D	0.115	0.144^{c}	0.199	0.172	0.188	0.174	0.116	0.136
E	0.271	0.273	0.341	0.282	0.313	0.330	0.261	0.272
F	0.423	0.385	0.480	0.412	0.466	0.562	0.425	0.424
G	0.504	0.417	0.506	0.452	0.444	0.624	0.516	0.447
Terrain	Rolling	Rolling	Rolling	Rolling	Rolling	Rolling	Hilly	Rolling

a : Stability due to the air temperature difference ΔT between 10 and 60 meters above ground

b : Stability due to the air temperature difference ΔT between 10 and 90 meters above ground

c : $^{1}/_{7} = 0.143$

IV-1-7 Solar Radiation and Net Radiation Flux

Solar radiation and net radiation intensities are the primary parameters of the stability classification. The monthly and hourly averages of solar radiation at National University of Singapore are shown in Table IV-1-10. Monthly changes are relatively small but the highest value appeared in August, and the lowest in December.

In Table IV-1-11, monthly and hourly averages of net radiation flux are shown. The net flux becomes negative from 19 ST (Singapore Time) to 8 in the morning, and monthly differences are also very small. The diurnal variations of solar radiation and net flux are shown in Fig. IV-1-14.

Table IV-1-10 Monthly and hourly averages of solar radiation

Site No.	1	Site name	N.U.S.	Item No.	3	Item name	Solar radiation	Yard-stick	(CAL/CM2/H)

Time	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Annual average
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.4	0.0	0.0	0.0	0.2	0.6	1.3	1.5	1.3	1.6	0.6
8	2.0	2.1	5.2	5.5	3.8	3.4	5.1	9.9	11.4	15.1	10.1	11.7	7.1
9	13.7	16.1	19.5	20.1	17.5	15.4	17.2	25.1	23.4	29.2	22.2	27.0	20.5
10	28.6	36.0	33.7	35.5	29.1	30.8	30.3	39.0	36.1	45.9	37.0	37.1	34.8
11	41.8	52.6	46.5	46.5	40.8	41.8	45.2	52.4	47.0	53.9	48.0	50.5	47.2
12	52.3	61.3	53.4	51.1	47.6	50.4	55.5	68.8	55.4	62.2	53.2	49.6	55.0
13	53.7	65.8	54.6	50.7	53.0	58.9	60.9	72.4	61.4	59.7	50.5	47.1	57.5
14	52.5	62.5	54.2	46.6	54.5	61.9	59.3	61.8	54.4	52.7	48.3	37.9	54.0
15	46.7	55.0	46.1	36.2	46.6	56.8	49.8	54.6	46.9	41.4	42.2	33.1	46.4
16	34.8	42.4	33.9	25.9	34.0	45.7	41.0	44.7	33.8	30.1	32.8	23.3	35.2
17	22.5	33.3	23.5	18.9	23.5	30.4	27.5	29.9	18.7	17.2	19.8	15.2	23.4
18	12.3	18.4	13.1	9.1	12.8	17.6	13.4	12.2	6.4	7.1	7.0	6.5	11.4
19	3.2	5.4	3.2	2.0	3.4	5.5	3.1	1.0	0.2	0.1	0.1	0.0	2.3
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daily average	15.2	18.7	16.0	14.5	15.1	17.4	17.0	19.7	16.5	17.0	15.6	14.2	16.4

Table IV-1-11 Monthly and hourly averages of net radiation flux

Site No.	1	Site name	N.U.S.	Item No.	13	Item name	Net radiation flux	Yard-stick	(CAL/CM2/H)				
Time	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Annual average
1	-4.6	-4.8	-3.6	-3.1	-3.2	-3.8	-4.0	-4.6	-3.6	-3.3	-3.2	-3.3	-3.8
2	-4.5	-4.8	-3.6	-3.1	-3.2	-3.7	-3.9	-4.3	-3.4	-3.1	-3.2	-3.4	-3.7
3	-4.4	-4.8	-3.5	-3.0	-3.0	-3.6	-3.9	-4.0	-3.3	-3.1	-3.2	-3.3	-3.6
4	-4.4	-4.7	-3.4	-2.7	-2.8	-3.3	-3.8	-3.7	-3.0	-2.7	-3.1	-3.2	-3.4
5	-4.2	-4.5	-3.2	-2.5	-2.8	-3.0	-3.8	-3.5	-2.7	-2.8	-2.9	-3.3	-3.3
6	-4.1	-4.4	-3.1	-2.3	-2.7	-2.9	-3.5	-3.4	-2.6	-2.8	-2.9	-3.4	-3.2
7	-4.1	-4.1	-3.0	-2.1	-2.6	-2.8	-3.2	-2.3	-1.2	-1.3	-1.8	-2.1	-2.5
8	-2.3	-2.4	0.3	1.7	0.2	-0.2	0.4	3.4	5.0	7.0	4.5	4.6	1.9
9	5.1	6.6	9.1	10.2	8.4	7.2	8.5	12.9	13.5	15.7	12.8	14.6	10.4
10	15.0	19.8	18.7	19.9	16.1	17.0	17.2	21.7	22.2	26.6	22.2	20.6	19.7
11	23.5	30.7	27.4	27.1	24.2	24.0	26.7	30.0	28.4	32.0	29.3	29.2	27.7
12	30.0	35.9	31.6	30.0	28.7	29.5	32.7	39.9	32.9	36.8	32.5	29.7	32.5
13	31.4	39.0	32.4	29.7	32.0	34.8	35.8	42.1	35.9	35.3	30.4	27.8	33.8
14	30.7	37.2	32.4	27.3	33.1	36.6	34.7	35.5	31.7	30.0	27.7	22.2	31.6
15	27.1	32.5	27.1	20.7	28.2	33.2	29.1	30.4	26.7	23.9	22.9	18.3	26.7
16	19.4	24.8	19.0	14.2	19.4	26.5	23.5	23.5	18.2	16.0	16.7	12.2	19.4
17	11.9	18.7	12.7	9.4	12.6	17.1	14.7	14.2	8.5	8.1	8.8	6.2	11.9
18	5.2	9.0	5.6	3.4	5.2	6.8	4.5	2.7	0.3	0.8	0.9	0.2	3.7
19	-1.0	0.1	-1.0	-1.5	-1.4	-0.6	-1.9	-4.1	-3.8	-3.6	-3.5	-3.1	-2.1
20	-3.7	-4.1	-3.3	-3.2	-3.7	-4.0	-4.2	-5.0	-3.9	-3.7	-3.6	-3.4	-3.8
21	-4.3	-4.6	-3.8	-3.3	-3.6	-4.2	-4.2	-4.9	-4.0	-3.9	-3.6	-3.5	-4.0
22	-4.4	-4.8	-3.8	-3.4	-3.6	-4.1	-4.2	-4.8	-3.9	-3.7	-3.3	-3.5	-4.0
23	-4.4	-5.0	-3.8	-3.3	-3.5	-4.0	-4.0	-4.8	-3.9	-3.7	-3.3	-3.5	-3.9
24	-4.4	-5.0	-3.7	-3.1	-3.5	-4.0	-4.0	-4.8	-3.7	-3.6	-3.1	-3.4	-3.8
Daily average	6.0	8.1	7.1	6.5	6.9	8.0	7.5	8.4	7.5	7.8	7.0	5.9	7.2

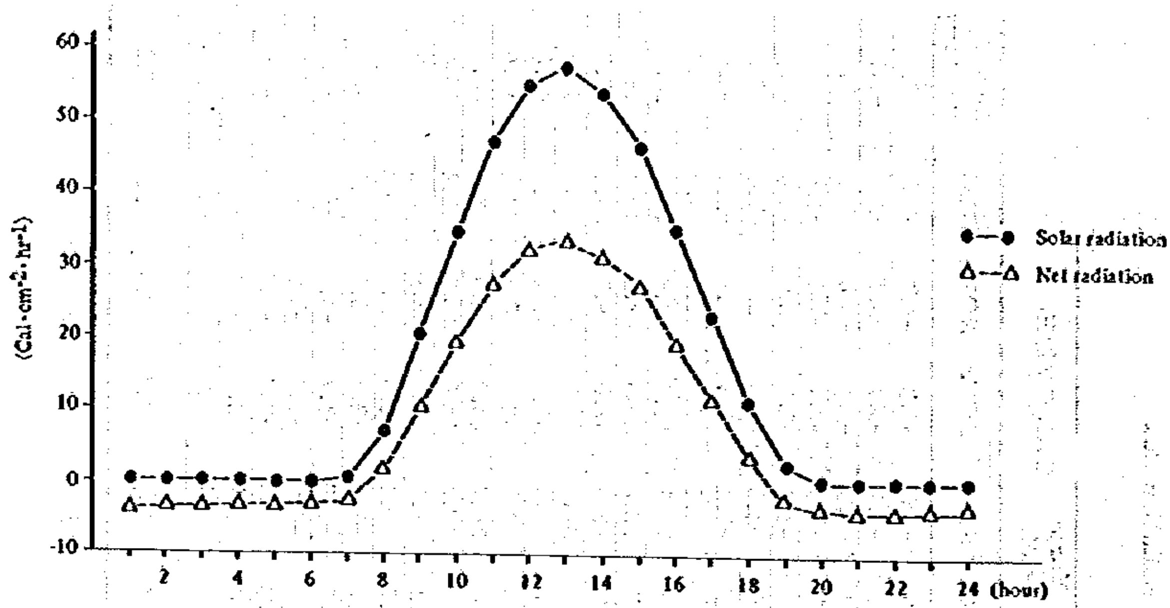


Fig. IV-1-14 Diurnal variation of solar radiation and net radiation flux averaged one year

IV-1-8 Atmospheric Stability

Atmospheric stability is the index of thermal stability of atmosphere, and it is related to vertical temperature profiles as in Fig. IV-1-15.

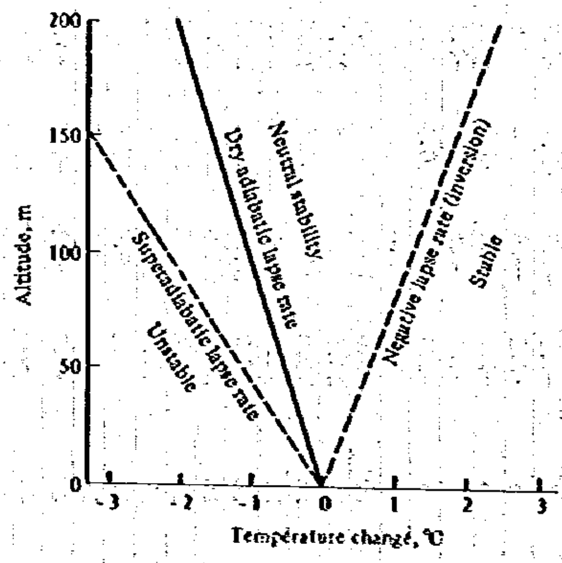


Fig. IV-1-15 Atmospheric air-temperature lapse rates

In unstable condition, the lapse rate of the air temperature is larger than the dry adiabatic lapse rate, and colder air mass in upper level descends and warmer air mass in lower level ascends upper layer. Then, thermally induced air mass mixing occurs. This is called unstable. On the other hand, when the lapse rate is smaller than the dry adiabatic, lower air mass is heavy and light in upper level. Therefore, air mass mixing is restrained, and this condition is called stable.

Plume diffusion of different stability conditions are typically illustrated as in Fig. IV-1-16.

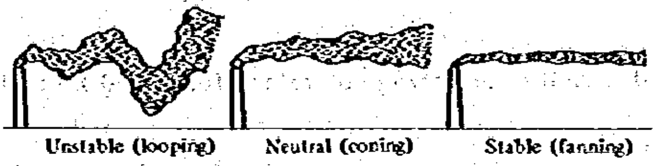


Fig. IV-1-16 Characteristic forms of smoke plumes from chimneys (Church 1949 and Slade 1968)

The best way of classification of thermal stability is done by temperature lapse rate. However, it is not easy technically and also financially to take temperature profile for a long period. Therefore, more convinient methods were proposed and used. One of the common methods of the stability classification is the so-called Pasquill's stability, in which, classifications are done by low level wind velocity, solar radiation and the rate of cloud cover in night time. All of them are easily obtained at the ground. Pasquill (1961) also gave the plume width for each stability class by a chart as in Fig. IV-1-17.

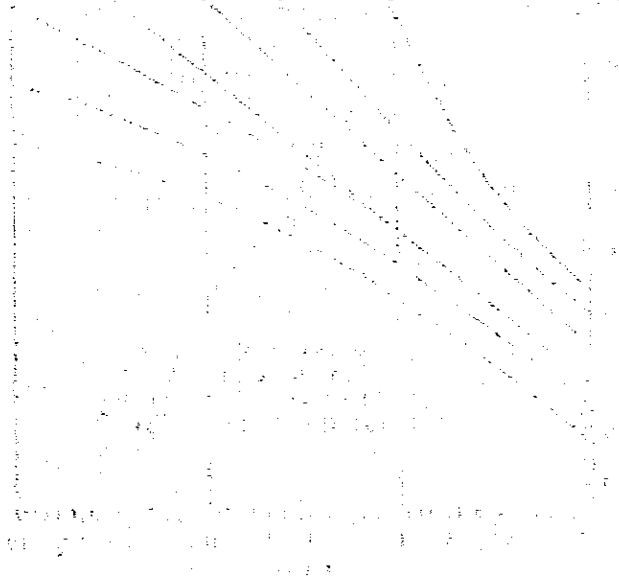


Table IV-1-12 Pasquill's stability classification

Key to stability categories

Surface wind speed (m/sec)	Insolation			Night	
	Strong	Moderate	Slight	Thinly overcast or ≥4/8 low cloud	≤ 3/8 cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

(for A-B take average of values for A and B etc.)

Strong insolation corresponds to sunny midday in midsummer in England, slight insolation to similar conditions in midwinter. Night refers to the period from 1 hr before sunset to 1 hr after dawn. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night, and for any sky conditions during the hour preceding or following night as defined above. The D (1) curve should be followed to the top of the dry-adiabatic layer; thereafter, in sub-adiabatic condition, D (2) or a curve parallel to D (2) should be followed. (Pasquill 1961, from the Meteorological Magazine, February 1961, H.M.S.O. Crown Copyright Reserved)

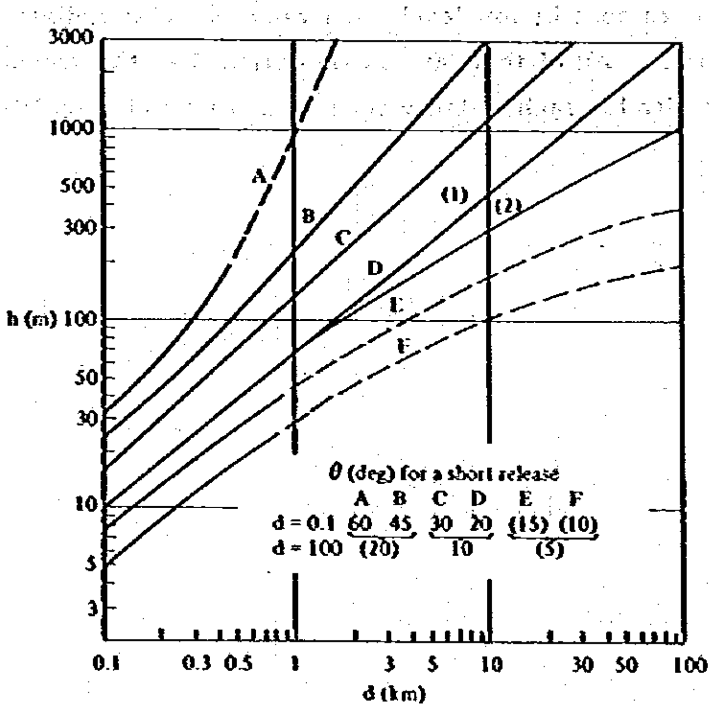


Fig. IV-1-17 Tentative estimates of vertical spread ($h \simeq 2.15\sigma_z$) and angular lateral spread ($\theta \simeq 4.3\sigma_y/x$) for a source in open country

Later Pasquill and Gifford (1961) revised the plume charts as shown in Fig. IV-1-18-(a) and -(b) and now the revised figures are commonly used for diffusion simulations.

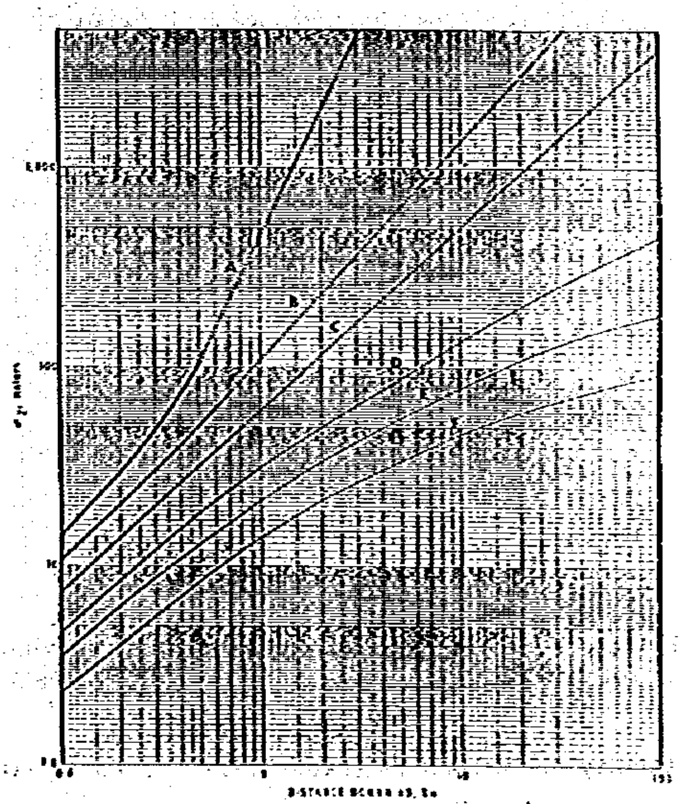


Fig. IV-1-18-(a) Vertical plume widths with respect to down wind distance for different stability classes (Pasquill-Gifford)

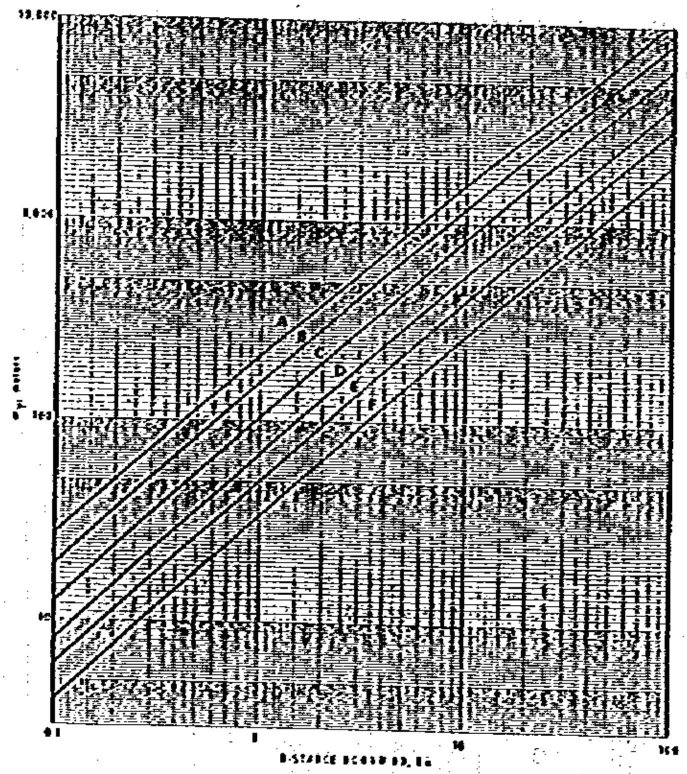


Fig. IV-1-18-(b) Lateral plume widths with respect to down wind distance for different stability classes (Pasquill-Gifford)

In the Pasquill's stability classifications (Table IV-1-12) solar radiation was not given quantitatively and night time classifications were dependent on the cloud cover. But recently due to the quick progress of measuring tools, solar radiation and net radiation lux are easily obtained, and the Pasquill's stability classification is improved.

Japanese MITI is using a modified Pasquill method as in Table IV-1-13 in presiting surveys of air pollution of industrial complexes. The MITI's stability classification system is shown in Table IV-1-13.

Table IV-1-13 Stability classification system by MITI

Wind velocity (m/s)	Solar radiation (cal/cm^2/H)				Net radiation flux (cal/cm^2/H)	
	- 50.0	49.9 - 25.0	24.9 - 13.0	12.9 - 0	0 - -2.9	-3.0 -
0.0 - 0.4	CA	CB	CC	CC	CC	CD
0.5 - 0.9	A	B	B	D	E	F
1.0 - 2.9	B	B	C	D	E	F
3.0 - 4.9	B	C	C	D	D	E
5.0 - 7.9	C	D	D	D	D	D
8.0 -	D	D	D	D	D	D

MITI's technical manual of air pollution simulation for presiting survey of environmental impacts of industrial complex, IPCAJ (1982).

In this system, the ranks of wind velocity are finer in low velocity range than the Pasquill's system. The frequency distributions of stability categories for each stations are shown in Table IV-1-14.

Table VI-1-14 Frequency distributions of stability categories

Station	CA	CB	CC	CD	A	B	C	D	E	F
(1) N.U.S	0.25	0.64	15.61	17.57	3.74	24.94	4.05	7.32	7.79	18.09
(2) J.T.C HALL	0.02	0.20	1.03	0.45	0.82	17.13	14.84	15.81	23.88	25.82
(3) S.I.U	0.99	2.76	18.88	18.46	15.10	11.16	2.09	5.55	7.34	17.67
(4) BOON LAY APARTMENT	0.02	0.17	1.79	1.30	0.98	18.25	14.01	13.58	21.01	28.89
(5) BUKIT TIMAH FIRE ST.	0.97	1.74	17.09	21.12	11.56	16.26	2.36	6.24	8.28	14.38
(6) CHANGI AIRPORT	0.01	0.10	2.28	1.77	0.87	16.50	14.37	15.89	23.06	25.15
(7) BEDOK POLICE STATION	0.06	0.24	3.91	4.77	2.55	23.69	7.76	10.21	16.68	30.13

IV-1-9 Analysis of Air Temperature

As stated in IV-1-8, vertical temperature profile or lapse rate is a primary factor of the thermal stability of the atmosphere, especially, it is the best index of stability in inversion conditions. The air temperature at two different levels (1.5 m, 10 m and 40 m above ground) were continuously measured at MP-1.

These temperature data were analyzed and the temperature gradients were examined together with stability categories. Fig. IV-1-19 shows the monthly changes of air temperature at two levels, the temperature at 10 m level was 0.3 to 0.4°C higher than that of 1.5 m level through the year.

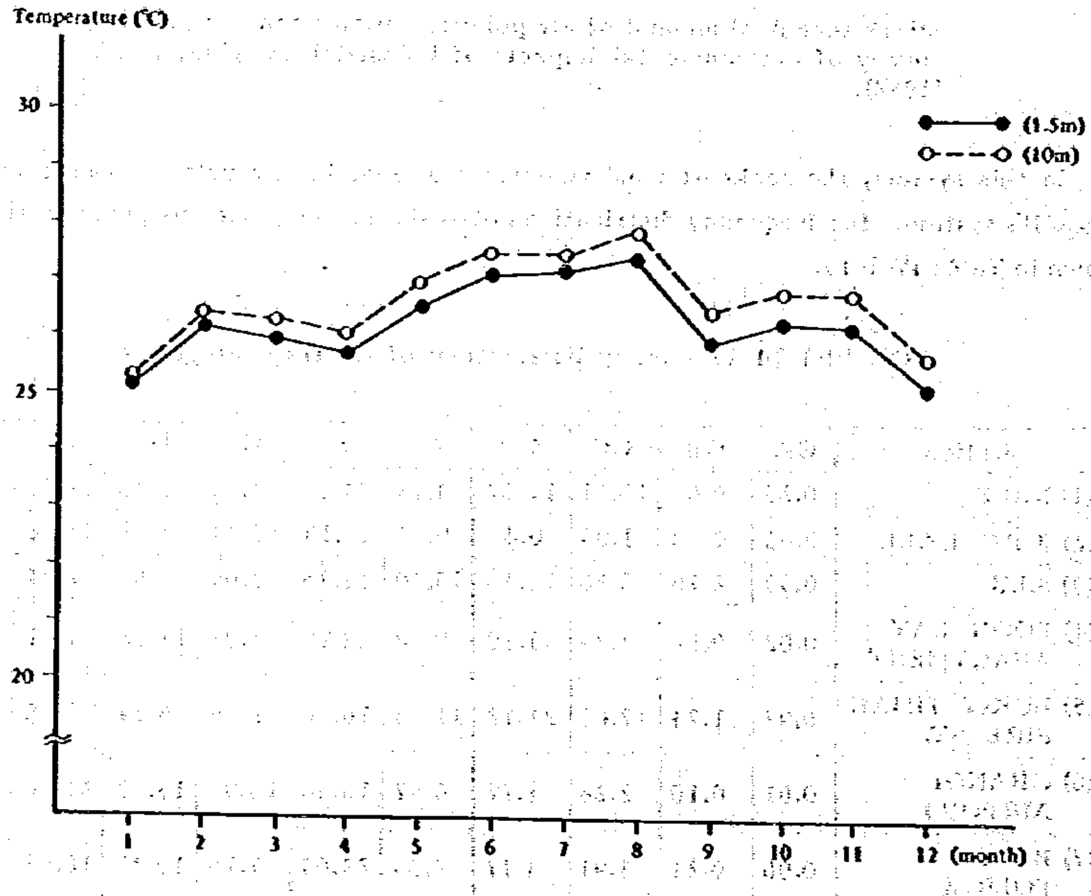


Fig. IV-1-19 Monthly change of air temperature

Fig. IV-1-20 shows the diurnal variations of air temperature at two levels. The difference was very small in daytime and nighttime environment at 10 m level became 0.5 to 0.6°C higher than 1.5 m. This is attributable to nighttime inversion.

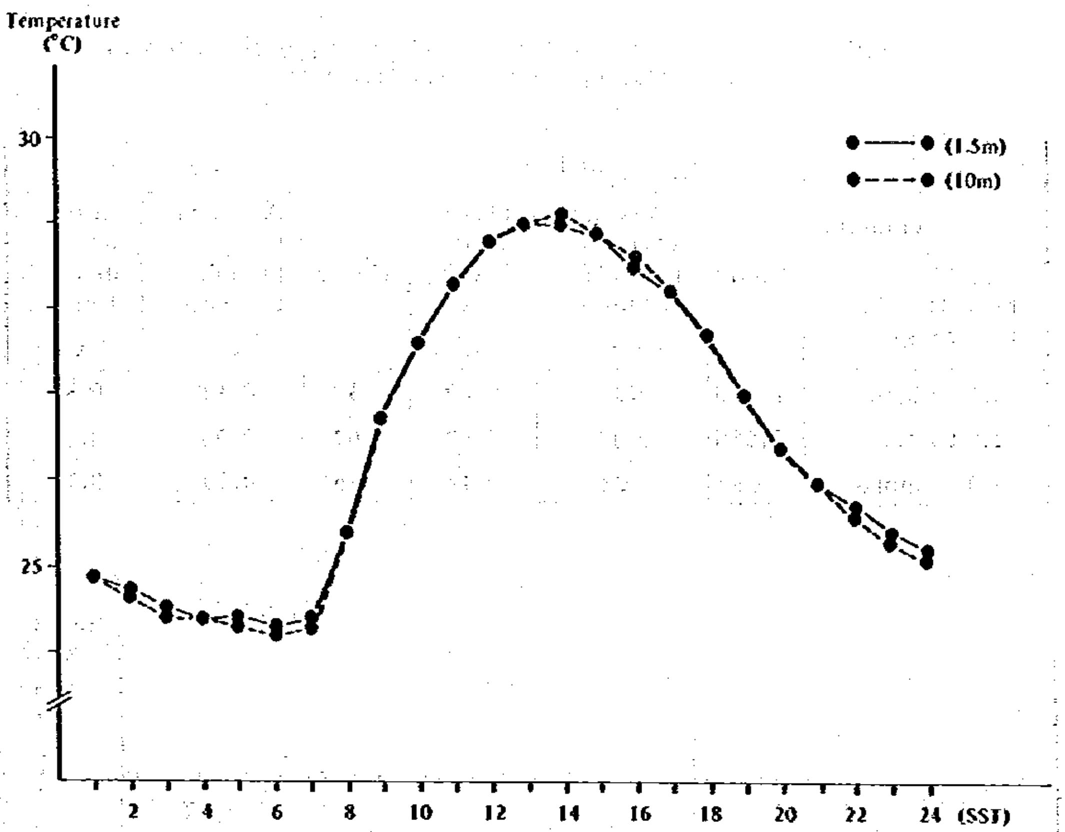


Fig. IV-1-20 Diurnal variation of air temperature

Daytime and night time averages of temperature for two seasons and the year are shown in Table IV-1-15. For every season and time of day, the temperature differences are very small, less than 0.3°C. For the annual averages, temperature at 10 m was about 0.3°C higher than 1.5 m level.

Table IV-1-15 Daytime and nighttime averages of temperature for two seasons and over year

Unit (°C)

Height	Southerly Monsoon			Northerly Monsoon			Yearly Average		
	Day time	Night	Through day	Day time	Night	Through day	Day time	Night	Through day
1.5 m	28.3	25.5	26.8	27.5	24.7	26.0	28.0	25.2	26.5
10 m	28.4	25.6	26.9	27.5	24.4	25.8	28.0	25.1	26.4

The temperature difference between 10 m and 1.5 m ($T_{10} - T_{1.5}$) classified by wind speed rank and net radiation flux is shown in Table IV-1-16, and the temperature difference for each stability category is shown in Fig. IV-1-21. It is clear that temperature inversion occurs when the net radiation flux is negative and low wind condition. In the relation with stability, inversion condition is seen to occur in nighttime.

Table IV-1-16 Temperature difference ($T_{10} - T_{1.5}$) classified by wind velocity and net radiation flux

Wind velocity / Net radiation flux range	0.5 m/s or less			less than 0.4 m/s		
	Hours	Average temperature difference (°C)	Standard deviation (°C)	Hours	Average temperature difference (°C)	Standard deviation (°C)
-0.3 or less	2,850	-0.05	0.79	37	0.33	0.83
-2.9 to 7.9	2,585	-0.07	0.57	67	-0.05	0.57
8.0 or more	2,682	0.03	0.32	35	0.09	0.17

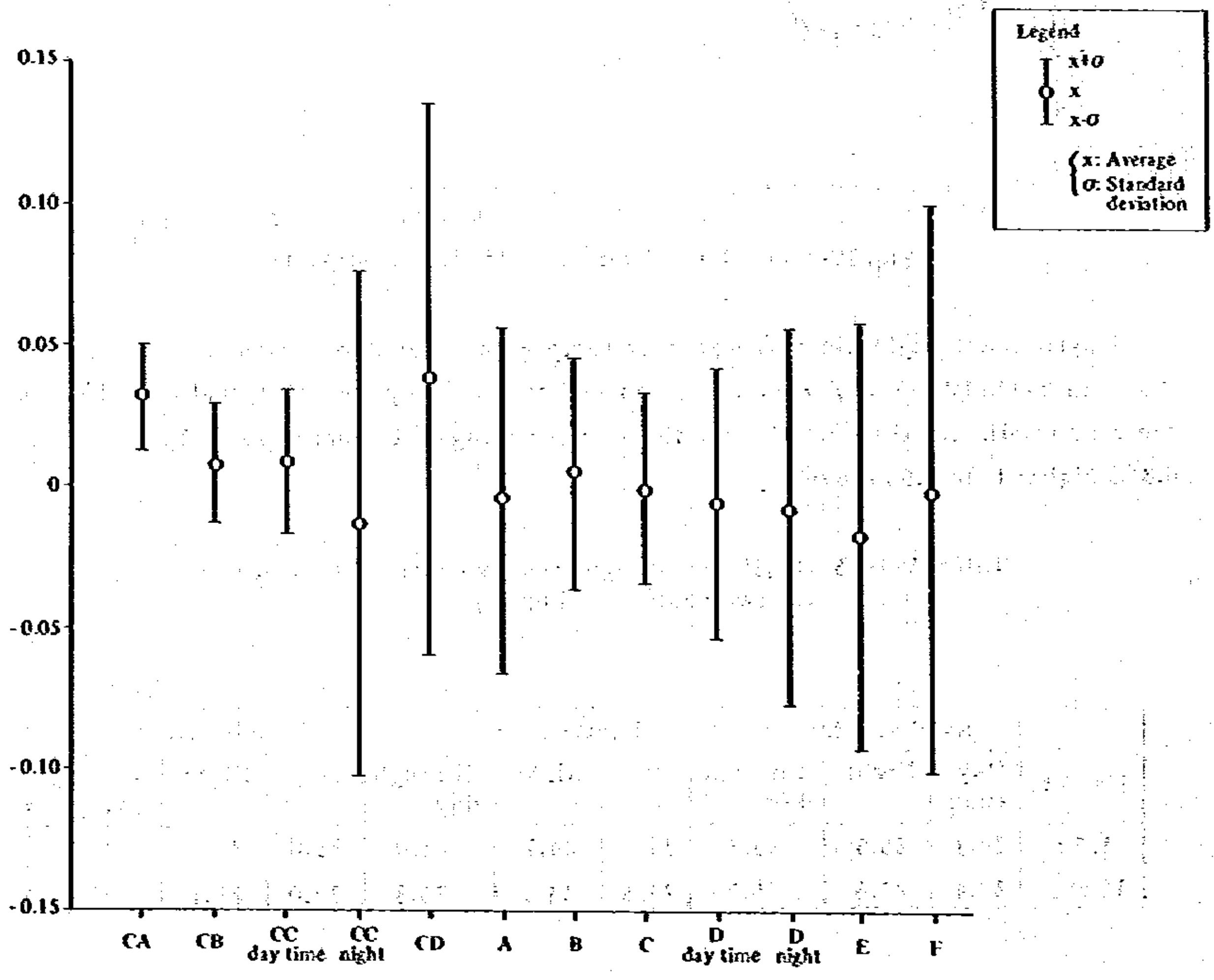


Fig. IV-1-21 Temperature difference ($T_{10} - T_{1.5}$) for each stability category

CHAPTER 2 STATISTICAL ANALYSIS OF SULFUR DIOXIDES CONCENTRATION

To clarify the variation of SO_2 concentration in space and time, and also its dependence on meteorological conditions, SO_2 data were analyzed by computer. The data were the SO_2 concentration, wind velocity and wind direction obtained at the seven monitoring stations.

IV-2-1 Seasonal, Daytime and Nighttime Averages of SO_2 Concentrations

Since the pollutant diffusion depends highly on the meteorological conditions such as wind direction and velocity and also on the source activity, the concentration of pollutants may vary widely by seasons and also by time of day. Therefore, it is very meaningful to calculate average concentrations for seasons, daytime and nighttime to understand the pollution characteristics.

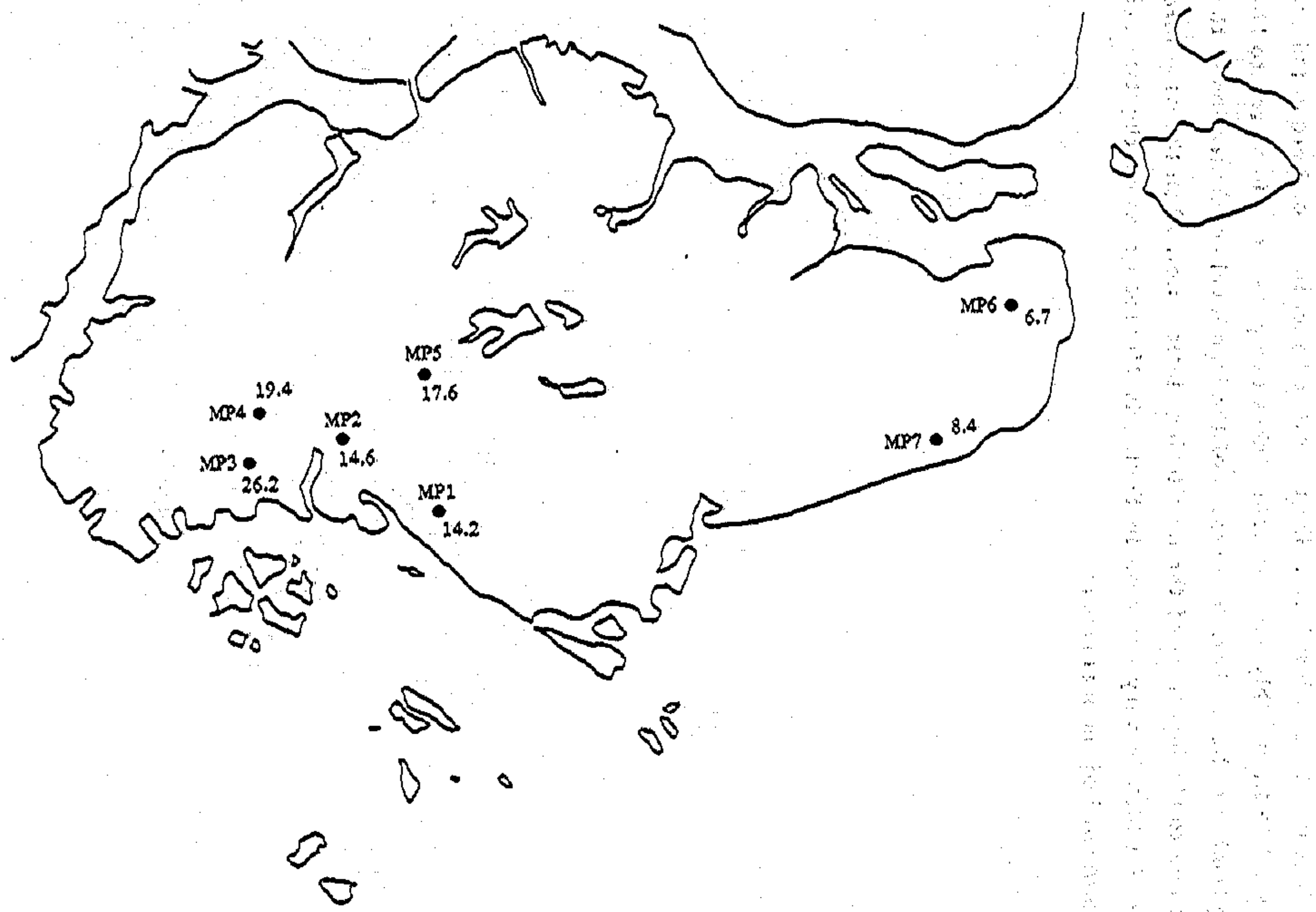
In Table IV-2-1, seasonal, daytime and nighttime average concentrations of SO_2 are shown. The daytime averages are almost twice as high as the nighttime. This may attribute to the difference of wind direction, wind velocity, thermal stability and also on source conditions. For seasonal change, at MP-3 and MP-4, SO_2 concentrations in Southerly Monsoon are higher than Northerly Monsoon, and at other stations, the difference is small. This is probably due to the relation between location of sources, monitoring stations and also the direction of prevailing wind.

Table IV-2-1 Seasonal, daytime and nighttime concentration of SO_2 at each station

Unit (ppb)

Stations	Southerly monsoon			Northerly monsoon			Yearly average		
	Day time	Night time	Through day	Day time	Night time	Through day	Day time	Night time	Through day
(1) N.U.S.	17.5	9.4	13.1	20.7	11.7	15.8	18.8	10.4	14.2
(2) JTC HALL	18.0	11.1	14.3	18.4	12.1	15.0	18.2	11.5	14.6
(3) S.I.U.	39.3	18.5	28.0	28.4	19.8	23.7	34.8	19.0	26.2
(4) BOON LAY APARTMENT	34.1	12.8	22.3	17.8	12.9	15.0	27.8	12.8	19.4
(5) BUKIT TEMAH FIRE STATION	26.9	10.3	17.9	23.6	11.8	17.2	25.5	10.9	17.6
(6) CHANGI AIRPORT	7.7	6.0	6.8	8.7	4.9	6.6	8.1	5.5	6.7
(7) BEDOK POLICE STATION	11.3	7.6	9.3	9.6	5.2	7.2	10.6	6.6	8.4

The annual average concentrations at seven monitoring stations are shown in Fig. IV-2-1. The results show that SO_2 concentrations are relatively higher in Jurong area than in Changi.

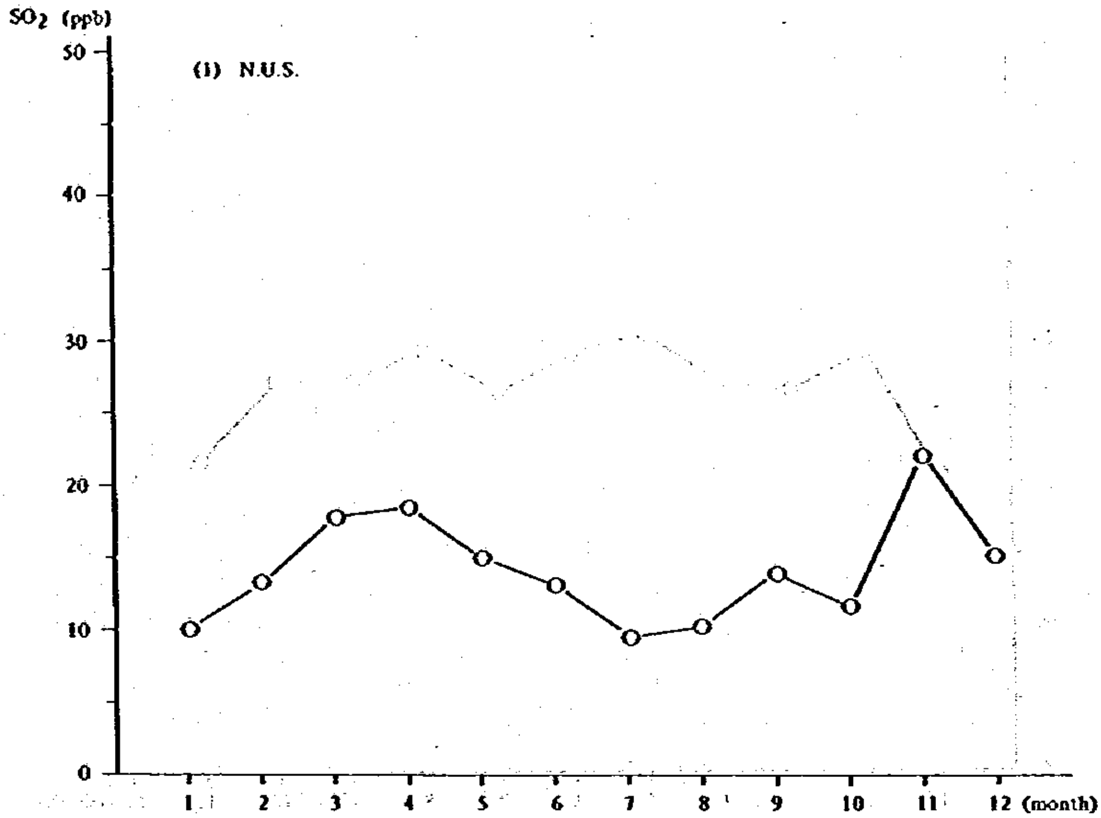


(Unit: ppb)

Fig. IV-2-1 Annual averages of SO_2 concentration

IV-2-2 Monthly Variations of SO_2 Concentration

Monthly changes of SO_2 concentration for seven monitoring stations are shown in Figs. IV-2-2. The figures show that the monitoring stations are divided into two groups by monthly change of SO_2 concentration. The first group consists of MP-3 and MP-4, where relatively high concentration continues from February through October and from November to January stays in low level. On the other hand, in second group (all stations except MP-3 and MP-4), monthly average value takes two peaks, one in March to May and another in September to November. The reason of the high level concentration in the first group may be due to the locations of the monitoring station, i.e., when the wind direction is from SE to S which is very common in Southerly Monsoon season, the two stations situate just down wind of the main sources.



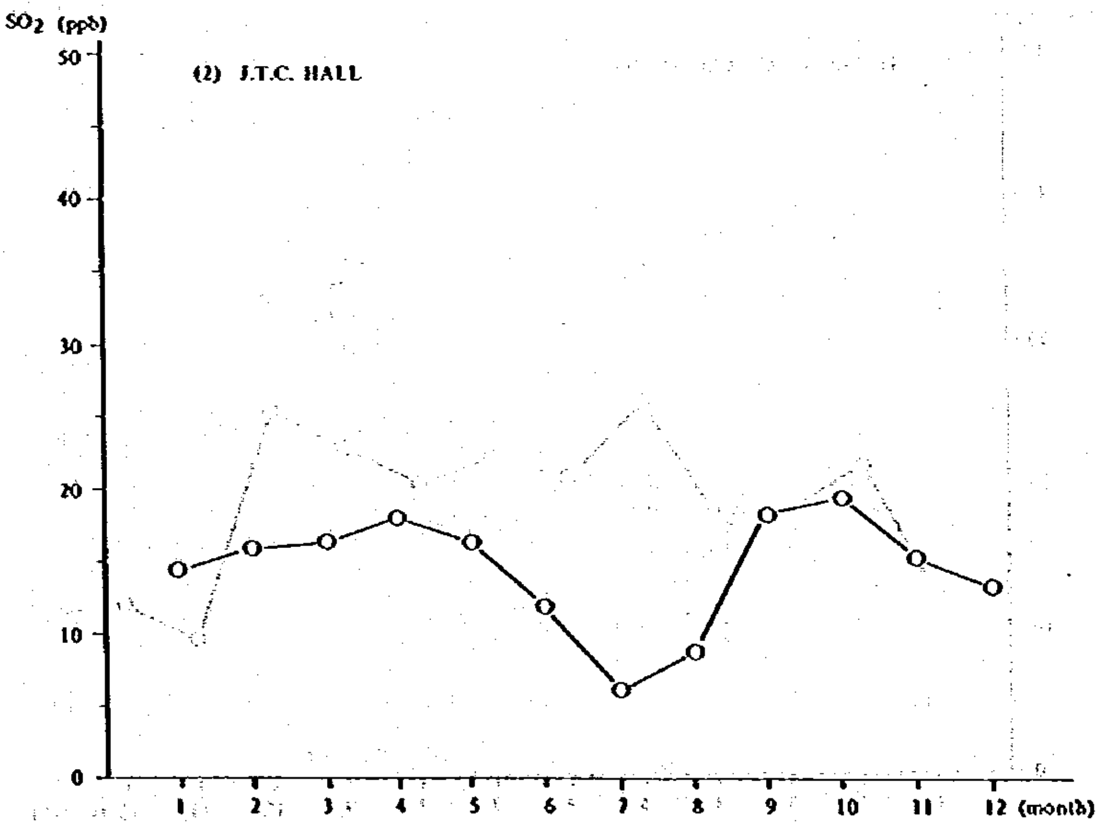
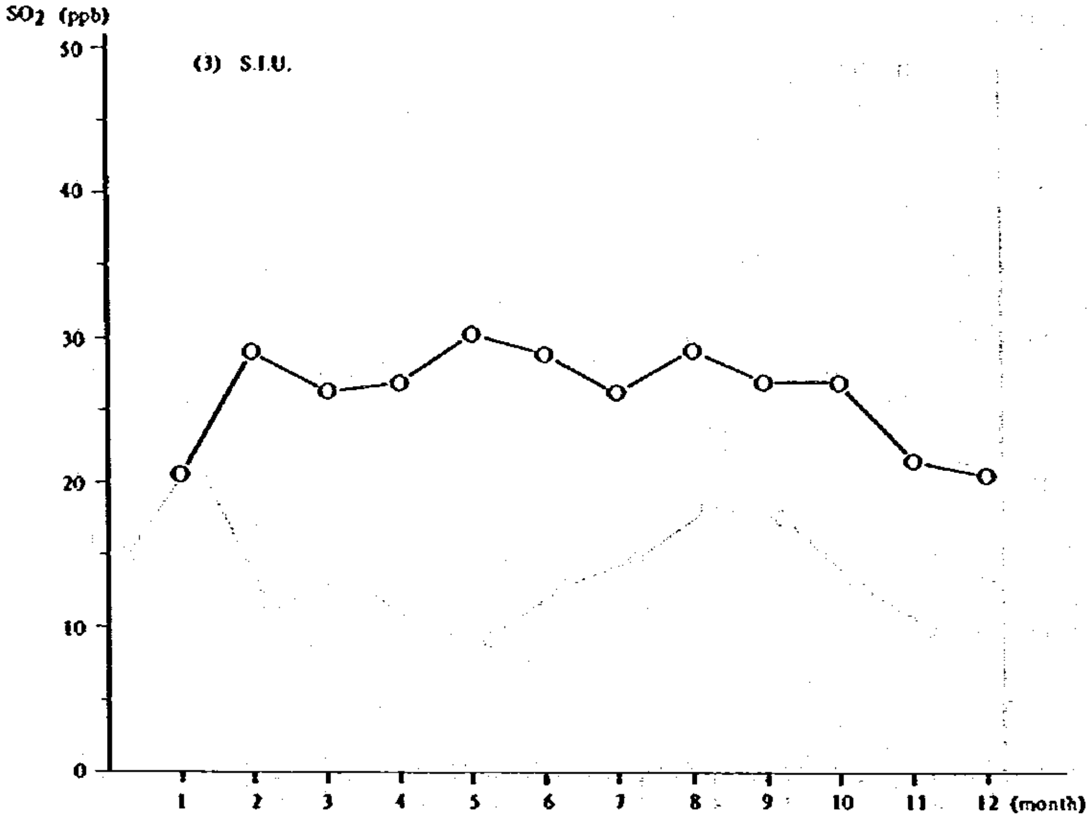


Fig. IV-2-2 Monthly changes of SO_2 concentration (a)



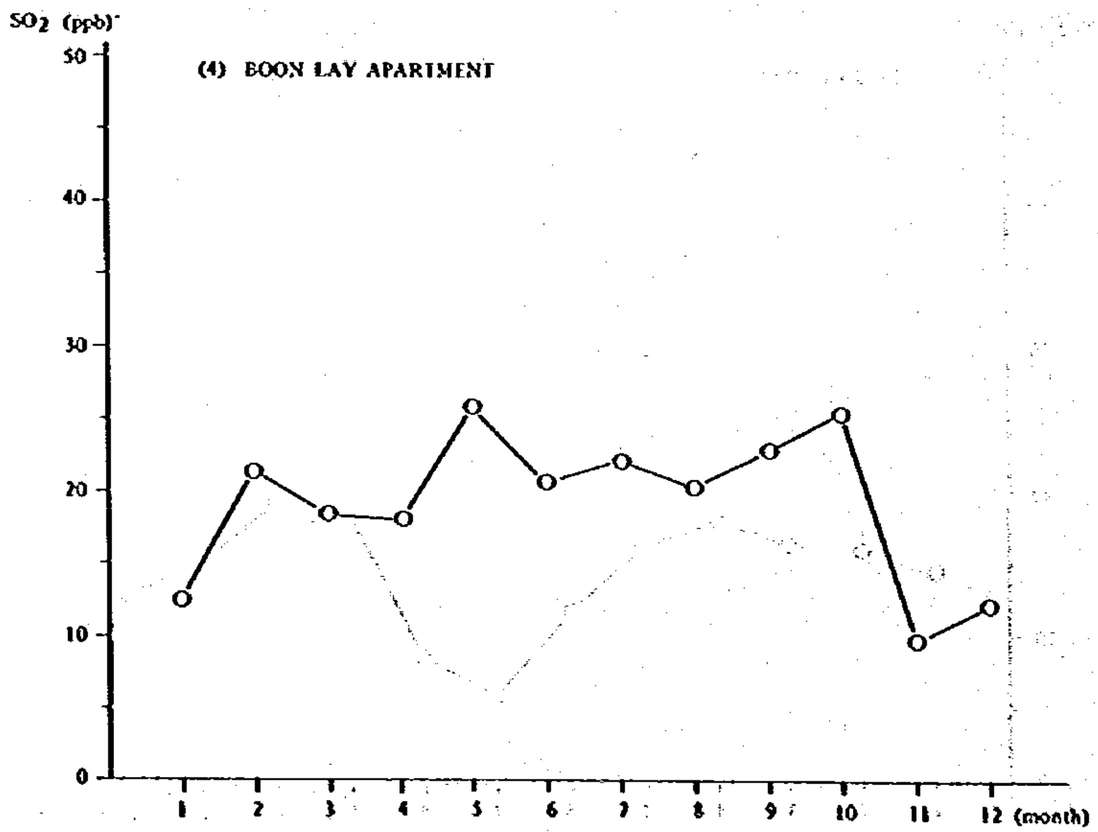


Fig. IV-2-2 Monthly changes of SO_2 concentration (b).

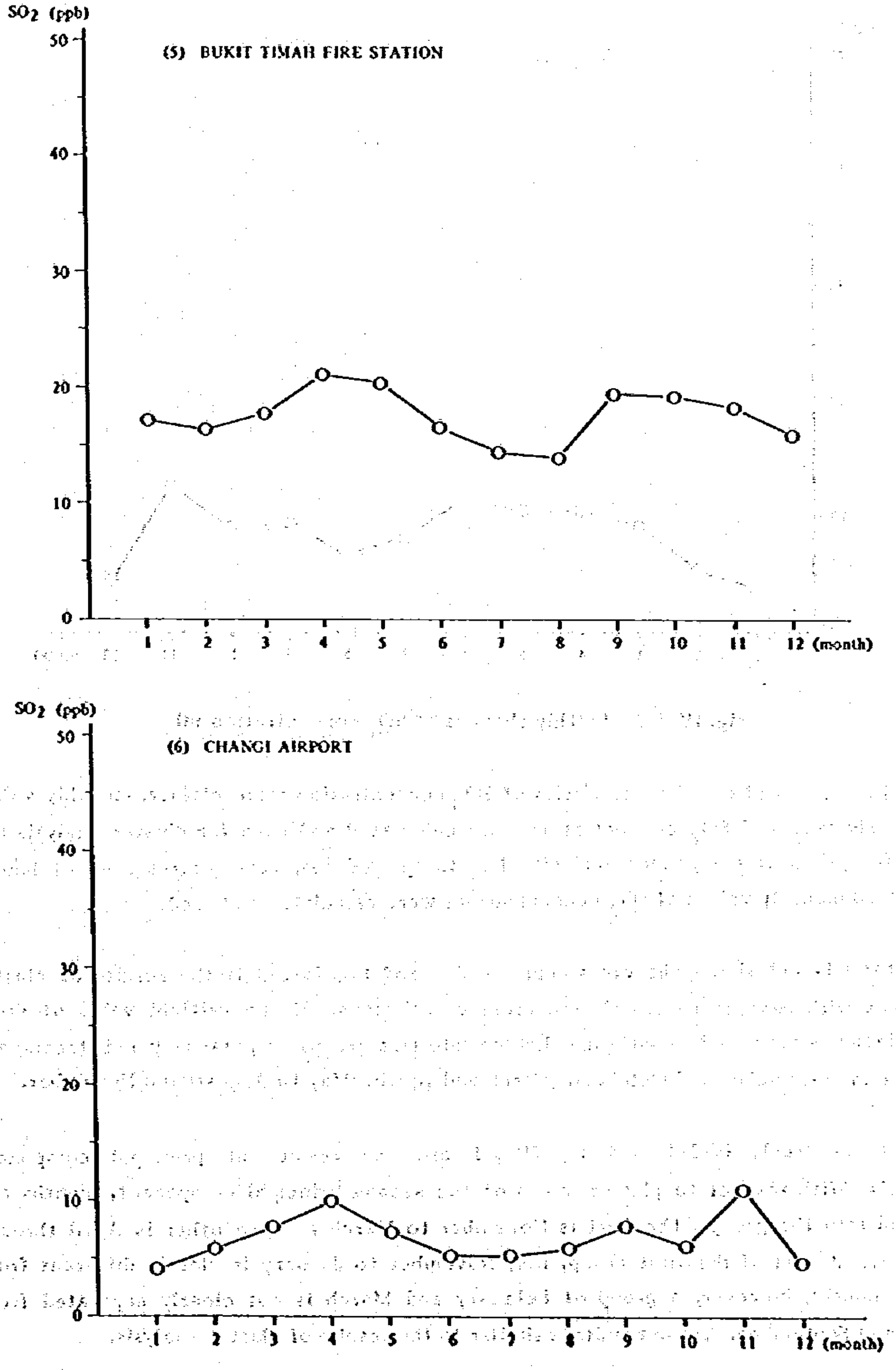


Fig. IV-2-2 Monthly changes of SO_2 concentration (c)

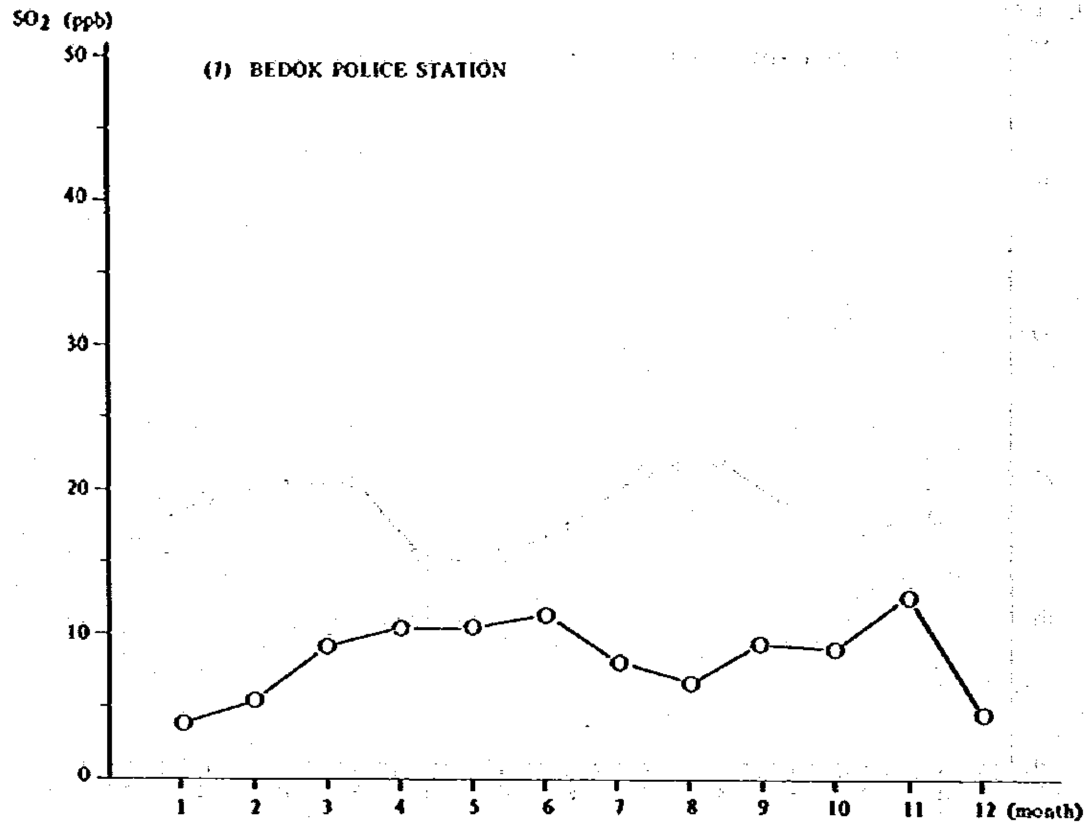


Fig. IV-2-2 Monthly changes of SO_2 concentration (d)

To understand the characteristics of SO_2 concentration more clearly, monthly values of hourly averaged SO_2 concentration were calculated and used for cluster analysis and also for principal component analysis. For these analyses, cross correlations of hourly averaged monthly values of SO_2 concentrations were calculated and used.

Table IV-2-2 shows the cross correlations, and Fig. IV-2-3 is the results of cluster analysis with respect to month and cross correlations. If the critical value of cross correlation is set to 0.8, months are divided into five groups i.e., (January and December), (February, September and October), (March and April), (May to August) and November.

Tables IV-2-3, IV-2-4 and Fig. IV-2-4 are the results of principal component analysis. With respect to plus or minus of the second principal component, months are divided into the groups, the first is November to March and the other is April through October. A part of the first group, i.e., November to January is clearly different from other months, however, a group of February and March is not clearly separated from April and September. Those results is similar to the results of cluster analysis.

Table IV-2-2 Cross correlation of SO_2 concentration averaged by hours and months

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Jan.		0.724	0.668	0.583	0.517	0.491	0.452	0.446	0.615	0.638	0.547	0.841
Feb.	0.724		0.871	0.740	0.812	0.790	0.822	0.725	0.874	0.855	0.494	0.798
Mar.	0.668	0.871		0.901	0.836	0.844	0.794	0.774	0.883	0.831	0.708	0.826
Apr.	0.583	0.740	0.901		0.870	0.866	0.768	0.812	0.866	0.843	0.641	0.697
May	0.517	0.812	0.836	0.870		0.922	0.904	0.899	0.886	0.897	0.434	0.602
June	0.491	0.790	0.844	0.866	0.922		0.937	0.913	0.859	0.834	0.470	0.604
July	0.452	0.822	0.794	0.768	0.904	0.937		0.901	0.852	0.838	0.325	0.556
Aug.	0.446	0.725	0.774	0.812	0.899	0.913	0.901		0.796	0.809	0.365	0.530
Sep.	0.615	0.874	0.883	0.866	0.886	0.859	0.852	0.796		0.930	0.493	0.701
Oct.	0.638	0.855	0.831	0.843	0.897	0.834	0.838	0.809	0.930		0.386	0.658
Nov.	0.547	0.494	0.708	0.641	0.434	0.470	0.325	0.365	0.493	0.386		0.746
Dec.	0.841	0.798	0.826	0.697	0.602	0.604	0.556	0.530	0.701	0.658	0.746	

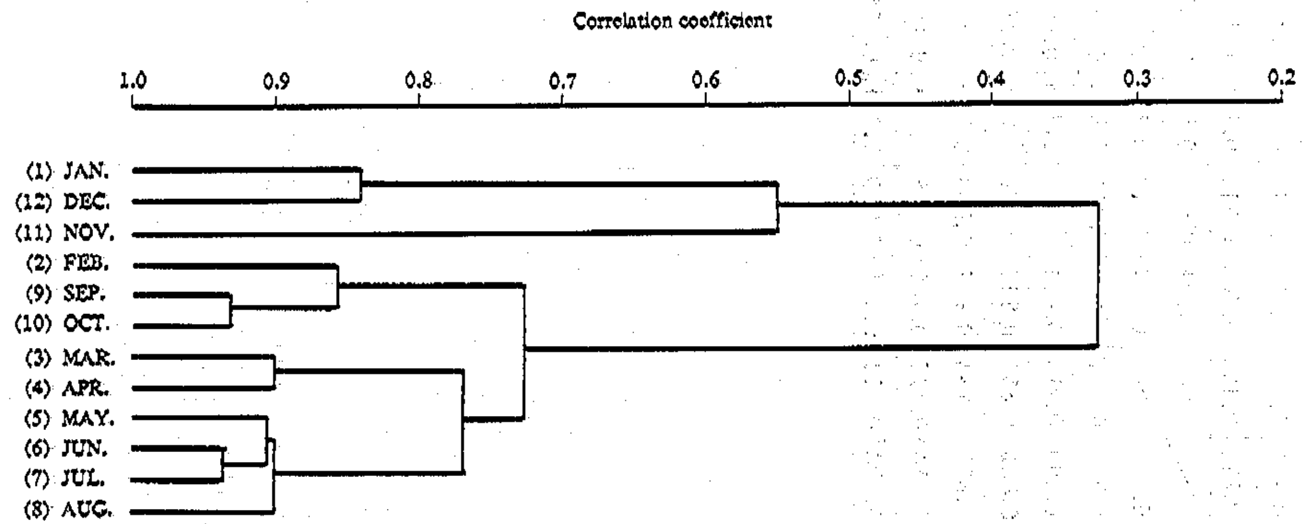


Fig. IV-2-3 Results of the cluster analysis

Table IV-2-3 Eigen vectors and eigen values

Principal components	Factor 1	2	3	4
JAN.	0.234	-0.436	-0.520	-0.018
FEB.	0.303	-0.056	-0.327	-0.220
MAR.	0.315	-0.121	0.153	0.024
APR.	0.305	0.003	0.297	0.441
MAY	0.308	0.228	0.056	0.084
JUNE	0.306	0.225	0.173	-0.247
JULY	0.295	0.312	-0.037	-0.403
AUG.	0.289	0.301	0.122	-0.304
SEP.	0.312	0.078	-0.090	0.376
OCT.	0.305	0.133	-0.245	0.477
NOV.	0.202	-0.526	0.614	-0.060
DEC.	0.267	-0.449	-0.129	-0.247
Eigen values	9.130	1.344	0.602	0.249

Table IV-2-4 Loading factor

Principal components	Factor 1	2	3	4
JAN.	0.706	-0.506	-0.404	-0.009
FEB.	0.914	-0.065	-0.254	-0.109
MAR.	0.952	-0.141	0.119	0.012
APR.	0.922	0.003	0.231	0.220
MAY	0.930	0.264	0.043	0.042
JUNE	0.924	0.260	0.134	-0.123
JULY	0.892	0.361	-0.028	-0.201
AUG.	0.872	0.348	0.095	-0.152
SEP.	0.943	0.091	-0.070	0.187
OCT.	0.923	0.154	-0.190	0.238
NOV.	0.611	-0.610	0.476	-0.030
DEC.	0.806	-0.521	-0.100	0.123

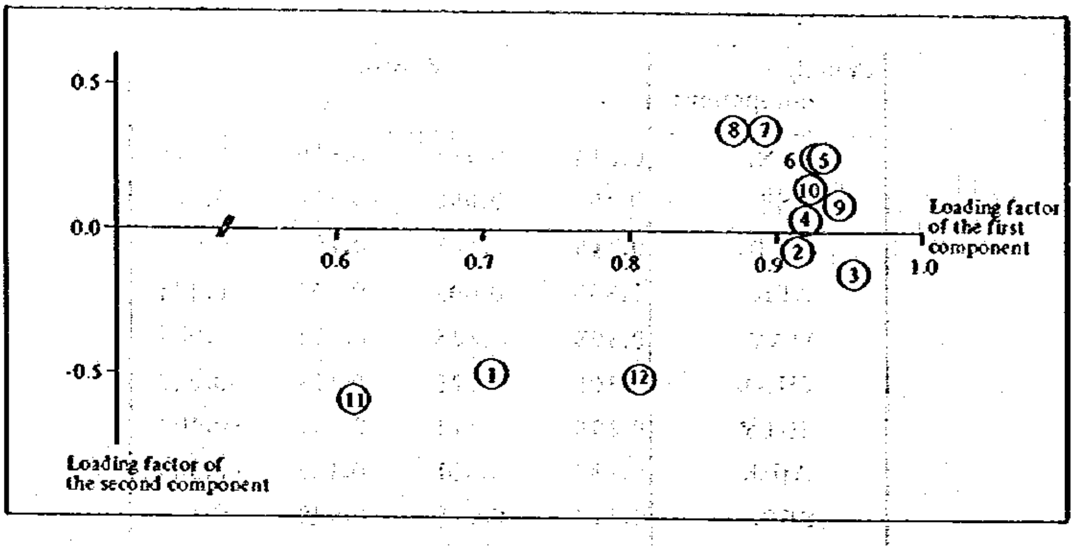


Fig. IV-2-4 Relation between the loading factors of the first and second principal components

IV-2-3 Diurnal Variation of SO_2 concentrations

Monthly averaged diurnal variations of SO_2 concentration are shown in Figs. IV-2-5. At every stations, concentration in daytime is higher than in nighttime, and the fluctuations by hours at MP-1 to MP-5, those are rather closer to the sources, are larger than MP-6 and MP-7 where not any large sources exist around. Yearly averaged diurnal variations of SO_2 concentration are shown in Fig. IV-2-6.

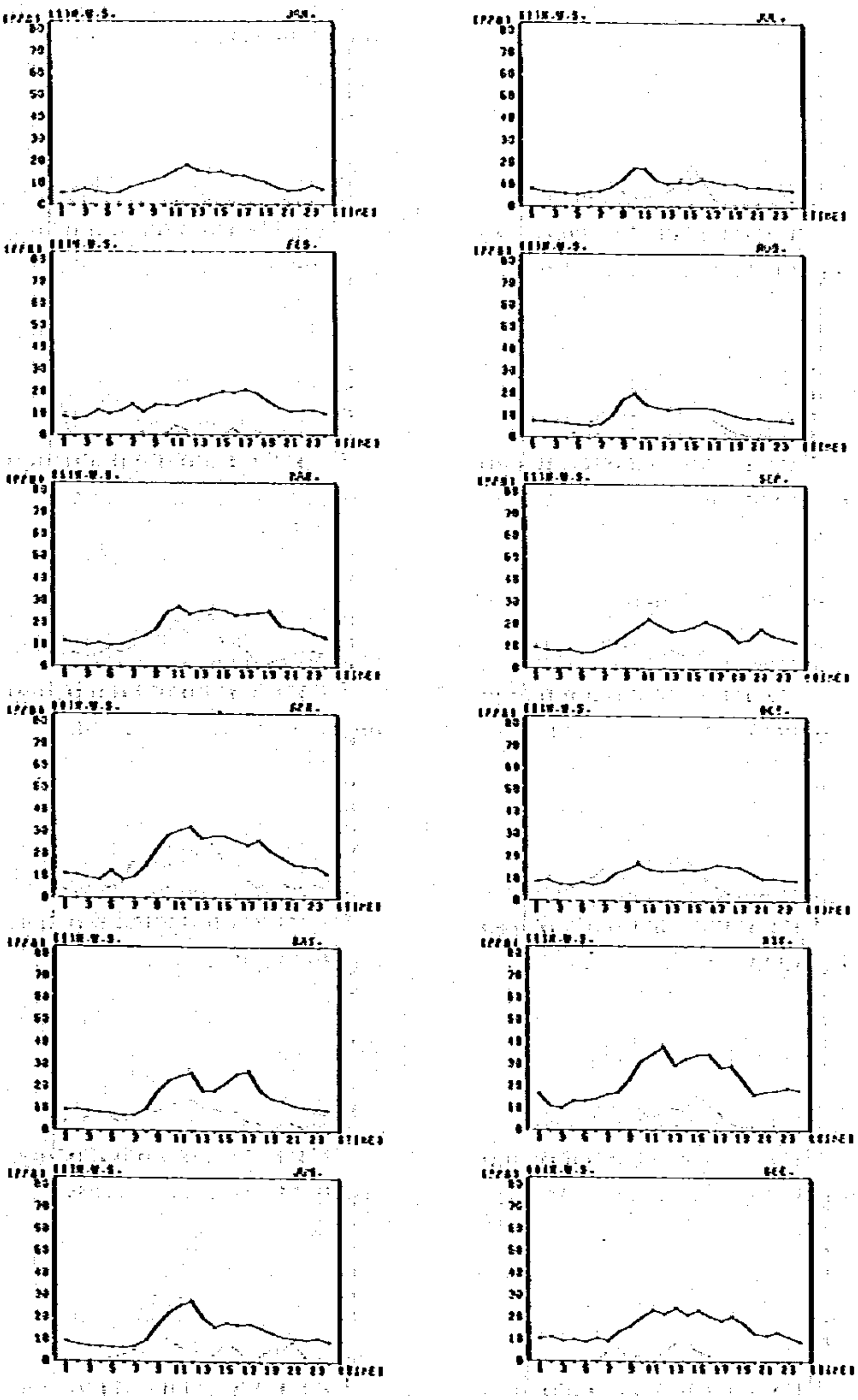


Fig. IV-2-5 Diurnal variations of SO_2 concentration for each month (a)

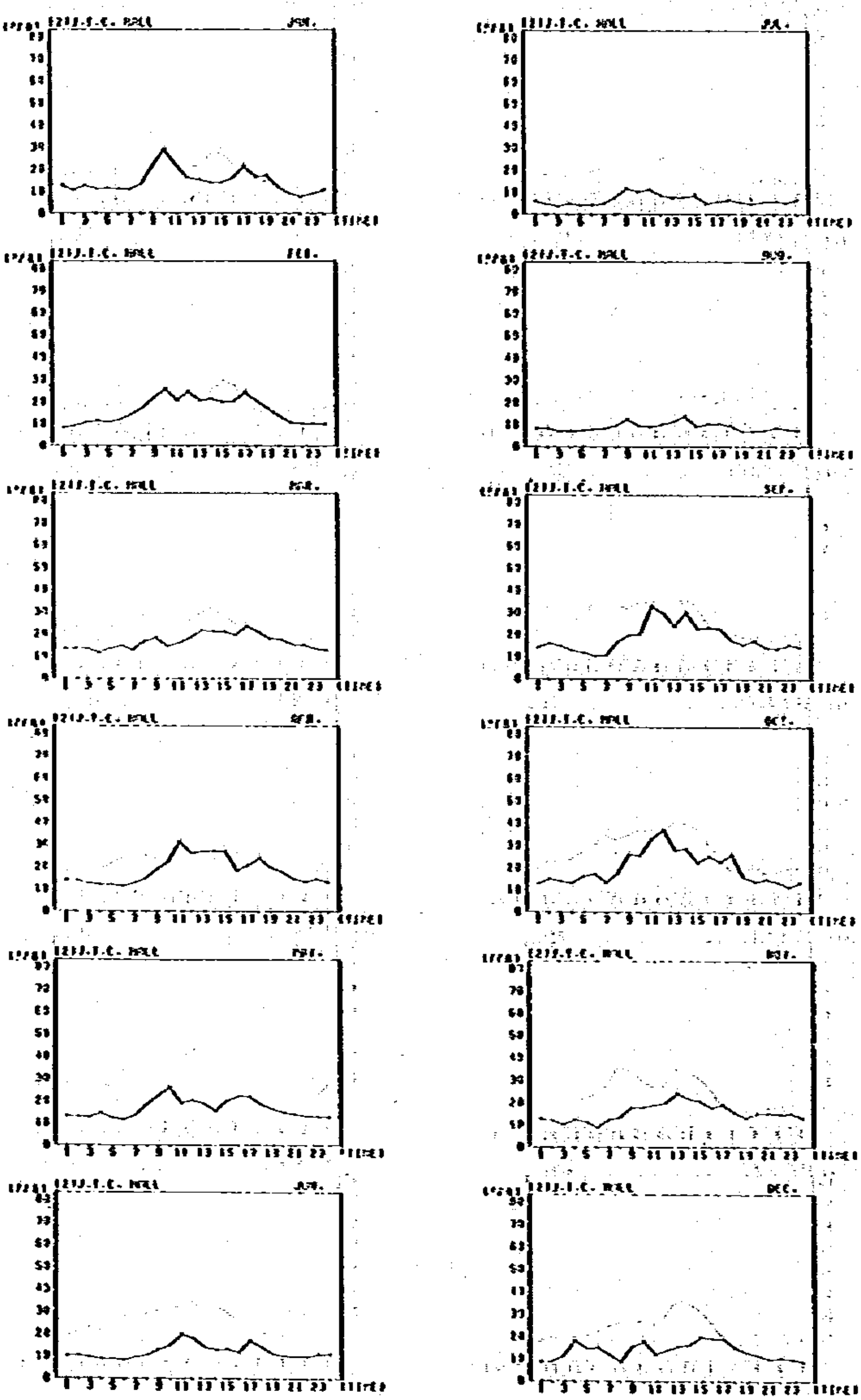


Fig. IV-2-5 Diurnal variations of SO_2 concentration for each month (b)

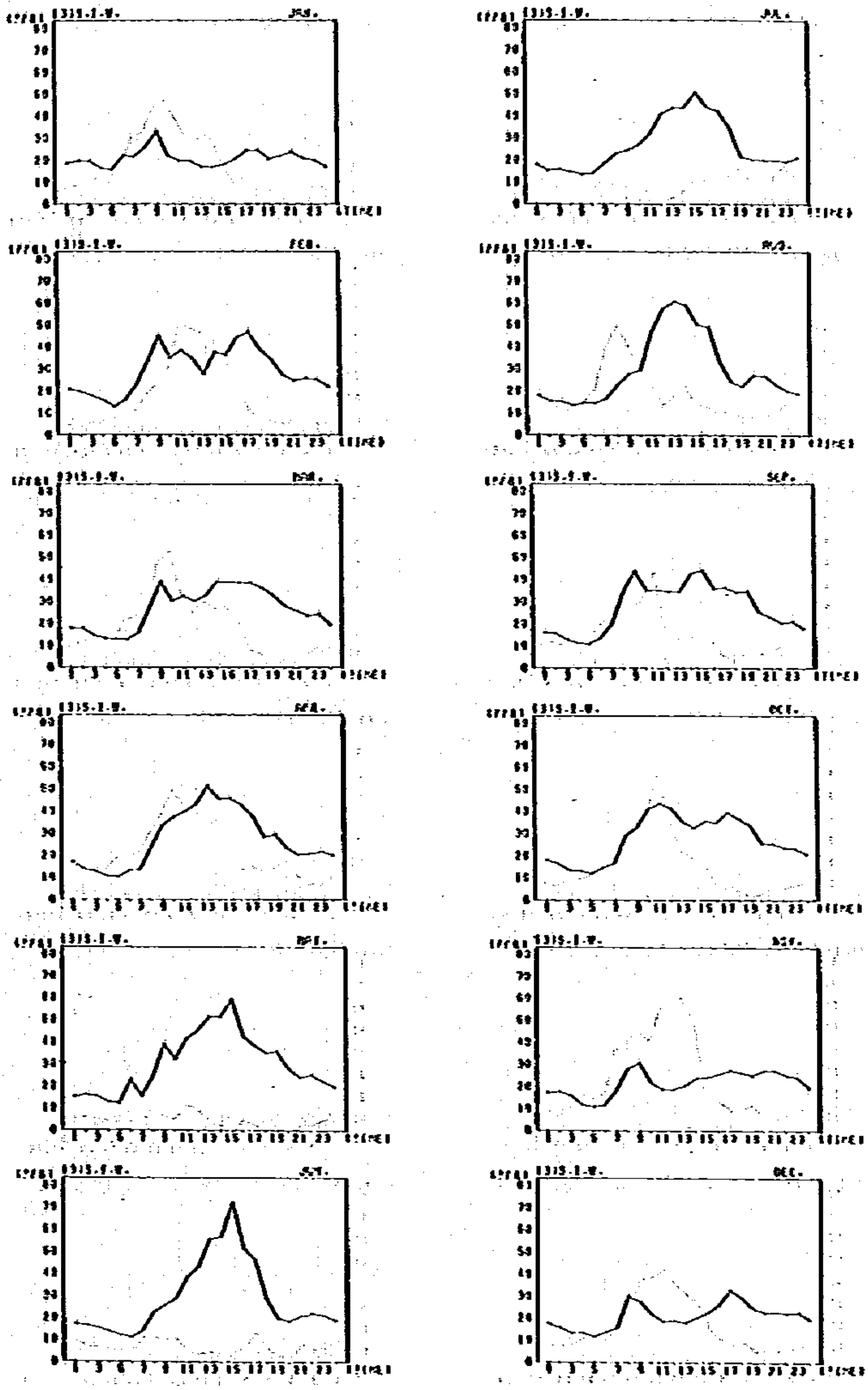


Fig. IV-2-5 Diurnal variations of SO_2 concentration for each month (c)

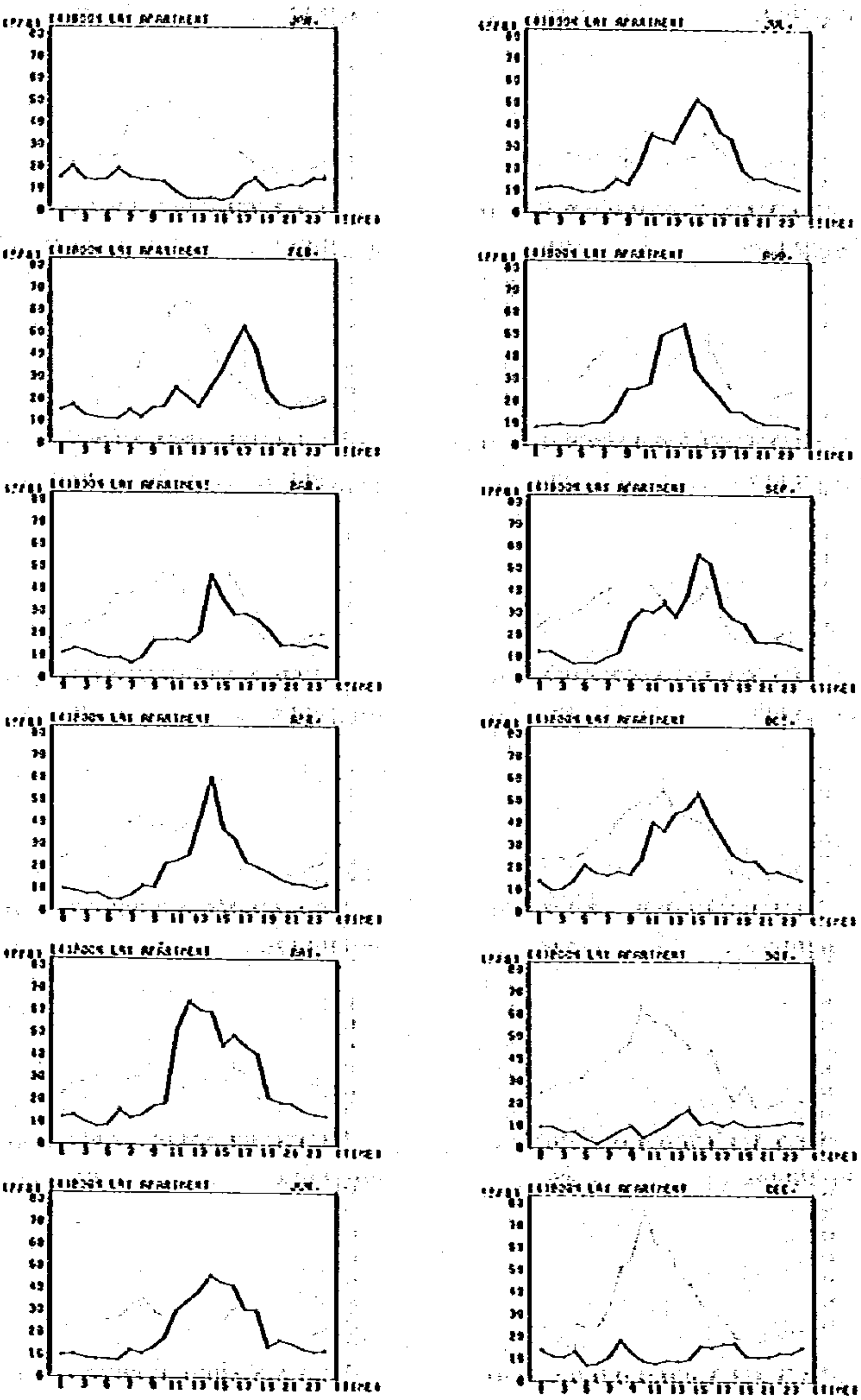


Fig. IV-2-5 Diurnal variations of SO_2 concentration for each month (d)

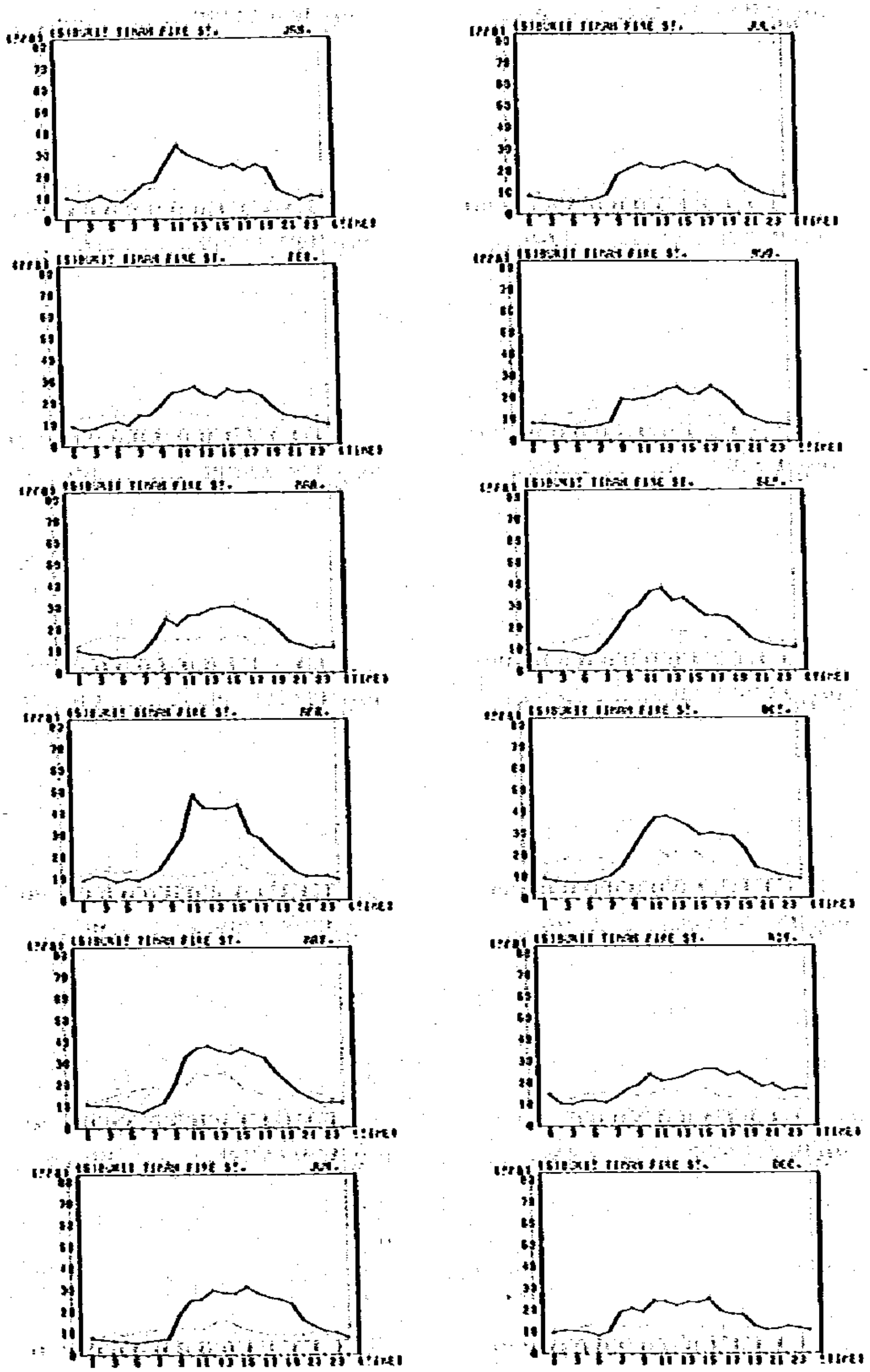


Fig. IV-2-5 Diurnal variations of SO_2 concentration for each month (e)

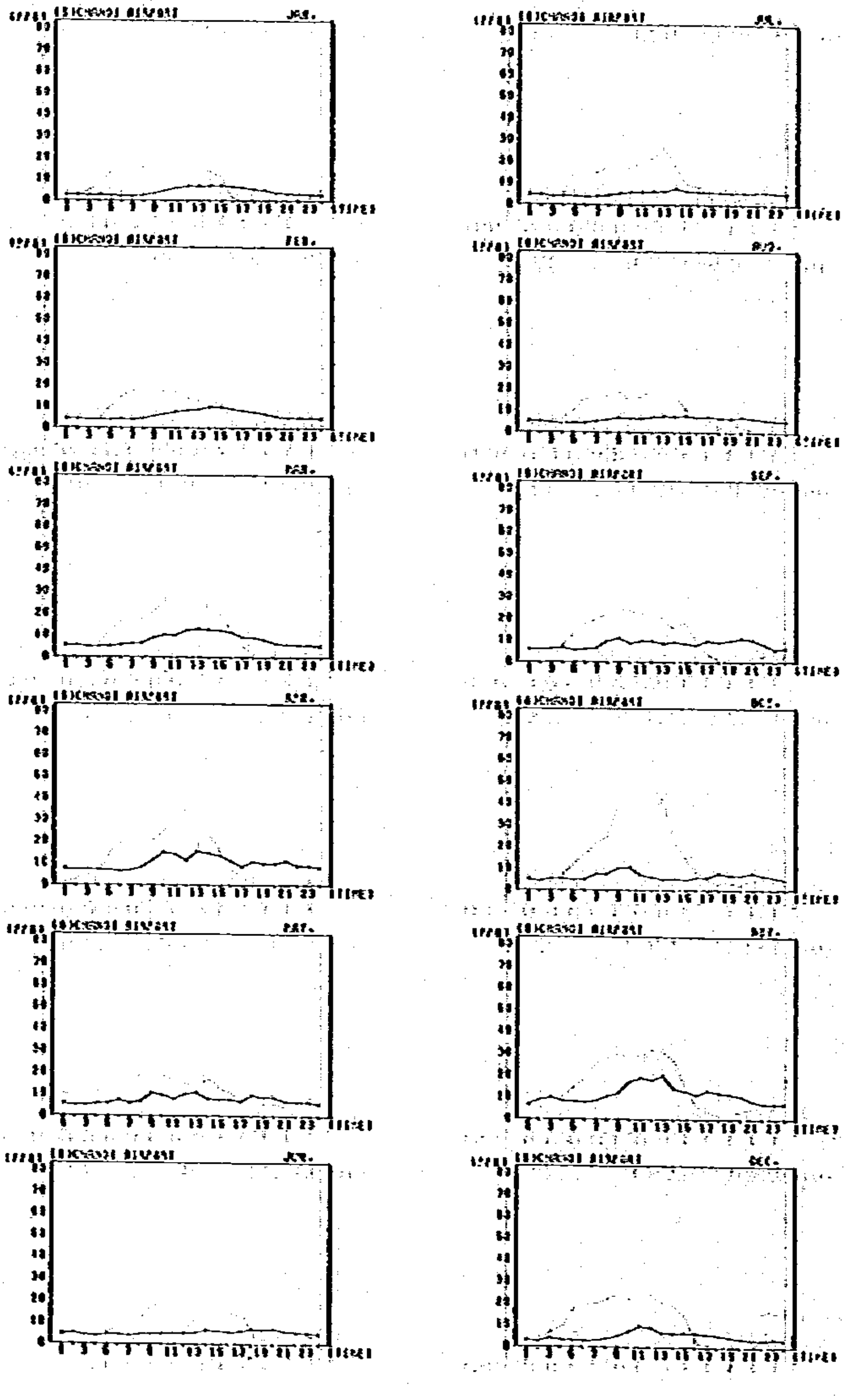


Fig. IV-2-5 Diurnal variations of SO_2 concentration for each month (f)

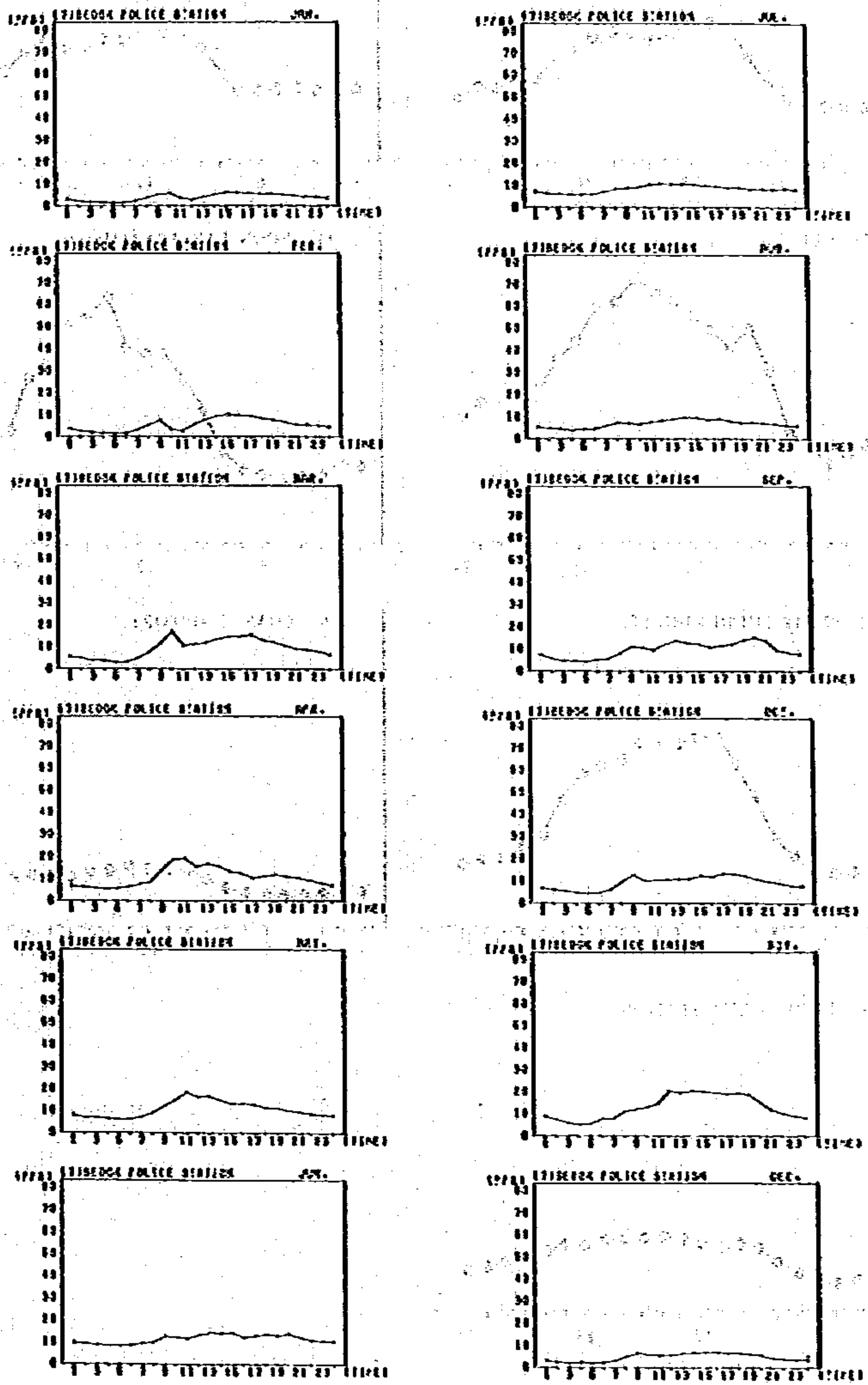


Fig. IV-2-5 Diurnal variations of SO_2 concentration for each month (g)

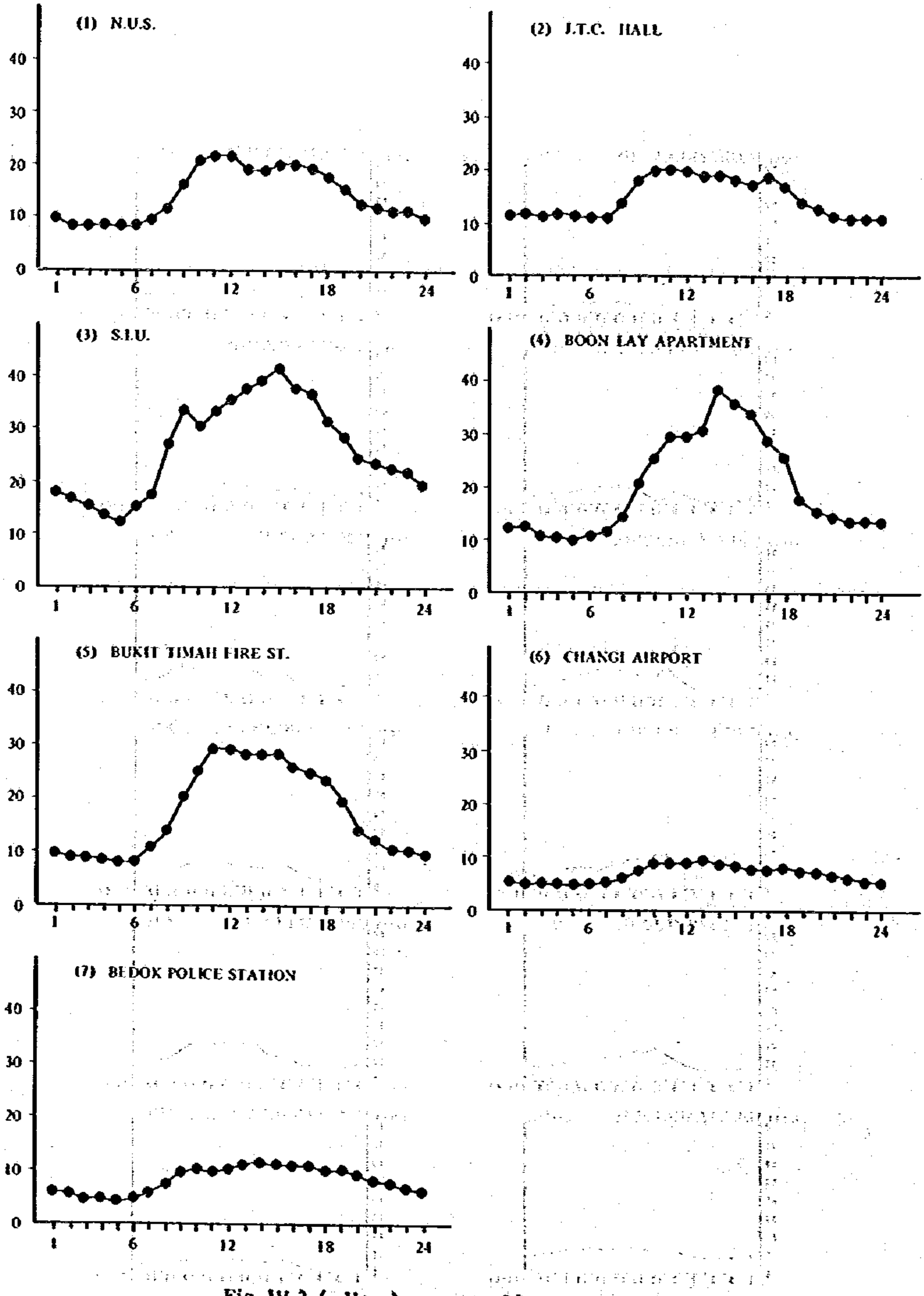


Fig. IV-2-6 Hourly average SO_2 concentration

IV-2-4 Frequency Distribution of SO_2 Concentration

R. I. Larsen (1969) has found out from statistical analysis of concentration data of atmospheric pollutants that the frequency distribution of pollution follows a log normal profile, and he has proposed following mathematical model:

$$f(c) = \frac{1}{\sqrt{2\pi}\, Sg} \exp\left\{-\frac{(\ell nC - \ell n mg)^2}{2Sg^2}\right\} \qquad \text{Equation IV-2-1}$$

where the symbols are;

f(c): occurrence frequency of concentration level c

mg : Arithmetic mean of concentration and denoted by

$$mg = \exp\left(\frac{\sum_{i=1}^{n} \ell nCi}{n}\right)$$

Sg : Arithmetic standard deviation of concentration

$$Sg = \exp\sqrt{\frac{\sum_{i=1}^{n} (\ell nCi - \ell n mg)^2}{n}}$$

Figs. IV-2-7 show cumulative frequency distributions of hourly and daily averaged SO_2 concentration plotted in log normal charts. The cumulative frequency distribution is calculated by accumulating the frequency of concentration level C from lower level and evaluate the frequency by C.

For the hourly data, lines are almost straight and clear log normal profiles are obtained for hourly averages. For daily averages, even some of the lines show slight kinks at low and high level, the frequency distributions follow nearly log normal profiles.

The gradient of the line is equal to Sg, the standard deviations of concentration, and Sg is larger for slower slope. And the concentration at cumulative frequency of 50 percents is equal to the arithmetic mean mg. Assuming the log-normal profile, the value of Sg is calculable from the curve by the following equation:

$$Sg = \exp\left\{\frac{\ell n(Ca/Cb)}{Za - Zb}\right\} \qquad \text{Equation IV-2-2}$$

where, the symbols are as follows;

Ca, Cb : Concentration level at cumulative frequency a and b, respectively.

Za, Zb : Standard deviation of concentration at cumulative frequency a and b, respectively.

R. I. Larsen adopted 99.9 percent and 50 percent as a and b, where the profiles follow long-normals well. Then, Za and Zb are equal to 3.09 and 0.52, respectively, the arithmetic standard deviation of hourly concentration of SO_2 calculated by Equation IV-2-2 for seven stations are shown in Table IV-2-5. These values are slightly larger than the values commonly obtained in Japan.

Table IV-2-5 Arithmetic standard deviation of hourly SO_2 concentration

Observation site	Arithmetic standard deviation (ppb)
MP-1	2.32
MP-2	2.38
MP-3	2.22
MP-4	2.97
MP-5	2.13
MP-6	2.47
MP-7	2.04

The relation of cumulative frequency distribution is effectively used to estimate the concentration corresponding to cumulative frequency of a value and vice versa.

The values of daily average concentration at cumulative frequency 98 percent (the highest value of concentration data in which highest 2 percent are excluded) are shown in Table IV-2-6, together with the highest values corresponding to 100 percent of the hourly averages.

Table IV-2-6 Values of 98 percent cumulative of daily average and the maximum of the hourly values

Observation site	Values of 98 percent cumulative of daily average	Maximum of the hourly values
MP-1	32	194
MP-2	32	183
MP-3	44	477
MP-4	54	381
MP-5	36	197
MP-6	18	100
MP-7	18	94

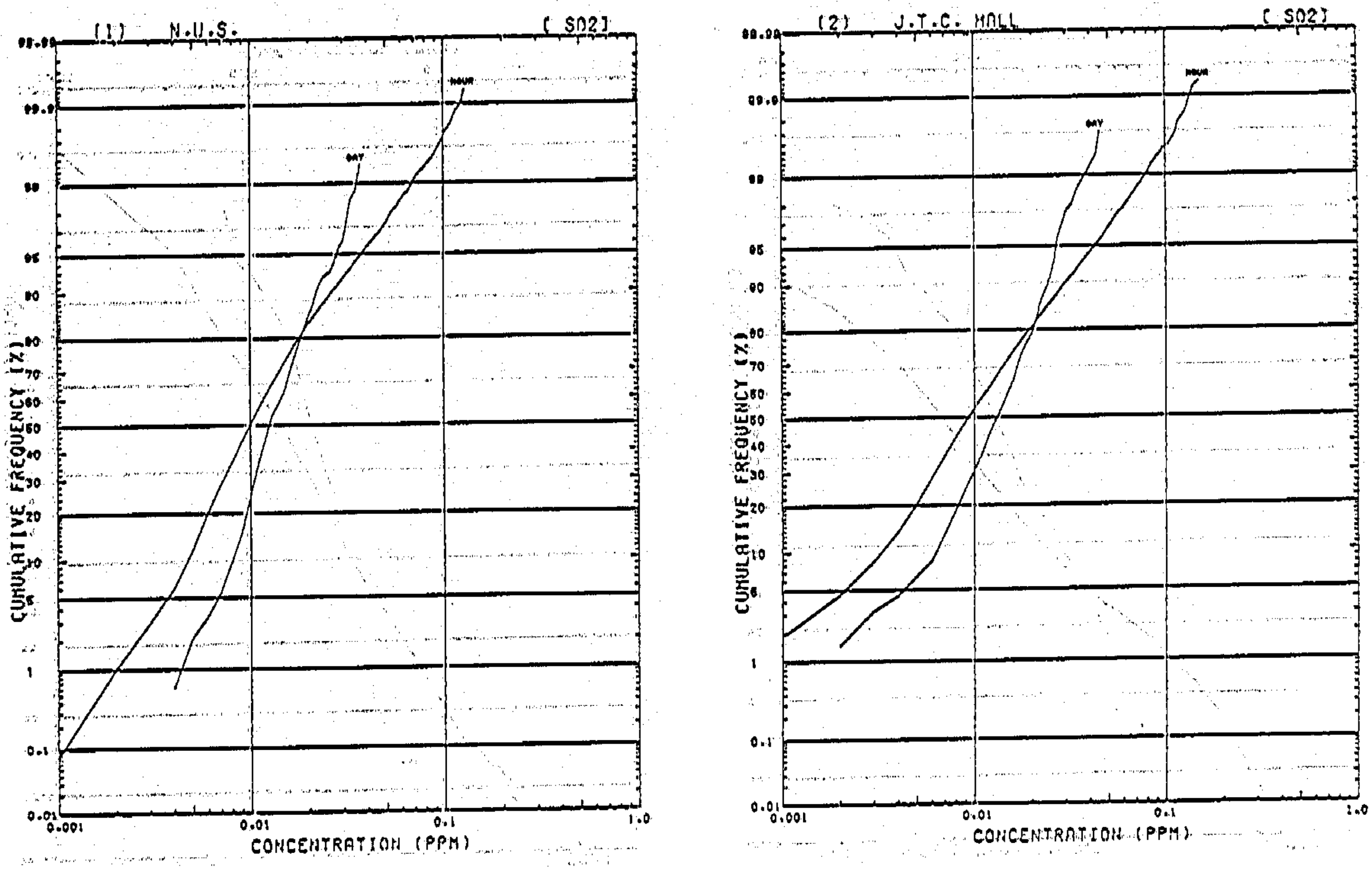


Fig. IV-2-7 Cumulative frequency distribution of hourly and daily average SO_2 concentration (a)

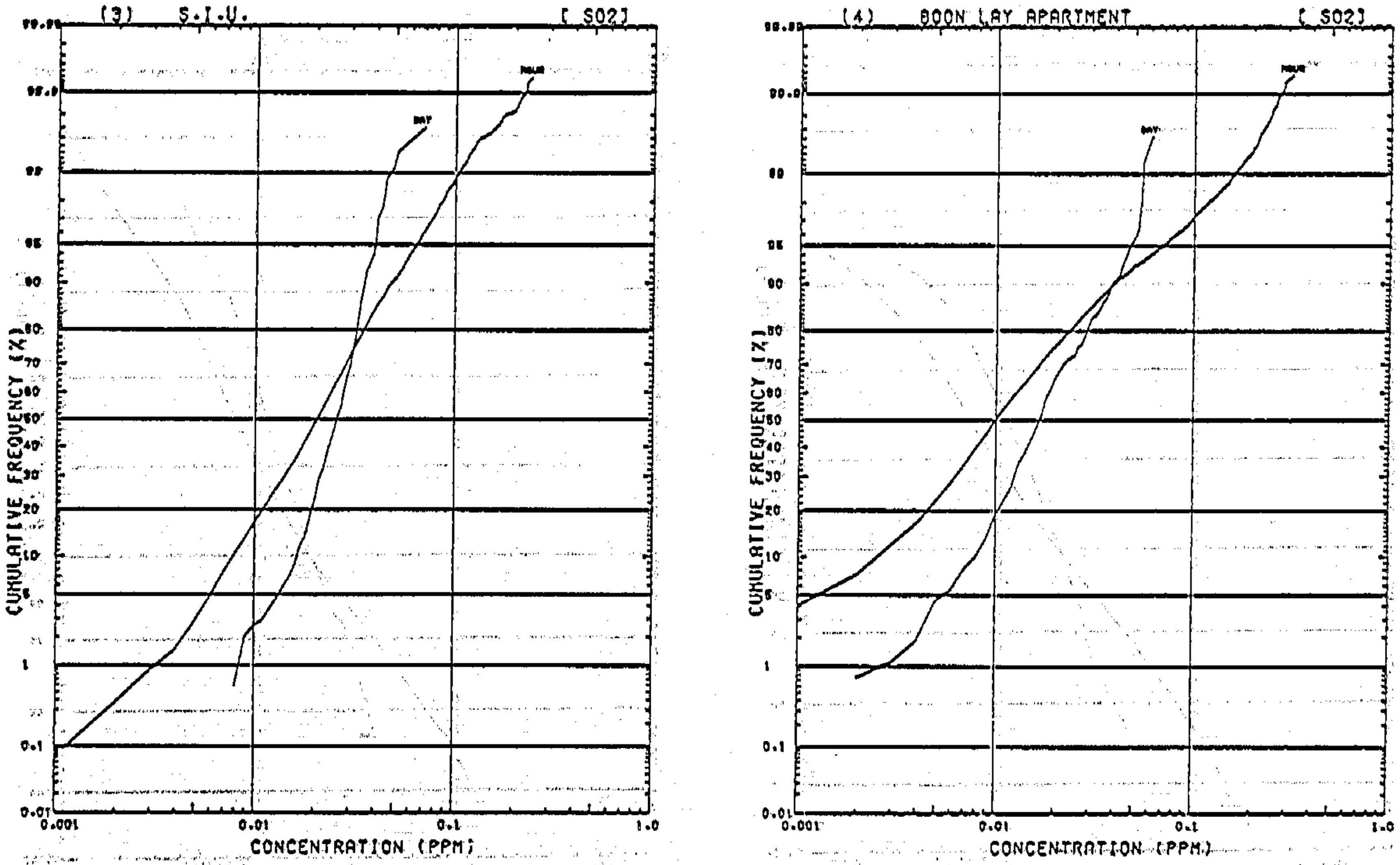


Fig. IV-2-7 Cumulative frequency distribution of hourly and daily average SO_2 concentration (b)

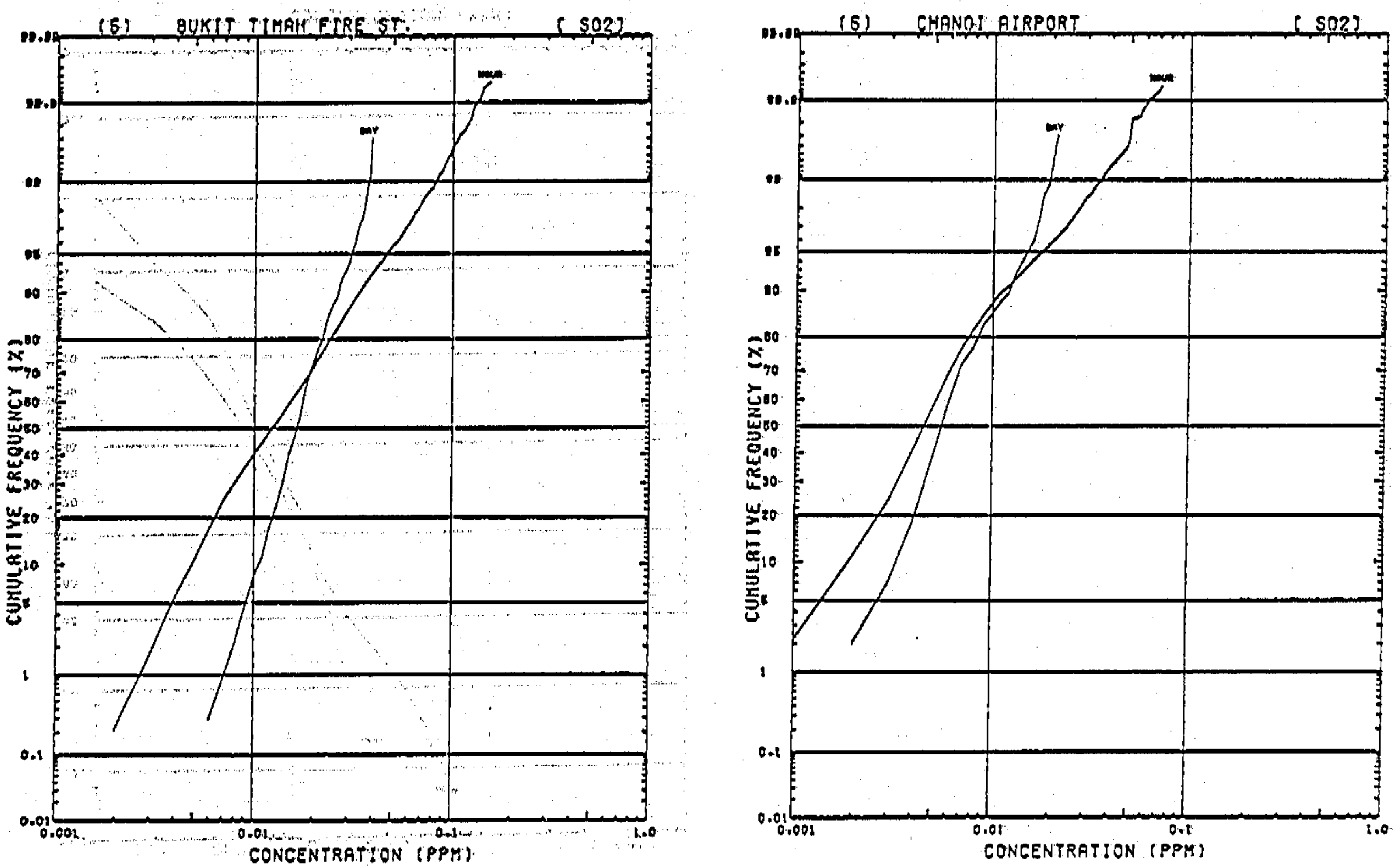


Fig. IV-2-7 Cumulative frequency distribution of hourly and daily average SO_2 concentration (c)

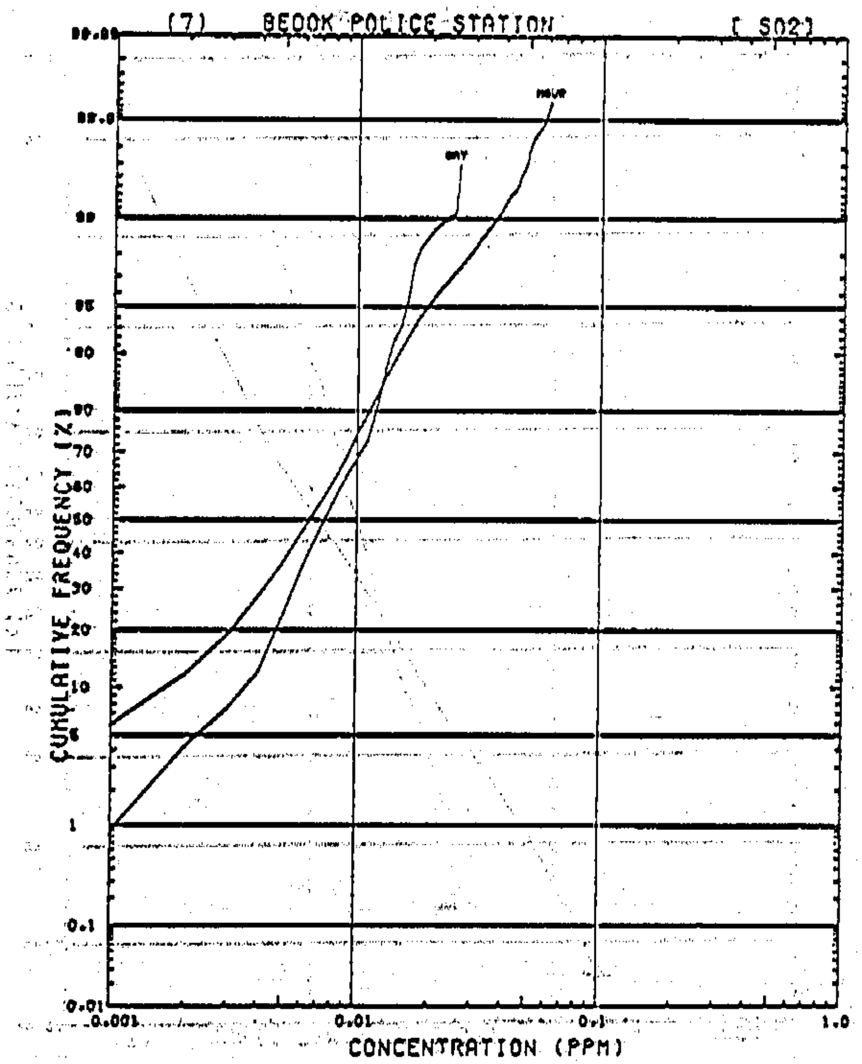


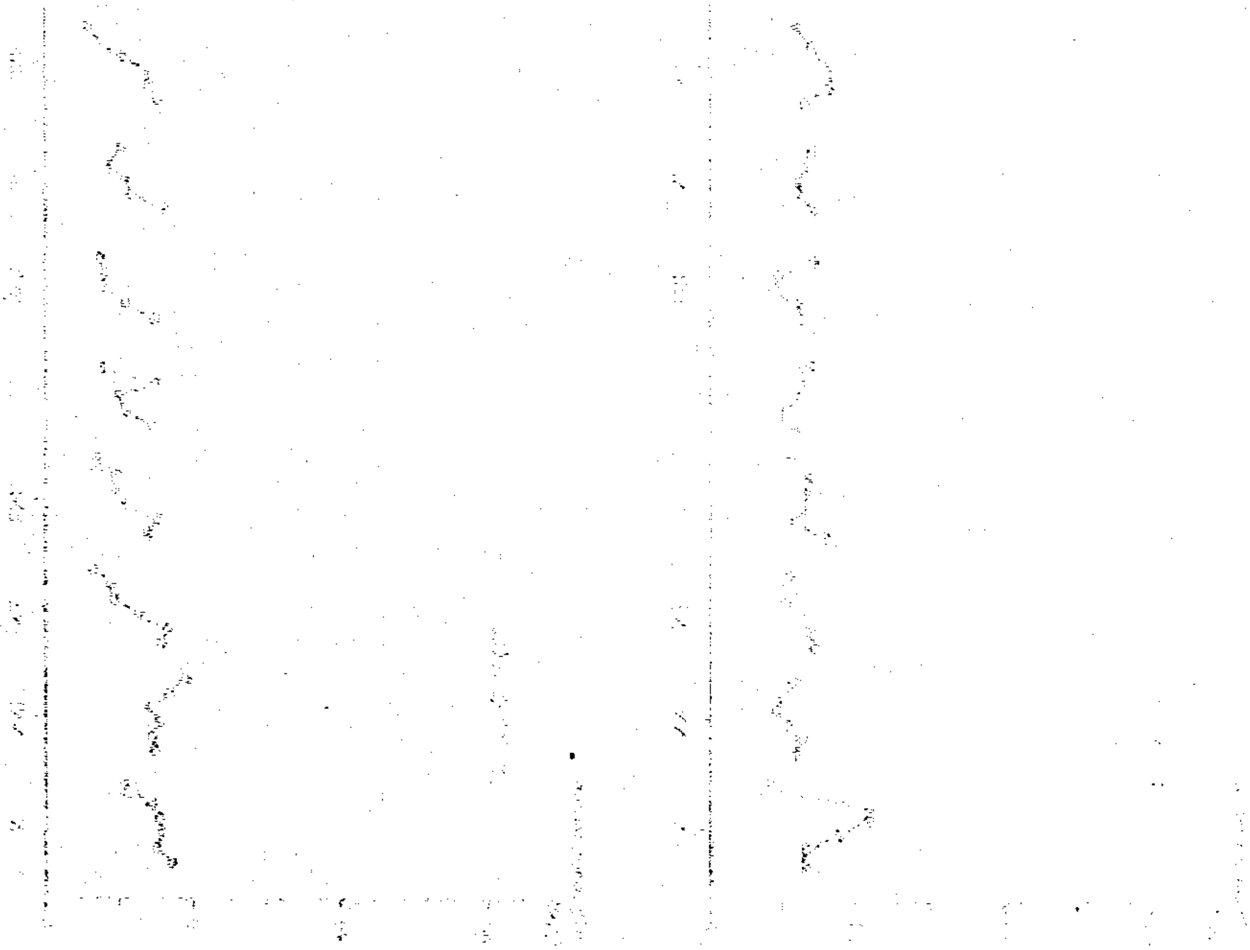
Fig. IV-2-7 Cumulative frequency distribution of hourly and daily average SO_2 concentration (d)

IV-2-5 Dependence of SO_2 Concentrations on Wind Directions and Wind Velocity Ranks

The wind direction and wind velocity is the most important controlling factors for the pollutants concentration at a monitoring station. The SO_2 concentration data were analyzed and averages for each wind direction together with wind velocity ranks are calculated. The results are shown in Figs. IV-2-8. In each wind direction, average concentrations for six velocity ranks are plotted.

In this analysis, wind data at MP-2 was used as the representative for monitoring stations of MP-1 to MP-5, and MP-7 for stations of MP-6 and MP-7. These areal separation is based on the cluster analysis and principal component analysis of hourly wind and concentration data shown in IV-1-5 and IV-2-2. MP-2 and MP-6 are the representative stations of wind field in west and east part of Singapore, respectively.

Figs. IV-2-8 show that SO_2 concentration is relatively high for westerly wind at MP-1, south-western at MP-2 and MP-5, and at MP-3 and MP-4 for southerly wind. These concentration characters are reasonable from the view of the positions of sources and stations. For MP-6 and MP-7, of which not any large sources exist around, dependences of concentration on wind direction and velocity are very small.



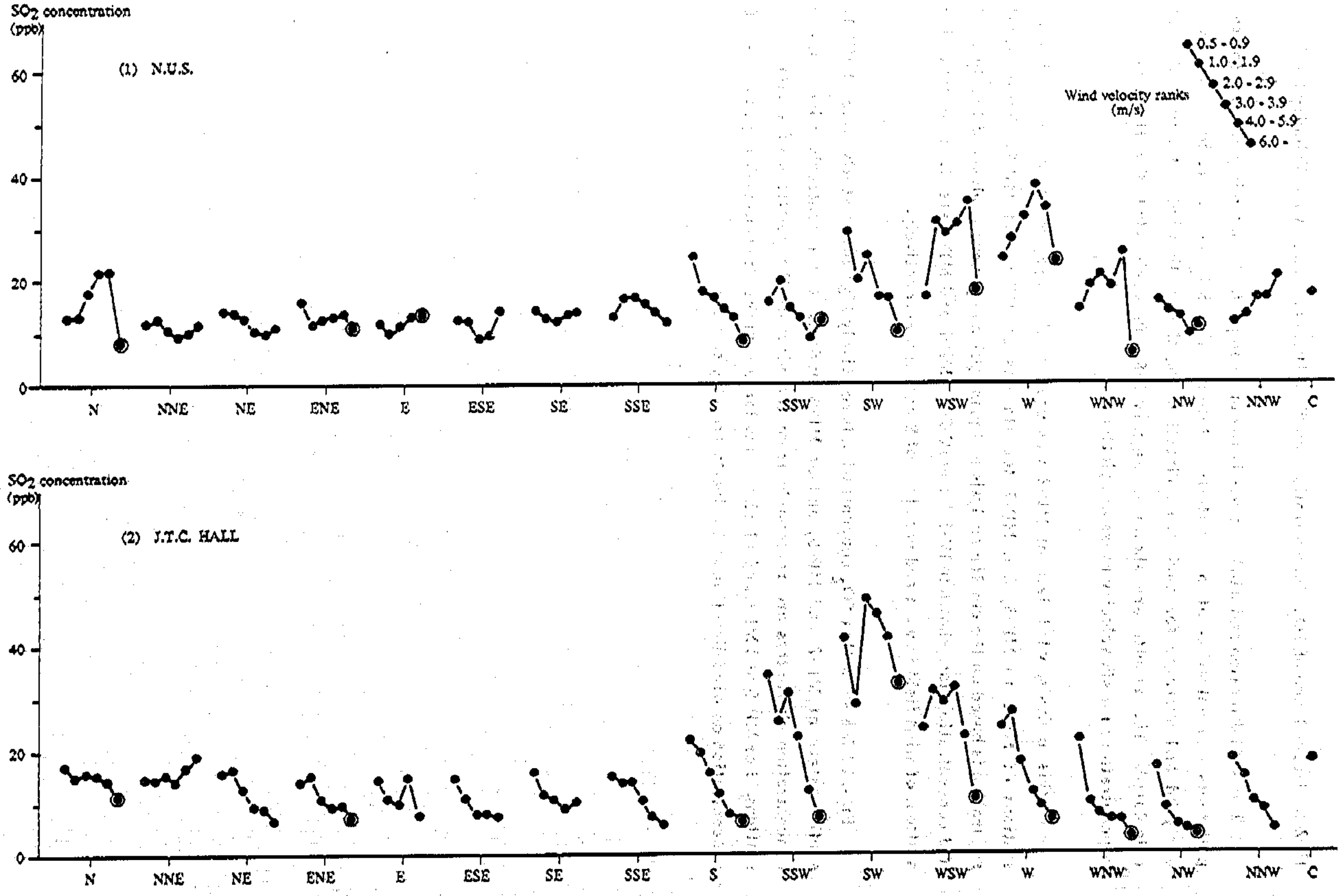


Fig. IV-2-8 Average SO_2 concentration for wind direction and velocity ranks (a)

Note: ◉ are the concentration of which averaging is less than five hours.

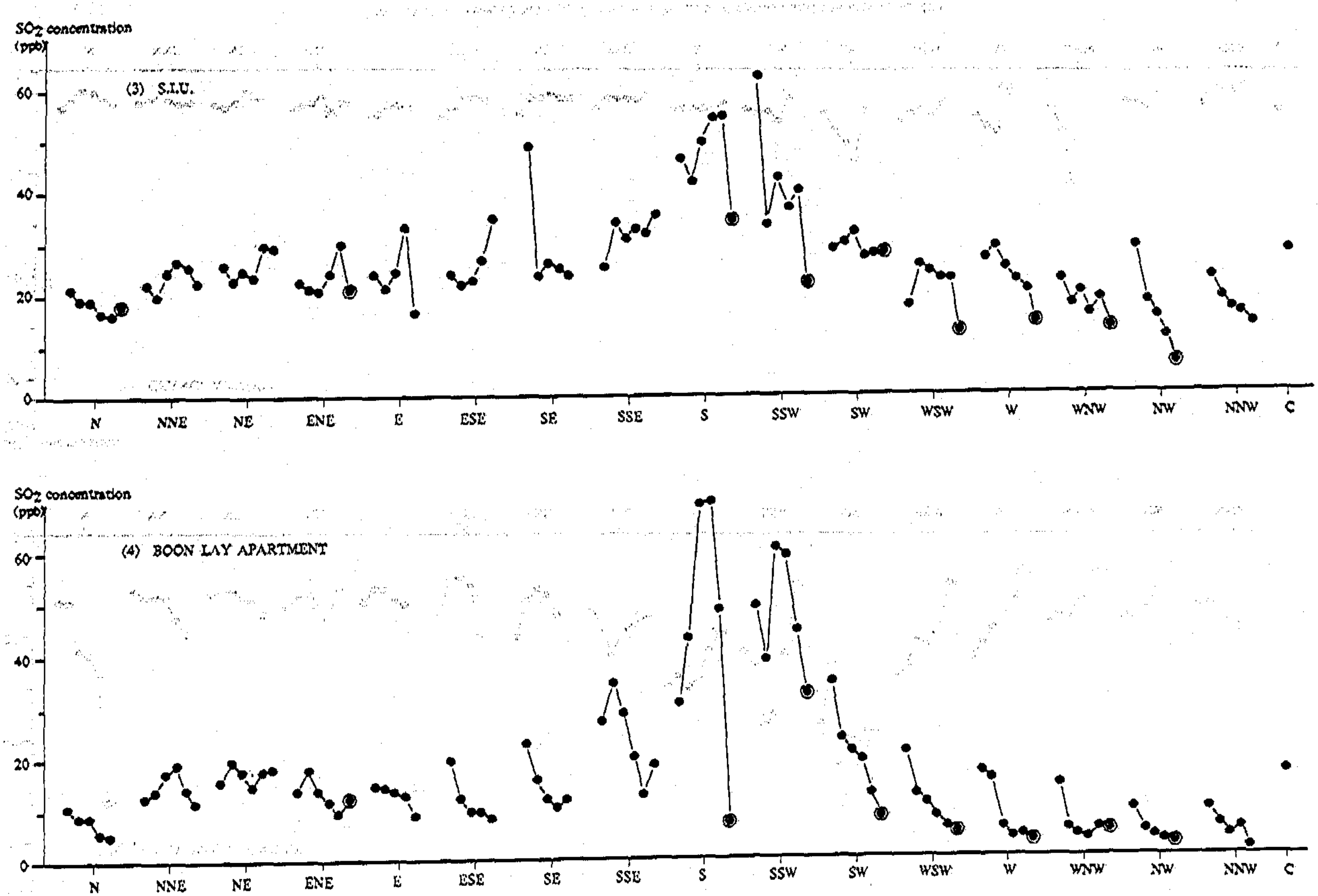


Fig. IV-2-8 Average SO_2 concentration for wind direction and velocity ranks (b)

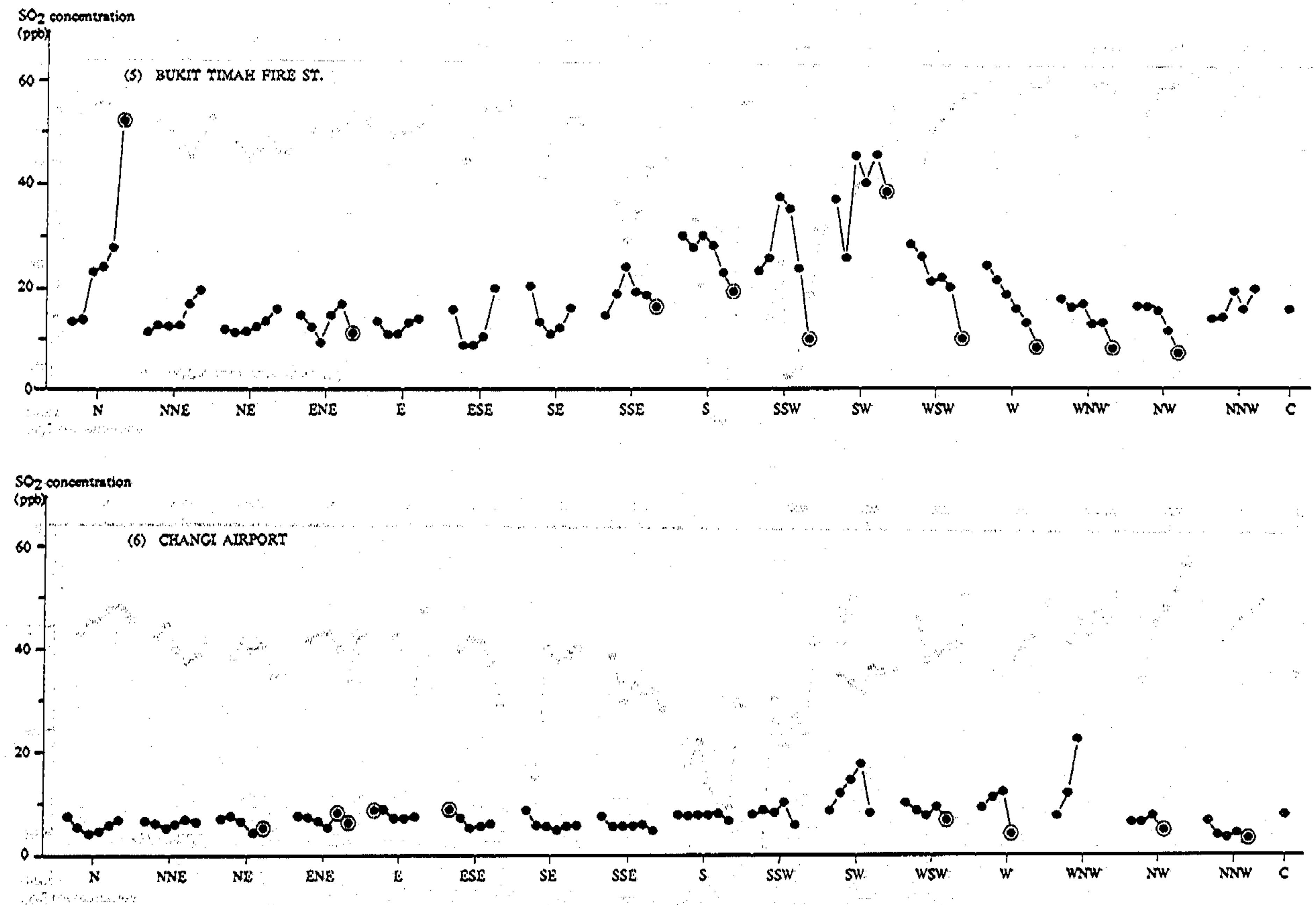


Fig. IV-2-8 Average SO_2 concentration for wind direction and velocity ranks (c)

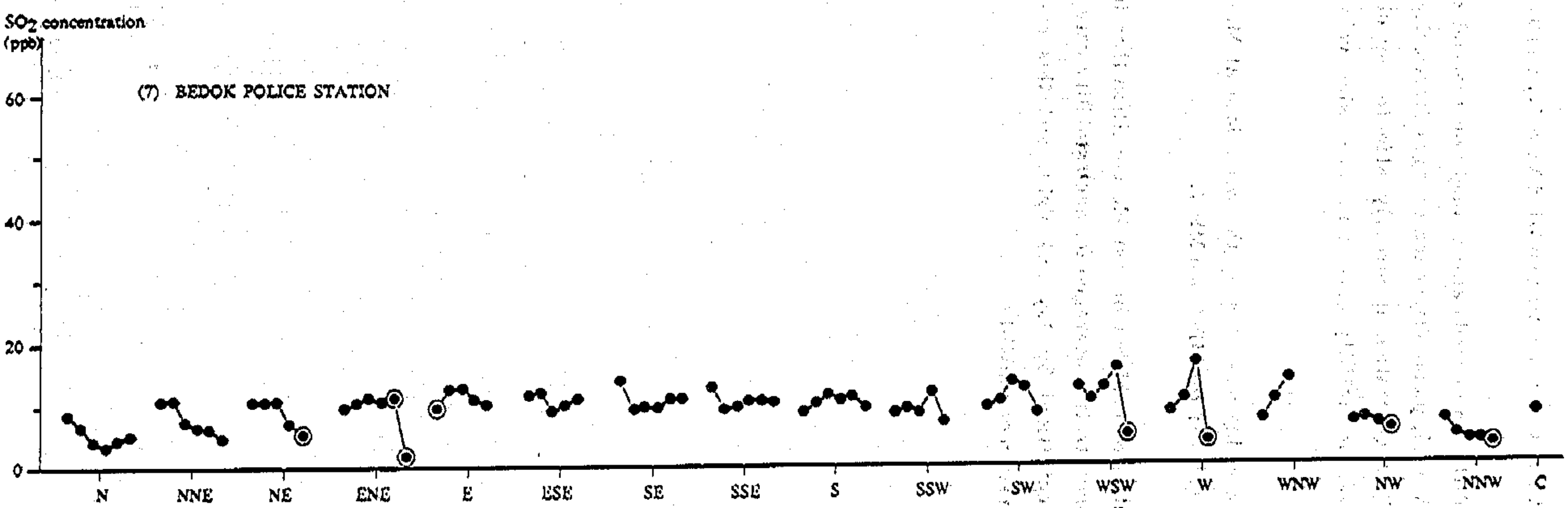


Fig. IV-2-8 Average SO_2 concentration for wind direction and velocity ranks (d)

IV-2-6 Dependence of SO_2 Concentration on Wind Velocity and Thermal Stability

The atmospheric diffusion depends also strongly on thermal stability of atmosphere. As illustrated in Fig. IV-1-16, plume dispersion changes drastically with thermal stability. And the ground level concentration is strongly affected by diffusion condition. SO_2 concentrations for different stability classes in each wind velocity rank are shown in Figs. IV-2-9.

The stability categorizing was done by the wind data at MP-2 for stations MP-1 to MP-5, and by the wind at MP-7 for MP-6 and MP-7.

Generally, concentration is higher in unstable condition than in stable for every wind velocity ranks. The concentration averaged for each stability category includes the effect of change of source conditions by day and night, and this may somehow affect the dependence of concentration on stability.

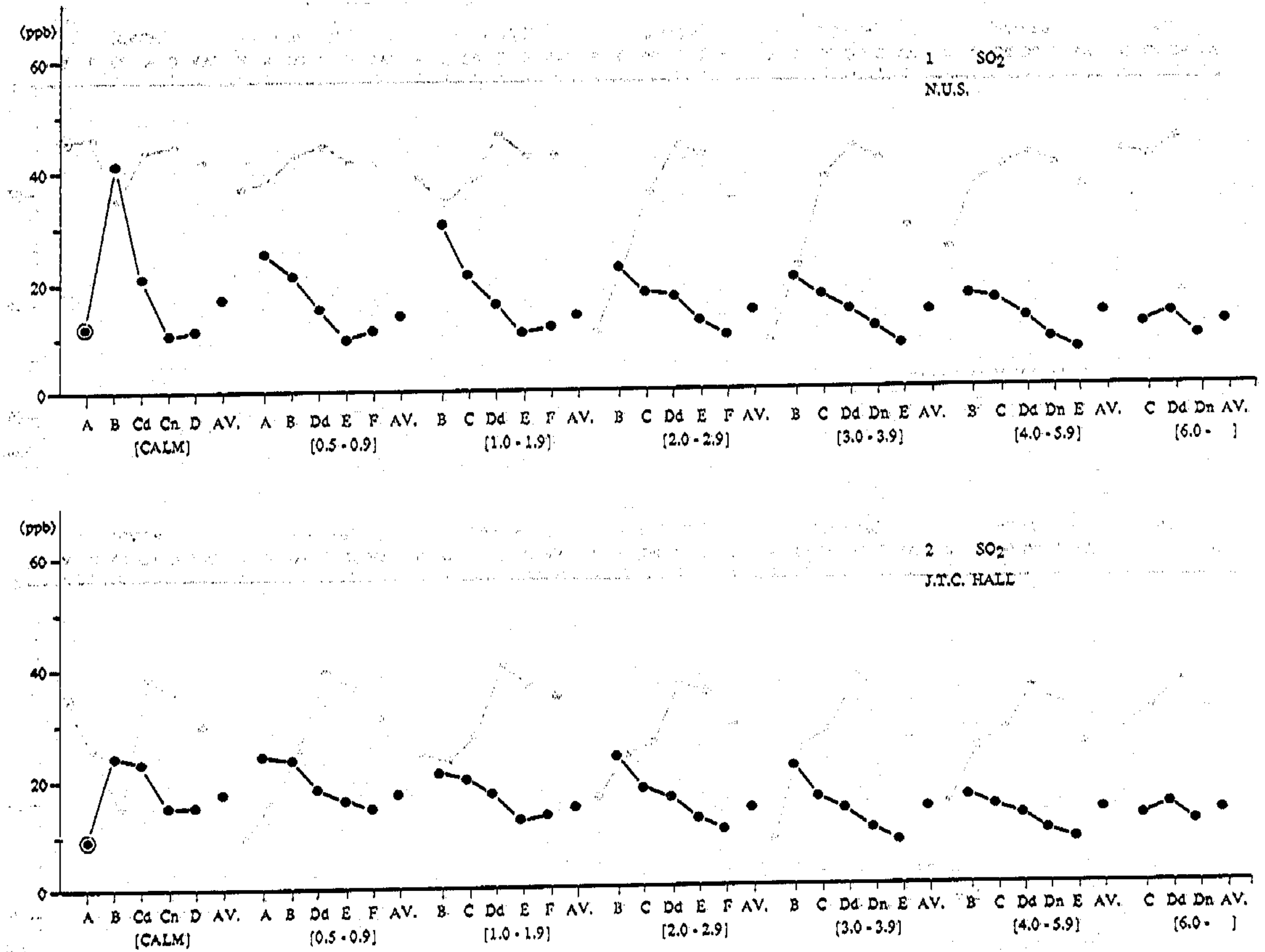
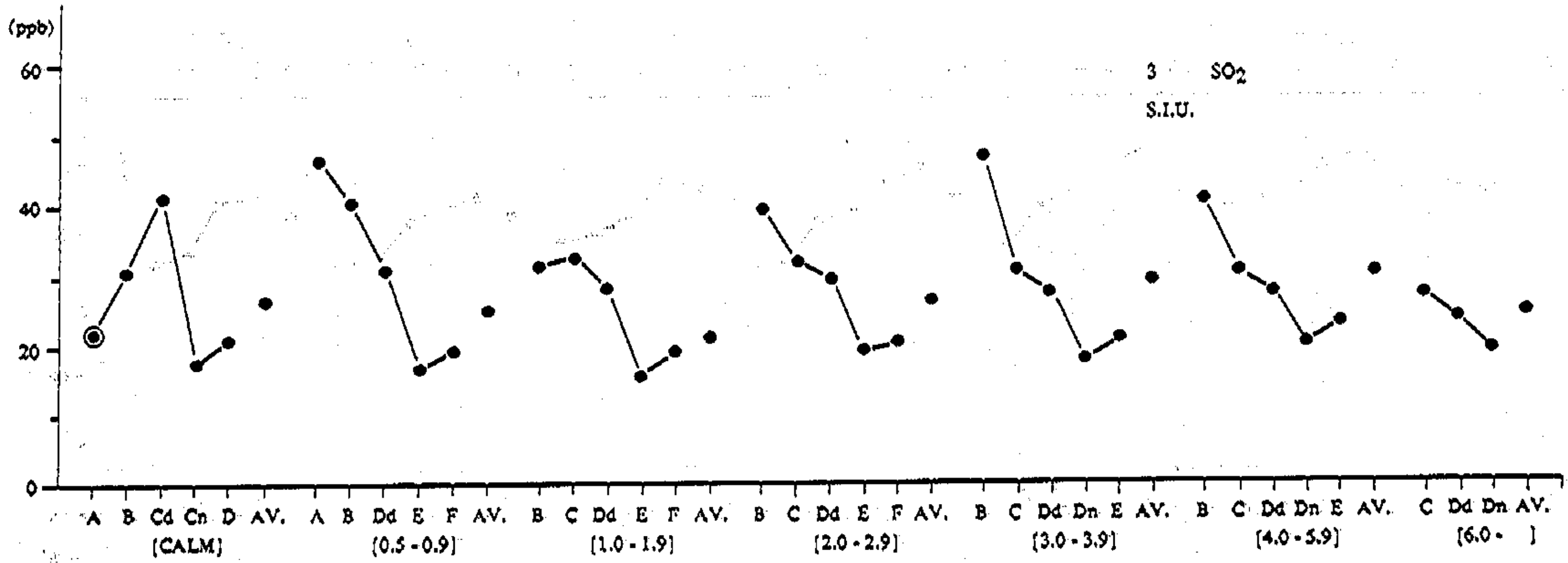


Fig. IV-2-9 Average SO_2 concentrations for wind velocity and stability categories (a)

Note: ◉ are the concentration of which averaging is less than five hours.
Subscripts d and n mean day time and night time, respectively.



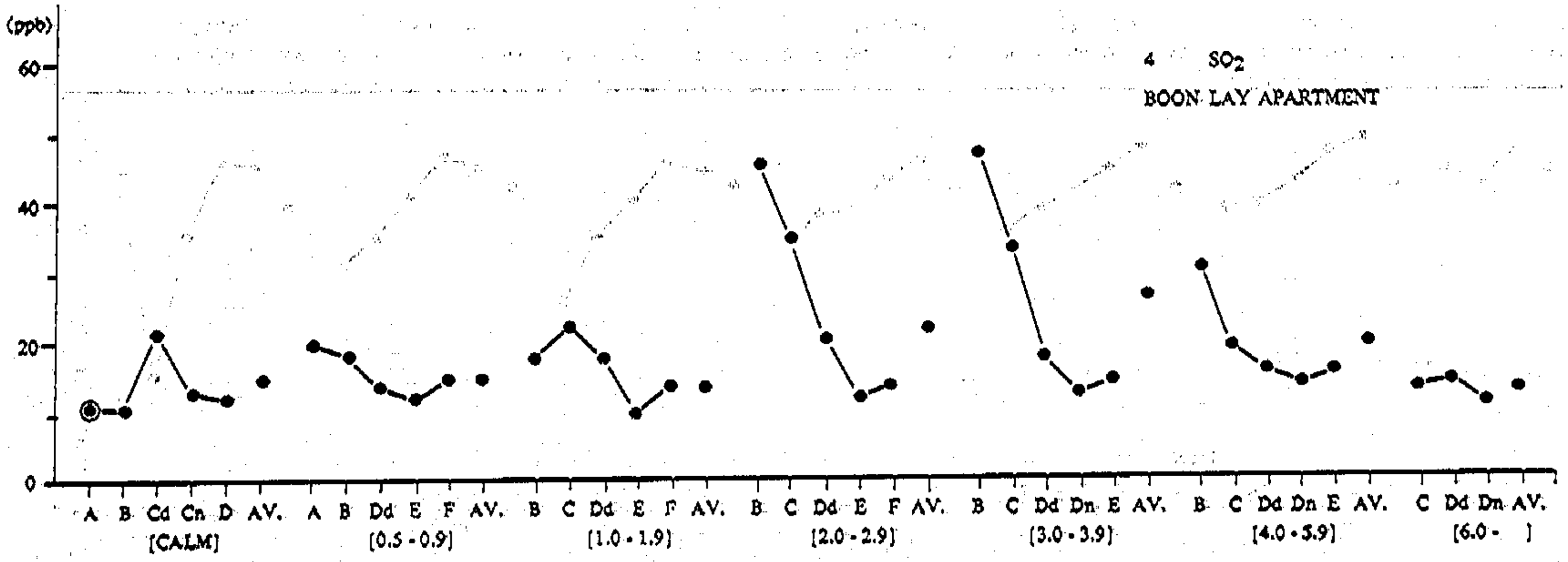
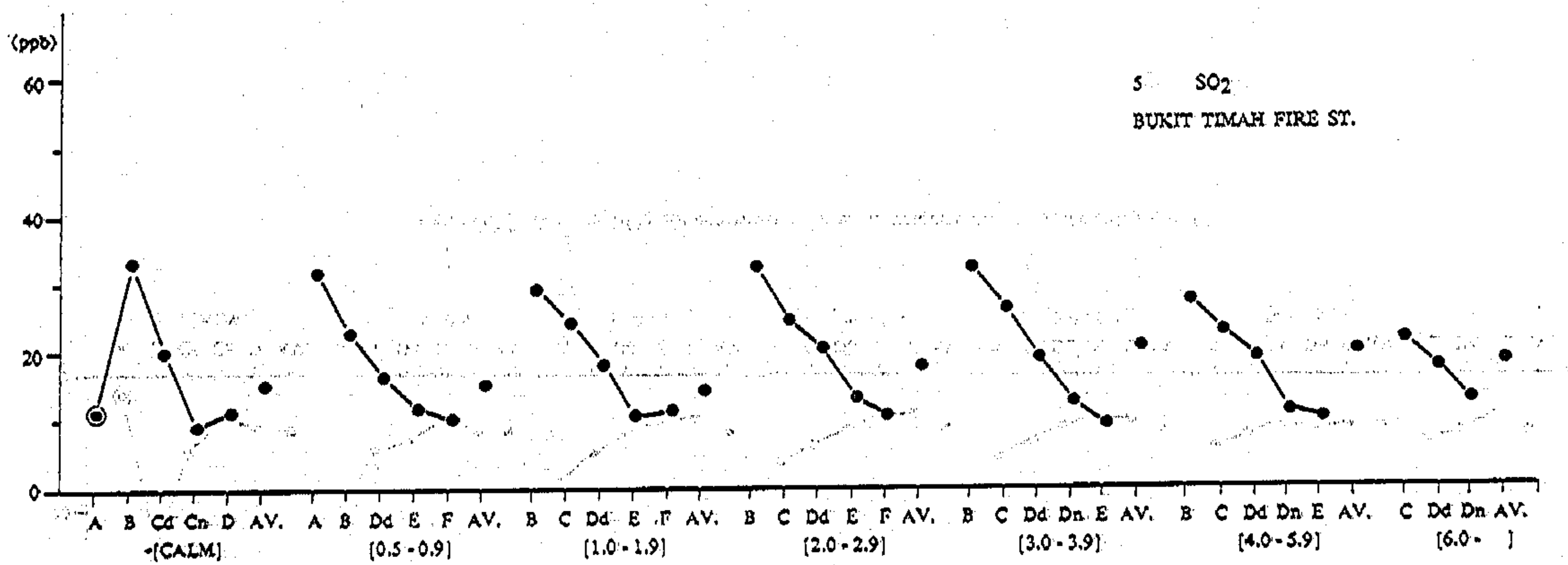


Fig. IV-2-9 Average SO_2 concentrations for wind velocity and stability categories (b)



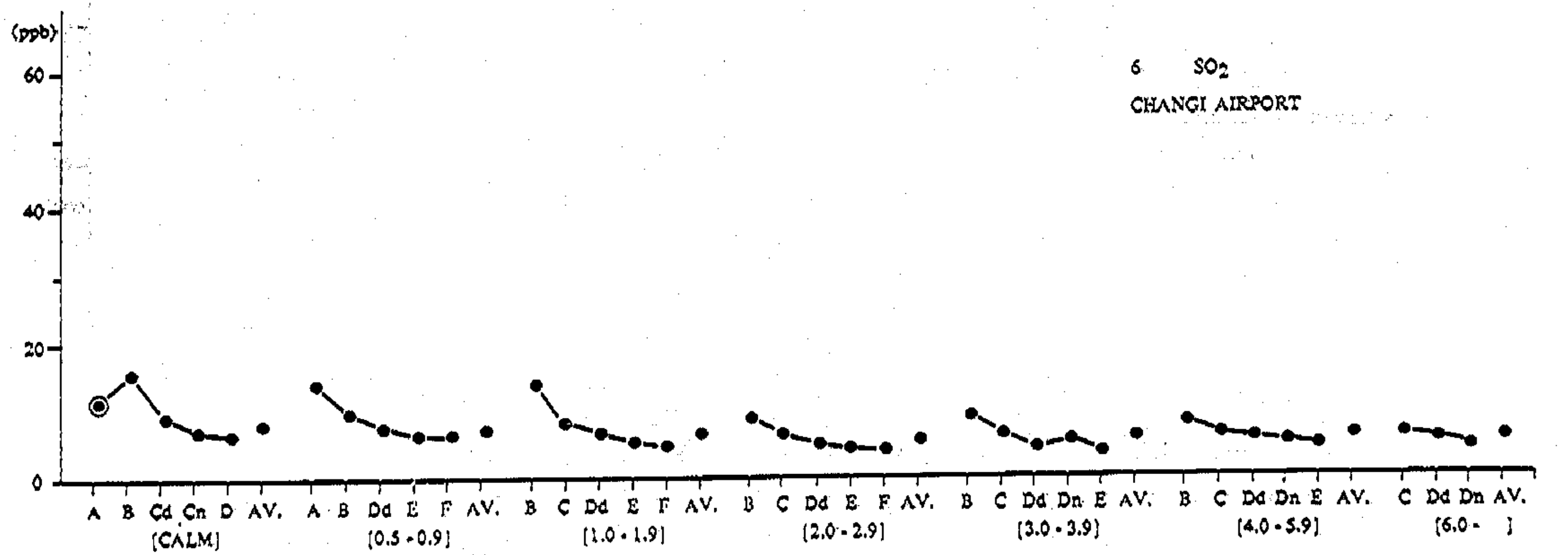


Fig. IV-2-9 Average SO_2 concentrations for wind velocity and stability categories (c)

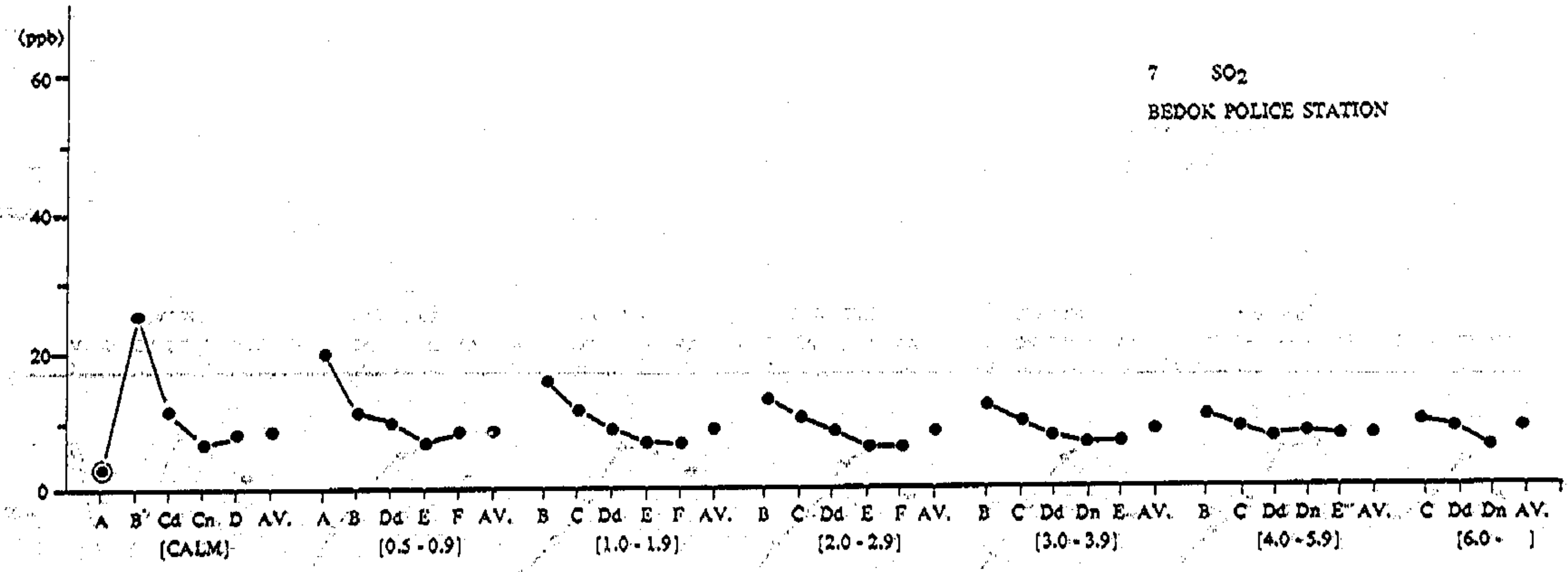


Fig. IV-2-9 Average SO_2 concentrations for wind velocity and stability categories (d)

IV-2-7 Analysis of High Concentration Conditions

To clarify the mechanism of hourly and daily high concentration, concentration and meteorological data were analyzed.

(1) Analysis of hourly high concentration

The highest 50 hours (0.6 percent of total samples of one year) of SO_2 concentration were picked up for each station and the date, hour, wind velocity, wind direction and stability etc. at the time were listed in Table IV-2-7.

	Date		Hour	SO2 concentration and meteorological conditions												Meteorological conditions at the representative station					
				Conditions at the highest 50 hours						Conditions one hour before						At the highest hour			One hour before		
				SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST	WD	WV (0.1m/s)	ST
1	11	7	12	194	SW	12	820	488	A	90	WSW	9	627	379	A	W	18	B	WSW	14	B
2	11	27	10	153	N	19	580	350	A	75	NNE	11	510	171	B	N	35	B	N	23	B
3	11	10	11	145	W	13	779	457	A	70	W	16	505	301	B	WSW	30	B	W	35	B
4	5	19	18	139	E	6	221	102	A	72	C	3	336	187	CB	NNE	18	C	NE	19	B
5	12	8	11	129	N	17	530	313	A	97	N	16	503	180	B	NNE	42	B	N	27	B
6	11	25	12	128	W	12	473	260	A	27	W	12	616	370	B	C	4	CB	NW	13	B
7	11	17	24	126	C	4	2	-38	CD	71	NNE	5	0	-36	F	N	19	F	NNE	22	F
8	5	31	11	125	SSW	6	448	255	A	100	WNW	8	355	185	A	SSE	13	B	C	4	CB
9	11	4	16	122	W	8	****	90	****	69	W	13	****	124	****	WSW	32	****	WSW	38	****
10	5	26	16	120	WNW	6	123	63	DEN	31	C	3	127	69	CCEN	W	22	DEN	W	16	DEN
11	2	28	7	115	C	2	0	-40	CD	48	C	2	0	-44	CD	NNE	18	F	NNE	16	F
12	9	25	11	114	WNW	28	330	195	A	34	NW	36	109	61	DEN	W	41	C	W	31	DEN
13	9	27	22	114	WNW	23	0	-52	F	111	WNW	25	0	-51	F	W	36	E	W	36	E
14	9	27	21	111	WNW	25	0	-51	F	25	WNW	21	0	-51	F	W	36	E	W	30	E
15	5	24	19	111	WNW	28	77	10	E	75	WNW	20	228	109	C	W	37	DBN	W	36	C
16	5	28	17	109	SE	16	130	64	C	****	SSE	16	352	210	B	SE	36	C	SSE	43	C
17	5	19	14	107	C	4	439	262	CA	41	ENE	6	551	318	A	SSW	11	B	SW	9	A
18	11	5	11	105	WSW	11	****	340	****	36	WNW	12	****	262	****	W	19	****	NW	16	****
19	11	23	11	105	WNW	17	398	244	A	84	WNW	21	331	201	B	W	36	C	W	22	B
20	11	20	13	102	W	16	554	322	A	68	W	19	431	256	B	W	38	B	WSW	43	C
21	11	25	13	102	WSW	14	532	327	A	128	W	12	423	260	B	SW	20	B	C	4	CB
22	5	26	11	100	NNE	7	480	281	A	16	NW	5	351	193	A	N	12	B	NNW	8	A
23	11	21	9	100	WNW	17	316	174	A	23	C	4	150	65	CCEN	NW	13	B	W	18	C
24	5	31	10	100	WNW	8	355	183	A	44	NW	10	320	157	B	C	4	CB	NW	10	B
25	4	17	10	98	WNW	16	25	5	DEN	24	NW	10	74	33	DEN	W	37	DEN	NW	25	DEN
26	11	25	14	97	W	12	444	267	B	102	WSW	14	532	327	B	W	29	B	SW	20	B
27	12	1	13	97	W	20	688	393	A	55	WSW	16	801	472	B	WSW	52	C	SW	53	C
28	12	8	10	97	N	16	303	180	A	37	N	12	250	141	B	N	27	B	N	26	B
29	11	17	16	95	W	17	530	292	A	90	WSW	12	470	276	B	W	36	B	W	24	B
30	11	28	13	94	NNE	13	286	168	A	44	N	13	298	180	B	NNW	21	B	N	36	C
31	4	22	12	93	SW	6	688	392	A	52	C	2	516	291	CA	SW	8	A	NNW	6	A
32	5	17	19	93	NE	8	8	-16	E	59	ENE	13	4	-18	DEN	N	25	E	NE	35	DEN
33	4	6	5	92	C	0	0	-19	CCDN	16	C	0	0	-19	CCDN	NNW	15	E	NW	12	E
34	11	7	10	92	WNW	18	652	388	A	28	W	10	****	269	****	WNW	19	B	W	12	****
35	11	20	17	92	NW	20	760	122	A	38	W	15	495	278	B	W	29	B	W	40	C
36	5	26	10	92	WNW	15	432	236	A	18	WNW	12	336	170	B	W	15	B	WNW	16	B
37	4	4	12	90	WSW	15	758	472	A	60	W	13	679	423	B	WSW	24	B	WSW	18	B
38	11	7	11	90	WSW	9	627	379	A	97	WNW	18	652	388	B	WSW	14	B	WNW	19	B
39	11	17	15	90	WSW	12	470	276	A	38	W	12	636	380	B	W	24	B	NW	17	B
40	5	16	11	90	N	16	488	289	A	39	N	12	369	211	B	N	31	C	N	24	B
41	4	17	18	88	S	6	119	45	DEN	81	C	4	208	100	CCEN	ENE	5	DEN	ENE	8	B
42	11	11	18	88	WNW	13	81	19	DEN	52	WNW	18	273	140	B	W	25	DEN	W	32	C
43	11	25	19	88	NNE	9	0	-23	E	43	NE	13	48	6	DEN	N	21	E	N	33	DEN
44	6	2	11	86	SE	7	363	214	A	8	SSE	7	110	64	DEN	ESE	10	B	SSE	23	DEN
45	5	30	13	85	WSW	14	902	542	A	80	W	10	803	478	B	SSW	33	B	SW	21	B
46	6	9	12	84	SSE	13	703	403	A	31	SE	19	563	320	B	SSE	33	B	SSE	33	B
47	11	5	7	84	WNW	31	****	-16	DBN	54	WNW	22	****	-19	E	WSW	57	DBN	WSW	42	DBN
48	11	9	19	84	C	4	0	-44	CD	40	W	7	102	15	DEN	WSW	18	F	W	23	DEN
49	11	23	10	84	WNW	21	331	201	A	27	NW	12	186	102	C	W	22	B	WNW	12	C
50	11	10	14	82	W	12	446	252	A	35	W	15	591	343	B	WSW	43	C	WSW	54	C

Note:

SO_2: SO_2-concentration
WD: Wind direction
WV: Wind velocity
Q_H: Solar radiation
Q_N: Net radiation flux
ST: Atmospheric stability

Table IV-2-7 The highest 50 hours of SO_2 and meteorological conditions (a)

(1) N.U.S.

No.	Date		Hour	SO2 concentration and meteorological conditions: Conditions at the highest 50 hours						Conditions one hour before						Meteorological conditions at the representative station: At the highest hour			One hour before		
				SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST	WD	WV (0.1m/s)	ST
1	10	29	18	183	SW	25	98	26	DEW	65	SW	25	322	136	B	SW	25	DEW	SW	25	B
2	10	29	15	182	SW	43	****	****	****	115	SSW	38	****	****	****	SW	43	****	SSW	38	****
3	8	2	14	172	****	****	725	439	****	112	****	****	298	174	****	****	****	****	****	****	****
4	11	20	13	170	SW	35	698	421	A	96	SW	32	661	406	B	SW	35	B	SW	32	B
5	9	15	11	152	SW	41	579	331	A	52	SW	33	310	175	C	SW	41	B	SW	33	C
6	10	21	11	150	SSW	24	608	384	A	71	SW	25	662	395	B	SSW	24	B	SW	25	B
7	9	18	11	140	SW	24	646	381	A	56	SSW	31	486	289	C	SW	24	B	SSW	31	C
8	4	21	11	137	SW	8	620	352	A	17	NW	8	392	222	A	SW	8	A	NW	8	A
9	9	18	14	135	SW	36	593	340	A	65	SSW	30	595	348	B	SW	38	B	SSW	30	B
10	10	9	9	133	SSW	34	****	****	****	52	SSW	39	****	****	****	SSW	34	****	SSW	39	****
11	5	9	10	131	SW	40	199	121	C	16	N	8	182	84	B	SW	40	C	N	8	B
12	9	29	12	130	SW	45	660	310	A	95	SW	31	767	449	B	SW	45	B	SW	31	B
13	10	10	11	129	SSW	28	561	333	A	60	SSW	14	560	321	B	SSW	28	B	SSW	14	B
14	10	31	6	127	SW	5	****	-31	F	115	W	19	****	-33	F	SW	5	F	W	19	F
15	4	30	11	126	SW	25	369	203	A	30	WSW	19	378	211	B	SW	25	B	WSW	19	B
16	10	10	12	126	S	35	827	489	B	129	SSW	28	561	333	B	S	35	B	SSW	28	B
17	9	29	13	121	WSW	29	705	380	A	55	SW	36	779	431	B	WSW	29	B	SW	36	B
18	11	7	17	119	SSW	26	336	149	A	66	SSW	33	543	288	B	SSW	26	B	SSW	33	B
19	9	10	18	116	W	15	66	17	DEW	65	SSW	5	135	60	B	W	15	DEW	SSW	5	B
20	9	15	14	116	SW	37	570	305	A	30	SW	40	701	410	B	SW	37	B	SW	40	B
21	9	15	16	115	SSW	27	474	256	A	55	SW	30	473	269	C	SSW	27	B	SW	30	C
22	10	29	14	115	SSW	38	****	****	****	87	S	28	****	****	****	SSW	38	****	S	28	****
23	10	31	5	115	W	19	****	-33	F	16	S	33	****	-24	DDN	W	19	F	S	33	DDN
24	2	10	17	114	SSW	33	265	148	C	26	NNW	20	390	227	B	SSW	33	C	NNW	20	B
25	1	30	10	113	NNE	47	434	224	C	34	NNE	26	197	78	C	NNE	47	C	NNE	26	C
26	3	4	6	113	NNE	25	0	-50	F	25	NNE	31	0	-52	E	NNE	25	F	NNE	31	E
27	8	2	13	112	****	****	298	174	****	49	****	****	220	128	****	****	****	****	****	****	****
28	10	4	16	111	SSW	34	134	66	C	7	SSW	63	320	174	DEW	SSW	34	C	SSW	63	DEW
29	11	1	12	111	SSW	30	****	300	****	64	SW	27	****	464	****	SSW	30	****	SW	27	****
30	11	2	13	111	SW	31	****	197	****	57	SW	38	****	252	****	SW	31	****	SW	38	****
31	10	10	13	109	SSW	35	826	490	A	126	S	35	827	489	B	SSW	35	B	S	35	B
32	11	7	14	107	SW	42	831	480	A	40	SSW	14	863	505	B	SW	42	B	SSW	14	B
33	9	15	12	106	SW	41	654	310	A	152	SW	41	579	331	B	SW	41	B	SW	41	B
34	10	16	12	106	SW	38	620	377	B	76	WSW	31	649	381	B	SW	38	B	WSW	31	B
35	10	12	14	105	SSW	22	274	140	A	21	SSW	27	411	241	B	SSW	22	B	SSW	27	B
36	11	7	15	105	SW	37	710	402	A	107	SW	42	831	480	B	SW	37	B	SW	42	B
37	6	17	17	104	SW	27	274	160	A	27	SSW	33	380	224	C	SW	27	B	SSW	33	C
38	11	6	11	102	SSW	26	****	292	****	25	W	9	****	221	****	SSW	26	****	W	9	****
39	4	21	12	100	S	21	319	200	A	137	SW	8	620	352	A	S	21	B	SW	8	A
40	3	6	17	100	NNE	29	265	150	B	73	NNE	28	373	201	B	NNE	29	B	NNE	28	B
41	4	22	13	96	SW	33	628	477	A	24	SW	8	688	392	A	SW	33	B	SW	8	A
42	9	3	14	96	WSW	15	308	224	A	74	W	5	308	184	A	WSW	15	B	W	5	A
43	11	20	12	96	SW	32	661	406	A	36	WSW	24	432	262	B	SW	32	B	WSW	24	B
44	9	26	12	95	SW	36	511	301	A	16	WSW	36	347	209	C	SW	36	B	WSW	36	C
45	9	29	11	95	SW	31	767	449	A	7	S	19	301	171	B	SW	31	B	S	19	B
46	10	8	10	95	SW	34	656	486	A	50	SW	35	826	473	B	SW	34	B	SW	35	B
47	5	4	16	94	S	19	672	341	A	14	S	17	740	470	B	S	19	B	S	17	B
48	9	18	12	93	SSW	32	651	379	A	140	SW	24	646	381	B	SSW	32	B	SW	24	B
49	10	11	13	93	SW	21	536	323	A	67	SSW	28	721	443	B	SW	21	B	SSW	28	B
50	4	19	18	91	E	33	214	103	C	10	ESE	31	482	257	C	E	33	C	ESE	31	C

Table IV-2-7 The highest 50 hours of SO_2 and meteorological conditions (b)

(2) J.T.C. HALL

	Date		Hour	SO2 concentration and meteorological conditions												Meteorological conditions at the representative station					
				Conditions at the highest 50 hours						Conditions one hour before						At the highest hour			One hour before		
				SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST	WD	WV (0.1m/s)	ST
1	5	12	14	477	****	****	738	458	****	247	****	****	582	357	****	S	34	B	SSE	36	B
2	4	24	13	370	****	****	872	490	****	228	****	****	781	436	****	S	33	B	S	27	B
3	4	24	10	302	****	****	371	202	****	99	****	****	259	118	****	SE	8	A	NNE	5	B
4	10	9	11	287	SSW	6	****	****	****	46	SSE	6	****	****	****	W	17	****	SW	33	****
5	5	14	15	283	****	****	637	389	****	27	****	****	224	132	****	S	20	B	SW	19	C
6	5	12	13	242	****	****	582	357	****	53	****	****	540	330	****	SSE	36	B	S	35	B
7	4	24	12	228	****	****	781	436	****	104	****	****	641	360	****	S	27	B	SSE	24	B
8	8	22	12	227	S	7	779	448	A	130	SSE	5	656	388	A	SSE	32	B	SE	33	B
9	8	20	11	226	C	4	546	317	CA	63	S	5	198	115	B	SSE	10	B	SSE	31	C
10	5	2	13	218	****	****	809	443	****	63	****	****	759	428	****	SSW	22	B	S	26	B
11	5	12	15	212	****	****	440	411	****	477	****	****	738	458	****	S	49	B	S	34	B
12	5	17	12	212	****	****	203	120	****	121	****	****	468	272	****	S	18	C	S	19	B
13	9	20	14	212	SSW	6	310	181	A	18	SSW	5	292	168	A	SSW	44	C	SSW	37	C
14	5	22	6	204	****	****	0	-31	****	22	****	****	0	-28	****	SSW	9	F	C	4	CCBW
15	6	1	15	200	C	4	285	171	CA	69	S	5	524	323	A	S	26	B	S	31	B
16	7	13	13	199	SSE	7	694	424	A	57	SSE	8	718	437	A	****	****	****	****	****	****
17	5	5	11	183	****	****	629	383	****	51	****	****	443	261	****	SSW	26	B	SSE	26	B
18	5	18	12	175	****	****	693	420	****	53	****	****	429	255	****	S	26	B	SSE	21	B
19	10	20	10	172	C	3	315	****	CA	74	C	2	148	****	CCCN	S	17	B	NW	6	B
20	4	25	16	171	****	****	634	360	****	31	****	****	588	334	****	S	39	B	SSW	36	B
21	6	8	15	171	S	5	725	418	A	95	C	4	783	458	CA	SSE	34	B	S	29	B
22	5	14	16	168	****	****	487	275	****	283	****	****	637	389	****	S	25	B	S	20	B
23	5	4	15	165	****	****	740	470	****	69	****	****	512	310	****	S	17	B	S	18	B
24	2	10	18	164	SSW	7	271	132	A	39	SW	13	265	148	B	SSW	21	B	SSW	33	C
25	6	3	15	160	S	5	695	414	A	47	SSE	5	636	379	A	S	29	B	SSE	29	B
26	4	12	14	158	****	****	605	357	****	100	****	****	620	372	****	S	26	B	SE	11	B
27	8	19	16	155	S	7	525	284	A	41	S	5	672	374	A	S	49	B	S	41	B
28	9	23	15	155	SSW	8	701	394	A	34	SW	8	842	485	A	SSW	40	B	SSW	33	B
29	2	4	17	151	C	2	164	90	CCCN	70	C	3	278	162	CB	C	3	CCCN	S	23	B
30	4	16	15	149	****	****	371	200	****	58	****	****	439	252	****	S	22	B	S	23	B
31	4	24	14	149	****	****	551	308	****	370	****	****	872	490	****	S	30	B	S	33	B
32	6	9	14	141	C	4	741	432	CA	47	SSE	5	772	450	A	SSE	34	B	SSE	39	B
33	3	7	14	140	C	4	598	350	CA	33	S	5	468	278	A	S	25	B	SW	26	B
34	7	28	12	134	SSE	7	769	456	A	23	S	6	668	387	A	SE	29	B	SE	39	B
35	8	11	13	132	S	7	824	480	A	100	S	7	757	441	A	S	42	B	S	38	B
36	10	8	17	132	C	3	****	****	****	120	C	2	****	****	****	C	2	****	E	14	****
37	8	22	11	130	SSE	5	656	388	A	24	SSE	8	551	290	A	SE	33	B	SSE	33	B
38	6	10	13	128	SSE	6	770	453	A	44	SSE	5	670	390	A	S	33	B	SE	34	B
39	10	21	13	128	SSW	5	639	370	A	88	SSE	6	654	384	A	S	28	B	SSE	31	B
40	6	24	12	127	S	6	629	365	A	24	SSE	6	556	314	A	S	38	B	S	37	B
41	2	21	14	127	S	5	848	499	A	17	C	3	630	372	CA	S	31	B	NNW	13	B
42	6	11	13	126	S	7	765	450	A	30	SSE	5	647	380	A	SSE	38	B	SSE	35	B
43	7	1	16	125	S	7	634	365	A	116	S	7	719	420	A	S	43	B	S	43	B
44	10	1	17	125	C	4	257	107	CA	26	SSW	5	469	239	A	SSW	23	B	SSW	26	B
45	5	11	16	124	****	****	337	199	****	69	****	****	502	300	****	S	12	B	NW	6	A
46	4	25	16	122	****	****	253	139	****	74	****	****	330	188	****	SSE	17	B	S	22	B
47	9	14	19	122	C	4	0	-28	CCBN	34	S	5	31	-2	DCN	SW	20	E	S	41	DCN
48	4	1	13	121	C	3	901	564	CA	39	C	3	869	525	CA	SSW	33	B	S	30	B
49	5	17	11	121	****	****	448	272	****	51	****	****	320	180	****	S	19	B	C	2	CB
50	10	8	16	120	C	2	****	****	****	27	C	2	****	****	****	E	14	****	SSW	26	****

Table IV-2-7 The highest 50 hours of SO_2 and meteorological conditions (c)

(3) S.I.U.

	Date		Hour	SO2 concentration and meteorological conditions: Conditions at the highest 50 hours						Conditions one hour before						Meteorological conditions at the representative station: At the highest hour			One hour before		
				SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST	WD	WV (0.1m/s)	ST
1	2	5	18	381	SSE	22	130	55	C	353	SSE	28	281	148	B	S	21	C	S	25	B
2	2	5	17	353	SSE	28	281	148	A	115	SSE	20	410	230	B	S	25	B	S	27	B
3	10	21	15	337	SSE	26	478	267	A	135	SSE	26	738	458	B	S	24	B	S	31	B
4	3	28	14	317	SSE	28	676	390	A	69	S	24	688	392	B	S	31	B	S	28	B
5	2	26	17	316	S	29	443	252	A	174	S	44	520	380	B	SSW	37	C	SSW	47	B
6	3	13	18	288	S	26	195	99	C	264	S	32	524	305	B	S	23	C	S	39	B
7	10	30	15	287	SSE	35	****	438	****	111	S	33	****	502	****	S	32	****	S	36	****
8	3	29	13	280	S	26	375	228	A	37	SSW	20	492	305	B	S	30	C	SSW	28	B
9	8	5	14	268	SSE	36	749	430	A	193	S	32	709	410	B	S	36	B	S	33	B
10	3	13	17	264	S	32	524	305	A	250	S	33	708	421	B	S	39	B	S	38	B
11	10	8	15	262	S	22	****	****	****	30	SSW	20	578	305	B	SSW	30	****	SSW	27	B
12	3	14	16	260	SE	24	487	275	A	99	S	13	637	389	B	S	25	B	S	20	B
13	3	2	12	250	S	25	759	428	A	81	S	26	604	348	B	S	26	B	SSW	25	B
14	3	13	16	250	S	33	708	421	A	10	NNW	10	591	357	B	S	38	B	N	12	B
15	7	21	11	248	SSE	38	658	394	A	83	S	40	465	275	C	SSW	34	B	SSW	33	C
16	4	24	13	245	****	****	872	490	****	38	****	****	781	436	****	S	33	B	S	27	B
17	3	10	18	242	S	31	250	120	C	101	S	31	478	270	C	SSW	25	B	SSW	34	C
18	3	2	14	241	SSE	22	749	413	A	140	S	24	809	445	B	SSW	21	B	SSW	22	B
19	4	21	14	237	S	24	545	310	A	79	S	26	382	205	B	SSW	23	B	S	23	B
20	6	14	11	235	S	25	360	208	A	28	W	12	315	164	B	S	21	B	SSW	10	B
21	3	31	14	233	SSE	23	751	451	A	57	SSE	14	840	504	B	SSW	33	B	S	28	B
22	3	17	14	227	S	20	580	362	A	82	SSW	14	400	241	B	S	26	B	S	21	B
23	3	9	14	227	SSE	6	839	520	A	11	N	16	518	328	B	SSE	28	B	NNW	11	B
24	3	29	14	225	S	24	640	388	A	280	S	26	375	228	B	S	25	B	S	30	C
25	9	9	16	222	SSE	34	361	197	C	98	SSE	44	369	204	C	S	30	C	S	41	C
26	7	22	15	217	SSE	43	626	369	A	120	SSE	34	609	359	B	SSW	39	B	SSW	33	B
27	3	2	16	216	SSE	31	356	181	C	169	S	25	772	450	B	SSW	30	C	SSW	30	B
28	6	13	13	215	SSE	44	632	374	A	154	SSE	41	472	280	C	S	40	B	S	33	C
29	10	21	16	214	SSE	23	364	195	A	337	SSE	26	478	267	B	S	24	B	S	24	B
30	3	9	17	213	SE	27	343	224	A	106	SSE	48	559	341	B	S	30	C	S	46	B
31	3	31	15	213	SSE	26	601	350	A	233	SSE	23	751	451	B	S	38	B	SSW	33	B
32	7	13	16	212	SSE	29	333	192	A	92	SSE	41	546	324	B	S	26	B	S	34	B
33	9	4	14	210	S	23	434	248	A	181	S	31	670	395	B	S	22	B	SSW	28	B
34	8	23	14	209	SSE	38	403	226	C	206	SSE	43	734	420	B	S	32	C	S	33	B
35	4	1	14	208	SSE	47	782	480	A	126	SSE	27	901	564	B	S	47	B	SSW	33	B
36	9	22	16	208	S	27	556	313	A	97	SSE	33	659	383	B	S	30	A	SSW	33	B
37	8	23	13	206	SSE	43	734	420	A	164	SSE	44	713	414	B	S	35	B	S	38	B
38	7	2	17	205	SSE	48	270	145	C	197	S	51	386	342	C	S	45	C	S	43	B
39	3	10	12	200	S	26	540	319	A	163	S	22	229	120	C	SSW	22	B	S	27	C
40	3	29	16	200	SSE	28	343	348	A	62	S	27	463	273	B	SSW	32	B	SSW	29	B
41	7	21	12	200	S	44	759	454	A	248	SSE	38	658	394	B	SSW	40	B	SSW	34	B
42	2	26	18	200	SE	12	140	60	C	316	S	29	483	252	B	ENE	15	C	SSW	37	C
43	3	28	15	200	SE	26	651	377	A	317	SSE	28	676	390	B	ESE	20	B	S	31	B
44	4	24	14	198	****	****	551	308	****	245	****	****	872	490	****	S	30	B	S	33	B
45	8	5	15	198	S	38	654	381	A	268	SSE	36	749	430	B	S	33	B	S	36	B
46	8	5	13	193	S	32	709	410	A	142	SSE	33	598	341	B	S	33	B	S	31	B
47	7	2	16	192	S	31	346	342	C	154	SSE	44	677	392	B	S	43	B	S	45	B
48	9	4	12	190	SSE	36	803	480	A	121	SSE	36	740	442	B	SSW	35	B	S	33	B
49	9	4	16	190	SSE	39	247	135	C	113	SSE	38	544	320	B	S	36	C	SSW	32	B
50	9	20	15	190	SSE	48	375	213	C	17	S	47	310	181	C	S	44	C	SSW	44	C

Table IV-2-7 The highest 50 hours of SO_2 and meteorological conditions (d)

(4) BOON LAY APARTMENT

	Date		Hour	SO_2 concentration and meteorological conditions												Meteorological conditions at the representative station					
				Conditions at the highest 50 hours						Conditions one hour before						At the highest hour			One hour before		
				SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST	WD	WV (0.1m/s)	ST
1	4	21	11	197	W	6	620	352	A	31	NNW	6	392	222	A	SW	8	A	NW	8	A
2	3	1	9	193	N	14	198	100	C	119	NNE	6	29	-10	DEN	N	29	C	E	18	DEN
3	12	8	7	167	NNE	6	24	-10	F	28	C	4	0	-30	CD	N	24	E	N	23	F
4	1	22	18	167	C	1	64	8	CCEN	33	C	2	143	60	CCEN	SW	23	DEN	SW	29	C
5	1	22	19	154	C	0	76	-26	CCDN	167	C	1	64	8	CCEN	WSW	7	E	SW	23	DEN
6	11	9	16	142	SSW	7	315	159	A	93	SW	11	373	205	B	SW	38	C	SW	37	C
7	1	14	8	142	N	7	21	-28	DEN	74	C	3	0	-48	CD	N	18	DEN	N	25	F
8	4	21	12	137	SW	6	319	200	A	197	W	6	620	352	A	S	21	B	SW	8	A
9	10	10	14	132	SW	11	813	468	A	68	WSW	11	826	490	B	SW	36	B	SSW	35	B
10	2	13	12	128	NNE	16	460	278	A	83	NNE	16	393	233	B	NNE	29	B	N	29	B
11	10	6	13	126	SW	8	184	86	A	52	WNW	8	469	269	A	SSW	31	C	WSW	33	C
12	10	29	15	126	SSW	11	****	****	****	97	SW	11	****	****	****	SW	43	****	SSW	38	****
13	4	27	11	125	NW	10	457	378	A	38	N	8	433	240	A	S	19	B	SW	17	B
14	3	1	11	123	N	16	630	361	A	31	N	19	383	214	B	N	26	B	N	30	C
15	10	29	18	122	C	3	98	26	CCEN	40	SSW	9	322	156	A	SW	25	DEN	SW	25	B
16	9	13	11	120	WSW	8	579	331	A	63	W	13	310	175	B	SW	41	B	SW	33	C
17	3	1	8	119	NNE	6	79	-10	DEN	14	C	3	0	-33	CD	E	18	DEN	SSW	44	E
18	8	2	13	118	C	4	298	174	CA	11	C	4	220	128	CCEN	****	****	****	****	****	****
19	8	2	14	116	ESE	5	725	459	A	118	C	4	298	174	CB	****	****	****	****	****	****
20	4	13	11	115	N	8	457	389	A	48	N	10	447	153	B	NNW	23	B	N	22	B
21	6	17	15	114	WSW	8	518	310	A	44	WSW	10	560	338	B	S	28	B	S	28	B
22	9	18	12	110	SW	8	631	379	A	107	WSW	9	646	381	A	SSW	32	B	SW	24	B
23	5	9	11	108	WNW	10	510	189	A	104	NW	7	199	121	B	SSW	36	C	SW	40	C
24	10	8	11	108	SSW	9	551	299	A	22	SSW	9	856	486	A	SSW	23	B	SW	34	B
25	9	18	11	107	WSW	9	446	381	A	33	WSW	10	486	289	B	SW	24	B	SSW	31	C
26	4	2	15	106	C	2	84	34	CCEN	20	SSE	6	61	20	DEN	SSE	22	DEN	S	36	DEN
27	10	21	11	106	WSW	9	408	384	A	73	W	11	662	395	B	SSW	24	B	SW	23	B
28	3	9	10	104	NW	7	149	121	A	13	C	2	182	84	CCEN	SW	40	C	N	8	B
29	10	16	17	104	SE	13	115	54	DEN	68	SSE	14	157	88	C	SE	43	DEN	SSE	48	C
30	1	13	11	103	NNE	22	595	337	A	27	N	21	560	195	B	NNE	30	C	N	38	C
31	9	18	14	102	SW	10	593	340	A	69	SSW	10	593	348	B	SW	38	B	SSW	30	B
32	10	29	16	102	SW	13	560	313	A	126	SSW	11	****	****	****	SW	38	B	SW	43	****
33	3	26	13	100	SW	10	810	461	A	61	SW	11	690	312	B	SW	44	B	SW	42	B
34	10	7	12	99	SSW	10	359	192	A	41	C	4	483	279	CB	SW	42	C	SW	30	C
35	10	16	13	99	SSW	8	355	203	A	57	SW	7	331	202	A	SSW	33	C	SSW	21	B
36	4	13	13	98	N	5	613	377	A	62	NNW	11	612	361	B	N	16	B	NNW	21	B
37	5	7	13	98	NNE	5	660	405	A	58	C	2	844	315	CA	SW	46	B	SW	49	B
38	6	17	16	98	SW	10	380	224	A	114	WSW	8	518	310	A	SSW	33	C	S	28	B
39	10	7	17	98	WSW	5	797	132	A	75	SW	7	307	265	A	S	20	B	S	23	B
40	10	30	10	98	S	6	627	373	A	46	SSE	7	411	240	A	SSE	24	B	S	32	C
41	10	29	14	97	SW	11	****	****	****	90	SW	8	****	****	****	SSW	38	****	S	28	****
42	4	25	13	95	S	8	287	160	A	47	S	9	264	140	A	S	17	B	S	13	B
43	9	12	8	95	NNE	6	136	63	A	67	C	2	16	-10	CCBN	NNE	12	C	NNE	13	E
44	11	9	13	95	SW	11	373	205	A	77	SSW	8	487	276	A	SW	37	C	SW	40	C
45	4	21	14	94	C	4	545	310	CA	65	SSE	5	382	205	A	SSW	23	B	S	23	B
46	4	27	13	94	W	16	578	330	A	73	NW	12	636	304	B	SW	43	B	SW	38	B
47	10	10	10	94	C	4	560	321	CA	65	C	4	327	180	CB	SSW	14	B	C	4	CB
48	4	27	13	92	NW	14	745	429	A	91	NNW	19	598	340	B	S	28	B	S	21	B
49	9	17	12	92	SW	7	450	271	A	54	WSW	7	354	243	A	S	26	B	S	27	B
50	10	10	11	92	WSW	7	561	333	A	94	C	4	560	321	CA	SSW	28	B	SSW	14	B

Table IV-2-7 The highest 50 hours of SO_2 and meteorological conditions (e)

(5) BUKIT TIMAH FIRE ST.

	Date		Hour	SO2 concentration and meteorological conditions												Meteorological conditions at the representative station					
				Conditions at the highest 50 hours						Conditions one hour before						At the highest hour			One hour before		
				SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST	WD	WV (0.1m/s)	ST
1	4	26	13	100	WNW	16	709	411	A	15	NW	16	643	371	B	WNW	16	B	NW	16	B
2	10	26	21	95	WNW	7	0	-29	F	50	W	7	0	-40	F	WNW	7	E	W	7	F
3	10	26	18	80	W	6	92	15	DEN	7	WNW	11	140	69	C	W	6	DEN	WNW	11	C
4	4	6	11	76	NE	11	420	250	A	31	NNW	13	511	299	B	NE	11	B	NNW	13	B
5	12	10	11	75	WNW	18	660	400	A	4	NW	17	539	308	B	WNW	18	B	NW	17	B
6	12	10	12	71	W	20	640	378	A	75	WNW	18	680	400	B	W	20	B	WNW	18	B
7	5	6	18	69	S	22	256	120	A	20	NW	10	437	240	B	S	22	B	NW	10	B
8	11	17	12	65	NW	19	539	324	A	50	NW	19	571	349	B	NW	19	B	NW	19	B
9	11	9	13	61	WSW	7	745	438	A	50	W	14	712	419	B	WSW	7	A	W	14	B
10	11	16	13	60	W	14	590	230	A	10	WNW	17	547	329	B	W	14	B	WNW	17	B
11	10	26	19	59	C	4	0	-37	CD	80	W	6	92	15	DEN	C	4	CD	W	6	DEN
12	11	4	8	57	W	9	****	49	****	25	W	10	****	-14	E	W	9	****	W	10	E
13	4	26	14	56	W	11	518	301	A	100	WNW	16	709	411	B	W	11	B	WNW	16	B
14	11	11	17	56	SE	27	275	140	A	13	SSW	7	364	207	A	SE	27	B	SSW	7	A
15	11	9	14	55	S	32	447	276	C	61	WSW	7	745	438	A	S	32	C	WSW	7	A
16	4	22	14	50	SSE	39	721	420	B	7	SSE	22	828	477	B	SSE	39	B	SSE	22	B
17	5	6	19	50	SW	20	38	-27	F	69	S	22	256	120	B	SW	20	E	S	22	B
18	5	8	12	50	E	18	****	****	****	22	NW	9	629	373	A	E	18	****	NW	9	A
19	10	26	20	50	W	7	0	-40	F	59	C	4	0	-37	CD	W	7	F	C	4	CD
20	10	31	8	50	W	12	****	41	****	31	W	11	****	-11	E	W	12	****	W	11	E
21	11	7	19	50	SSW	14	0	-56	F	27	S	25	93	7	DEN	SSW	14	F	S	25	DEN
22	11	9	12	50	W	14	712	419	B	21	W	16	548	319	B	W	14	B	W	16	B
23	11	11	13	50	WNW	18	373	195	A	22	WSW	10	530	321	B	WNW	18	B	WSW	10	B
24	11	14	10	50	W	16	418	241	A	20	W	18	216	116	C	W	16	B	W	18	C
25	11	17	11	50	NW	19	571	349	A	53	W	20	363	217	B	NW	19	B	W	20	B
26	12	5	11	50	W	11	344	200	A	47	W	10	163	82	C	W	11	B	W	10	C
27	4	18	10	49	NNW	8	247	150	A	23	NW	14	199	113	C	NNW	8	A	NW	14	C
28	8	24	20	49	WSW	15	0	-32	F	37	WSW	19	10	-34	F	WSW	15	F	WSW	19	F
29	9	14	12	49	WSW	18	644	405	A	25	W	16	402	241	B	WSW	18	B	W	16	B
30	9	29	20	49	WSW	7	0	-50	F	40	SW	10	0	-50	F	WSW	7	F	SW	10	F
31	11	4	9	49	S	13	****	164	****	57	W	9	****	49	****	S	13	****	W	9	****
32	11	5	5	49	WNW	11	****	-28	E	5	W	7	****	-27	E	WNW	11	E	W	7	E
33	4	22	15	48	S	47	745	422	A	50	SSE	39	721	420	B	S	47	B	SSE	39	B
34	5	31	10	48	C	1	355	183	CB	46	S	12	320	157	B	C	1	CB	S	12	B
35	5	31	14	48	SSE	42	751	451	A	39	SSE	38	840	504	B	SSE	42	B	SSE	38	B
36	5	6	20	47	SSW	15	0	-52	F	50	SW	20	38	-27	E	SSW	15	F	SW	20	E
37	11	4	10	47	SW	17	****	240	****	49	S	13	****	164	****	SW	17	****	S	13	****
38	12	5	10	47	W	10	163	82	C	33	W	12	263	144	B	W	10	C	W	12	B
39	11	17	16	46	SE	41	550	292	A	57	S	14	470	276	B	SE	41	B	S	14	B
40	5	25	13	46	WNW	16	861	506	A	27	WNW	13	531	305	B	WNW	16	B	WNW	13	B
41	5	31	9	46	S	12	320	157	A	26	SW	7	110	20	DEN	S	12	B	SW	7	DEN
42	11	7	14	45	S	35	831	480	A	36	S	33	863	505	B	S	35	B	S	33	B
43	11	14	11	45	WNW	15	575	311	A	50	W	16	418	241	B	WNW	15	B	W	16	B
44	9	10	21	44	W	10	0	-39	F	22	W	9	0	-40	F	W	10	F	W	9	F
45	9	19	21	44	SW	11	0	-38	F	35	WSW	8	0	-39	F	SW	11	F	WSW	8	F
46	11	6	20	44	SSW	9	****	-35	F	39	SW	9	****	-36	F	SSW	9	F	SW	9	F
47	4	25	14	43	ESE	33	877	502	A	20	SE	26	812	441	B	ESE	33	B	SE	26	B
48	11	20	13	43	SSW	37	698	421	A	24	SSW	28	661	406	B	SSW	37	B	SSW	28	B
49	5	31	15	43	SSE	37	801	550	A	48	SSE	42	751	451	B	SSE	37	B	SSE	42	B
50	11	7	12	42	SSW	20	820	488	A	32	SW	19	627	379	B	SSW	20	B	SW	19	B

Table IV-2-7 The highest 50 hours of SO_2 and meteorological conditions (f)

(6) CHANGI AIRPORT

	Date		Hour	SO2 concentration and meteorological conditions												Meteorological conditions at the representative station					
				Conditions at the highest 50 hours						Conditions one hour before						At the highest hour			One hour before		
				SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST	WD	WV (0.1m/s)	ST
1	3	8	17	94	C	4	179	83	CCEN	56	SSW	10	158	62	C	E	27	C	E	24	C
2	11	4	19	90	SW	5	****	-27	F	60	SW	11	****	15	****	WSW	11	E	W	15	****
3	4	27	11	85	C	4	457	378	CA	28	SW	8	433	240	A	WNW	9	A	SW	10	B
4	3	8	10	68	WNW	13	269	149	B	17	WNW	10	173	75	C	W	16	B	W	13	C
5	3	31	12	67	SSW	8	882	396	A	58	C	4	448	295	CB	S	14	B	C	3	CB
6	4	22	14	61	SSW	16	771	420	B	29	SSE	11	828	477	B	SSE	39	B	SSE	22	B
7	11	4	18	60	SW	11	****	15	****	46	SW	10	****	116	****	W	15	****	W	13	****
8	3	31	13	60	S	12	840	504	A	67	SSW	8	662	396	A	SSE	38	B	S	14	B
9	3	31	11	58	C	4	448	255	CA	44	C	4	355	185	CB	C	3	CB	C	1	CB
10	4	23	13	57	S	12	812	441	B	38	SSE	9	747	423	A	SE	26	B	W	14	B
11	9	29	20	56	WSW	5	0	-50	F	39	SW	10	0	-50	F	WSW	7	F	SW	10	F
12	3	8	16	56	SSW	10	138	62	C	28	SW	15	208	103	C	E	24	C	S	15	C
13	11	9	13	53	S	13	745	438	A	26	NW	8	712	419	A	WSW	7	A	W	14	B
14	11	4	20	52	N	18	****	-34	F	90	SW	5	****	-27	E	WSW	5	F	WSW	12	E
15	3	31	16	52	SSW	15	405	346	A	44	SSW	14	601	350	B	SSE	24	B	SSE	37	B
16	3	8	11	51	NW	12	169	90	C	68	WNW	13	269	149	B	WNW	14	C	W	16	B
17	3	8	14	51	WSW	11	420	248	A	27	SW	6	393	228	A	WNW	10	B	W	10	B
18	9	19	20	50	C	4	0	-39	CD	45	C	4	0	-34	CD	WSW	8	F	SW	7	F
19	11	4	16	50	WSW	16	****	90	****	46	SW	11	****	124	****	NW	10	****	NNW	14	****
20	11	7	11	50	SSW	14	477	379	A	26	W	10	652	388	B	SW	19	B	WSW	19	B
21	11	7	14	50	SSW	18	831	480	A	46	SSW	17	863	505	B	S	35	B	S	33	B
22	11	7	18	50	SSW	11	95	7	DEN	35	SW	14	336	149	B	S	25	DEN	S	28	B
23	11	7	19	50	SW	7	0	-56	F	50	SSW	11	93	7	DEN	SSW	14	F	S	25	DEN
24	11	6	19	49	C	4	****	-36	CD	41	SSW	8	****	-3	****	SW	9	F	S	18	****
25	11	17	13	49	SSW	15	470	276	A	22	C	4	636	380	CA	S	14	B	WNW	16	B
26	11	25	13	49	SSW	10	552	327	A	39	C	3	423	260	CB	NNE	7	A	WNW	10	B
27	11	4	12	48	WSW	9	****	327	****	21	SW	15	****	241	****	WSW	5	****	WSW	9	****
28	11	4	13	48	SW	11	****	124	****	21	WSW	8	****	166	****	NNW	14	****	NNW	25	****
29	11	11	17	48	SW	15	275	140	A	39	SSW	12	364	207	B	SE	27	B	SSW	7	A
30	11	16	14	48	WNW	12	249	175	A	32	WNW	15	390	230	B	W	13	B	W	14	B
31	11	23	17	47	SW	10	172	52	DEN	46	SW	13	161	77	C	WSW	10	DEN	WSW	22	C
32	3	31	17	47	SSW	13	430	227	A	52	SSW	15	605	346	B	NNE	20	B	SSE	24	B
33	9	28	12	46	SSW	16	637	369	A	31	SSW	13	451	257	B	NW	13	B	NW	12	B
34	9	28	13	46	SSW	18	771	449	A	46	SSW	16	637	369	B	NW	14	B	NW	13	B
35	11	4	17	46	SW	10	****	116	****	30	WSW	16	****	90	****	W	13	****	NW	10	****
36	11	7	13	46	SSW	17	865	505	A	42	SW	14	820	488	B	S	33	B	SSW	20	B
37	11	23	16	46	SW	13	161	77	C	42	SW	15	220	123	C	WSW	22	C	SW	24	C
38	3	8	12	46	C	4	378	191	CA	51	NW	12	169	90	C	WNW	8	A	WNW	14	C
39	3	30	15	46	SSW	15	790	465	A	42	S	12	881	516	B	SSE	44	B	SSE	29	B
40	3	31	18	46	SW	5	228	108	A	47	SSW	13	430	227	B	NNE	19	C	NNE	20	B
41	4	23	14	45	S	14	877	502	A	57	S	12	812	441	B	ESE	33	B	SE	26	B
42	5	26	11	45	N	5	480	281	A	24	C	3	351	193	CB	NW	13	B	NW	9	A
43	9	19	19	45	C	4	0	-34	CD	24	SW	6	40	-9	DEN	SW	7	F	C	2	CCEN
44	11	3	15	45	SW	18	****	160	****	43	SW	20	****	201	****	NNW	15	****	NNW	18	****
45	11	26	14	44	WNW	12	288	161	A	34	NW	18	380	225	B	WNW	15	B	W	19	B
46	3	31	10	44	C	4	355	185	CA	30	WSW	5	320	157	A	C	1	CB	S	12	B
47	3	31	15	44	SSW	14	601	350	A	26	SSW	12	751	451	B	SSE	37	B	SSE	42	B
48	11	3	14	43	SW	20	****	201	****	40	SW	19	****	269	****	NNW	18	****	NW	6	****
49	9	29	21	42	C	4	0	-53	CD	56	WSW	5	0	-50	F	W	5	F	WSW	7	F
50	10	28	18	42	SSW	11	102	14	DEN	30	SW	16	354	167	B	WSW	9	DEN	SW	22	B

Table IV-2-7 The highest 50 hours of SO_2 and meteorological conditions (g)

(7) BEDIO-POLICE STATION

From the table, frequency occurrence of hours of highest fifty samples are calculated and shown in Table IV-2-8. It is clear that the high SO_2 concentration occurs mostly in daytime between 10 to 18 Singapore Time.

Table IV-2-8 Frequency distribution of hours of the highest 50 samples

Time	Hours of occurrence							
	MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-7	Total
1								
2								
3						1		1
4								
5	1	1						2
6		2	1					3
7	2				1			3
8					3	2		5
9	1	1			1	2		5
10	7	3	2		3	5	2	22
11	10	8	5	2	11	5	5	46
12	5	9	6	4	5	6	4	39
13	3	5	10	5	5	6	6	40
14	3	7	7	12	5	6	7	47
15	3	4	7	8	8	2	5	37
16	3	3	7	10	3	1	4	31
17	2	4	3	5	2	1	5	22
18	3	3	1	4	2	2	4	19
19	4		1		1	3	4	13
20						5	3	8
21	1					3	1	5
22	1							1
23								
24	1							1

The dependence of hourly high concentration on wind direction was also examined and shown in Table IV-2-9, where the wind direction is at the representative station. From the table, it is clear that except MP-6 and MP-7, the high concentration occurs when the wind is from some regulated directions proper to the stations.

The most frequent wind directions are, W at MP-1, SW at MP-2, S at MP-3 and MP-4, SW at MP-5, W at MP-6 and WSW at MP-7. Especially at MP-2, MP-3 and MP-4, the wind direction is very regulated and more than fifty percent of high concentration occurs at one direction. From these wind directions, we can estimate the direction of sources which are most responsible to the high concentration of each station.

Table IV-2-9 Dependence of hourly high concentration on wind directions

Unit (%)

Wind direction	Frequency of each wind direction at the representative stations		Hours of occurrence						
	MP-2	MP-6	MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-7
CALM	1.7	4.1	4		4			4	4
N	12.4	11.3	14				10		
NNE	17.7	8.2	6	6			6		6
NE	9.0	1.3						2	
ENE	2.7	1.2	2			2			
E	2.5	1.9		2	2		2	2	4
ESE	4.8	4.7	2			2		2	2
SE	5.8	9.3	2		6		2	4	4
SSE	6.6	8.5	4		14	2	4	6	10
S	7.9	8.1		6	53	68	15	12	10
SSW	5.0	4.4	4	27	16	26	23	10	2
SW	3.8	3.0	4	50	2		33	6	6
WSW	2.3	4.2	16	4			2	8	18
W	3.3	5.8	34	4	2			24	10
WNW	2.9	7.0	2					14	10
NW	4.1	6.8	2					4	18
NNW	7.5	10.2	4				2	2	6

Table IV-2-10 Frequency distribution of hourly high concentration of stability categories

Unit (%)

Stability categories	Frequency of total wind direction at the representative stations		Hours of occurrence						
	MP-2	MP-6	MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-7
CA	0.02	0.01							
CB	0.2	0.1	4					2	5
CCd	0.5	0.6			2				
CCn	0.6	1.6							
CD	0.5	1.8						2	
A	0.8	0.9	2	2	2		2	4	9
B	17.1	16.5	50	74	87	75	57	60	49
C	14.8	14.4	15	12	3	25	24	4	12
Dd	11.7	12.7	8	5			13	2	7
Dn	4.1	3.2	4						
E	23.9	23.1	10		2		4	7	2
F	25.8	25.2	6	7	2			18	16

Occurrence frequency of hourly high concentration for each stability category was also studied and shown in Table IV-2-10. For the stability classification, wind velocity at MP-2 or MP-6 and solar radiation and net radiation flux at MP-2 are used. From the table, very high frequency of stability category "B" is clearly seen, even though the total frequency of B is less than 17 percent.

However, it does not mean that under stability condition of A, high concentration does not occur, since the total frequency of "A" is quite low.

(2) High concentration of daily averages

Here we discuss the high values of daily average concentration. The highest 20 days (5% of total days) of daily average concentrations are listed in Table IV-2-11, for seven stations. The highest values change widely by station to station and range between 21.5 ppb to 73.3 ppb. The highest daily averages at east side stations (MP-6 and MP-7) are less than half of that of western stations.

The monthly frequency of daily high concentration are shown in Table IV-2-12. Except stations MP-3 and MP-4, high daily concentration occurs from March to May and September to November, but at the two stations occurrences in May to August are frequent. These frequency distributions are very similar to the monthly change of average concentration, i.e., monthly averages are high for the months when daily high concentrations were frequently recorded.

Table IV-2-11 The highest 20 days of daily averaged SO_2 concentration

	MP-1		MP-2		MP-3		MP-4		MP-5		MP-6		MP-7	
	Date	Daily average (ppb)	Date	Daily average (ppb)	Date	Daily average (ppb)	Date	Daily average (ppb)	Date	Daily average (ppb)	Date	Daily average (ppb)	Date	Daily average (ppb)
1	11/25	37.6	10/29	47.7	4/24	73.3	9/4	61.7	10/29	43.0	5/8	21.5	3/8	26.9
2	4/6	37.2	10/11	44.8	5/12	69.2	5/2	60.4	3/1	38.3	11/3	20.3	3/31	25.9
3	11/7	36.3	9/18	42.3	8/20	50.3	10/30	55.1	1/14	38.3	11/7	19.6	11/7	25.7
4	11/27	36.1	10/10	38.5	8/19	48.5	7/21	54.7	10/10	37.8	3/31	19.4	11/4	24.9
5	11/20	34.7	4/21	35.8	2/4	44.4	2/5	54.4	4/21	36.8	11/17	19.1	11/3	20.6
6	11/10	32.8	10/31	33.7	9/23	44.3	9/23	53.7	1/22	36.7	4/26	18.1	4/23	20.4
7	3/19	32.4	10/16	32.3	8/18	43.7	8/5	53.5	5/7	35.8	11/4	18.0	11/23	18.1
8	12/8	32.1	10/12	31.3	2/3	43.4	2/26	52.5	9/18	35.7	10/26	17.8	4/27	17.3
9	9/27	31.7	5/6	30.0	5/4	42.5	5/10	52.4	11/9	34.2	5/7	17.4	5/26	16.9
10	3/24	31.3	9/29	29.6	4/23	42.4	8/3	52.4	4/27	33.8	4/22	17.1	11/10	16.8
11	4/5	30.5	9/10	28.6	6/11	40.8	5/29	51.2	5/6	33.6	4/6	16.6	9/25	16.7
12	3/25	30.4	9/28	28.2	10/21	40.8	6/2	51.1	9/15	32.6	4/18	16.2	11/5	16.7
13	11/4	30.3	1/13	28.0	10/20	40.5	8/25	50.7	3/31	32.3	4/5	16.2	11/25	16.5
14	11/17	30.0	5/26	27.9	9/17	40.4	3/13	47.6	10/11	32.2	11/9	16.2	11/6	16.2
15	11/3	29.0	11/20	27.6	6/18	40.3	7/31	46.6	10/30	31.7	11/10	16.1	9/29	16.2
16	11/11	28.5	11/5	27.1	6/8	40.3	7/15	46.3	12/8	31.3	4/27	15.8	11/2	16.0
17	11/23	28.2	11/2	26.9	8/5	40.0	5/3	46.2	4/30	30.8	3/8	15.1	11/17	15.9
18	9/25	28.0	5/8	26.8	6/1	39.9	7/22	45.0	10/16	30.6	5/6	14.9	3/25	15.9
19	3/31	27.3	4/30	26.5	4/1	39.7	10/8	44.8	9/17	30.5	11/11	14.6	3/30	15.9
20	5/26	27.3	6/17	26.3	5/14	39.5	10/4	44.6	6/17	30.1	9/17	14.3	12/1	15.7

Table IV-2-12 Monthly distribution of daily high concentrations

Month	Frequency occurrence of highest 20 days							
	MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-7	Total
1		1			2			3
2			2	2				4
3	4			1	2	2	4	13
4	2	2	3		3	6	2	18
5	1	3	3	4	2	3	1	17
6	2	1	4	1	1			9
7				4				4
8			4	3				7
9		4	2	2	3	1	2	14
10		6	2	3	5	1		17
11	10	3			1	7	10	31
12	1				1		1	3

In Tables IV-2-13, concentrations and meteorological informations of the highest two days at seven stations are listed for the reference.

Table IV-2-13 Hourly SO_2 concentration and meteorological conditions of highest two days of daily averages (a)

(1) N.U.S. November 25th SO_2 daily average : 37.6 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	18	C	1	0	-29	CC3N	WNW	15	E
2	14	C	1	0	-30	CD	N	12	F
3	12	C	2	0	-30	CD	N	14	F
4	11	C	3	0	-30	CD	N	17	F
5	12	C	3	0	-39	CD	NNE	12	F
6	34	C	1	0	-38	CD	NNE	13	F
7	23	C	1	10	-20	CC3N	NNW	17	E
8	22	NW	9	85	30	DtN	NNW	20	DtN
9	16	NW	17	310	179	H	NW	21	B
10	11	WNW	18	582	348	A	NW	27	B
11	22	W	12	616	370	H	NW	15	B
12	128	W	12	423	260	A	C	4	CB
13	102	WSW	14	532	327	H	SW	20	A
14	97	W	12	444	267	B	W	29	B
15	39	WSW	10	451	268	B	WNW	16	B
16	54	NNW	5	231	130	B	N	23	C
17	19	NE	14	99	42	DtN	NNE	35	DtN
18	43	NE	13	48	6	DtN	N	33	DtN
19	88	NNE	9	0	-23	E	N	21	E
20	52	N	6	0	-23	F	N	17	E
21	28	C	4	0	-27	CC3N	N	16	E
22	19	C	4	0	-24	CC3N	NNW	18	E
23	20	C	3	0	-23	CC3N	N	14	E
24	19	C	2	0	-27	CC3N	N	17	E

Note:
WD: Wind direction
WV: Wind velocity
Q_H: Solar radiation
Q_N: Net radiation flux
ST: Atmospheric stability

(1) N.U.S. April 6th SO_2 daily average : 37.2 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	16	C	1	0	-19	CC3N	NW	9	E
2	14	C	1	0	-19	CC3N	NNW	12	E
3	15	C	1	0	-20	CC3N	WNW	12	E
4	16	C	0	0	-19	CC3N	NW	12	E
5	92	C	0	0	-19	CC3N	NNW	15	E
6	11	C	0	0	-20	CC3N	NNW	16	E
7	24	C	2	1	-15	CC3N	N	12	E
8	21	C	2	66	28	CCtN	NE	13	DtN
9	32	C	1	329	80	CB	N	13	B
10	48	C	4	511	299	CA	NNW	11	B
11	50	C	4	420	250	CB	C	4	CB
12	50	SSE	10	174	100	C	S	21	C
13	67	NW	10	239	140	C	SE	21	C
14	****	WSW	9	460	282	A	WSW	23	B
15	50	SSW	14	729	452	B	SSW	33	B
16	39	SSE	14	450	251	B	S	39	C
17	38	S	11	309	163	B	S	30	C
18	53	S	9	129	49	DtN	S	20	DtN
19	43	C	2	4	-23	CC3N	C	4	CC3N
20	40	NE	5	0	-32	F	N	21	F
21	33	C	2	0	-36	CD	N	14	F
22	38	C	1	0	-38	CD	NNW	11	F
23	37	C	1	0	-32	CD	N	11	F
24	29	C	1	0	-33	CD	N	13	F

Table IV-2-13 Hourly SO_2 concentration and meteorological conditions of highest two days of daily averages (b)

(2) J.T.C. HALL October 29th SO_2 daily average: 47.7 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	QH (0.1 cal/cm²/h)	QN	ST	WD	WV (0.1m/s)	ST
1	13	N	15	6	-25	E	N	15	E
2	15	N	14	15	-27	F	N	14	E
3	23	N	14	3	-27	E	N	14	E
4	20	N	13	1	-26	F	N	13	E
5	12	NE	14	2	-37	F	NE	14	F
6	6	SSE	37	2	-37	F	SSE	37	E
7	3	S	44	2	-33	E	S	44	E
8	24	WSW	26	96	34	DtN	WSW	26	DtN
9	26	WSW	35	269	127	C	WSW	35	C
10	23	SW	37	****	****	****	SW	37	****
11	7	S	31	****	****	****	S	31	****
12	66	SSW	35	****	****	****	SSW	35	****
13	82	S	28	****	****	****	S	28	****
14	115	SSW	38	****	****	****	SSW	38	****
15	182	SW	43	****	****	****	SW	43	****
16	79	SW	38	560	313	B	SW	38	B
17	85	SW	25	322	156	B	SW	25	B
18	183	SW	25	98	26	DtN	SW	25	DtN
19	26	SW	22	0	-44	F	SW	22	F
20	48	WSW	18	0	-45	F	WSW	18	F
21	43	WSW	11	0	-45	F	WSW	11	F
22	29	W	7	1	-40	F	W	7	F
23	16	NNW	9	2	-39	F	NNW	9	F
24	16	N	8	0	-36	F	N	8	F

(2) J.T.C. HALL October 11th SO_2 daily average: 44.8 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	QH (0.1 cal/cm²/h)	QN	ST	WD	WV (0.1m/s)	ST
1	12	N	10	0	-23	E	N	10	E
2	45	W	31	0	-16	D3N	W	31	D3N
3	15	SE	16	1	-22	E	SE	16	E
4	9	C	1	2	-27	CC3N	C	1	CC3N
5	26	NNW	6	0	-33	F	NNW	6	F
6	17	NNW	11	0	-24	E	NNW	11	E
7	14	NNW	9	5	-30	F	NNW	9	F
8	16	ESE	6	89	28	DtN	ESE	6	DtN
9	24	SW	30	164	94	C	SW	30	C
10	71	SW	25	662	395	B	SW	25	B
11	150	SSW	24	608	384	B	SSW	24	B
12	82	SSW	28	721	443	B	SSW	28	B
13	93	SW	21	536	323	B	SW	21	B
14	82	SW	36	716	427	B	SW	36	B
15	63	SW	41	681	403	B	SW	41	B
16	70	SW	48	380	207	C	SW	48	C
17	83	SW	40	224	111	C	SW	40	C
18	77	SW	27	96	21	DtN	SW	27	DtN
19	55	WSW	23	0	-37	F	WSW	23	F
20	16	W	18	0	-28	E	W	18	E
21	27	SW	18	0	-36	F	SW	18	F
22	9	SSW	24	0	-35	F	SSW	24	F
23	7	SSW	19	2	-36	F	SSW	19	F
24	12	SW	16	0	-36	F	SW	16	F

Table IV-2-13 Hourly SO_2 concentration and meteorological conditions of highest two days of daily averages (c)

(3) S.I.U. April 24th SO_2 daily average : 73.3 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	37	****	****	0	-42	****	NE	10	F
2	36	****	****	0	-42	****	N	13	F
3	43	****	****	0	-40	****	NNW	16	F
4	30	****	****	0	-39	****	N	12	F
5	12	****	****	0	-32	****	N	15	F
6	13	****	****	0	-26	****	NNE	10	E
7	28	****	****	0	-20	****	N	10	E
8	60	****	****	53	20	****	NNW	8	Dtv
9	99	****	****	239	118	****	NNE	5	B
10	302	****	****	371	202	****	SE	8	A
11	104	****	****	641	360	****	SSE	24	B
12	228	****	****	781	436	****	S	27	B
13	370	****	****	872	490	****	S	33	B
14	149	****	****	551	308	****	S	30	B
15	29	****	****	142	71	****	W	16	C
16	24	****	****	15	0	****	ENE	18	Dtv
17	20	****	****	28	0	****	E	17	Dtv
18	29	****	****	21	-2	****	ENE	14	Dtv
19	33	****	****	1	-21	****	NE	18	E
20	20	****	****	0	-28	****	NE	16	E
21	27	****	****	0	-22	****	NNE	15	E
22	30	****	****	0	-21	****	NNE	13	E
23	21	****	****	0	-21	****	NE	18	E
24	14	****	****	0	-22	****	NE	18	E

(3) S.I.U. May 12th SO_2 daily average : 69.2 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	18	****	****	0	-38	****	ESE	18	F
2	28	****	****	0	-30	****	SE	19	F
3	33	****	****	0	-22	****	SE	19	E
4	25	****	****	0	-22	****	ESE	15	E
5	18	****	****	0	-20	****	N	12	E
6	9	****	****	0	-20	****	N	12	E
7	19	****	****	0	-20	****	N	15	E
8	31	****	****	48	18	****	NNE	12	Dtv
9	62	****	****	213	117	****	NE	10	C
10	40	****	****	289	163	****	ESE	23	B
11	45	****	****	588	358	****	SE	26	B
12	53	****	****	540	330	****	S	35	B
13	242	****	****	582	357	****	SSE	36	B
14	477	****	****	738	458	****	S	34	B
15	212	****	****	660	411	****	S	49	B
16	105	****	****	637	381	****	S	43	B
17	44	****	****	402	230	****	SE	35	C
18	32	****	****	88	24	****	SE	30	Dtv
19	41	****	****	42	-8	****	ESE	20	E
20	25	****	****	0	-37	****	ENE	16	F
21	20	****	****	0	-39	****	E	14	F
22	35	****	****	0	-34	****	SE	19	F
23	30	****	****	0	-30	****	E	12	F
24	17	****	****	0	-38	****	E	17	F

Table IV-2-13 Hourly SO_2 concentration and meteorological conditions of highest two days of daily averages (d)

(4) BOON LAY APARTMENT September 4th SO_2 daily average : 61.7 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	28	S	9	0	-44	F	SSW	21	F
2	40	SSW	6	0	-49	F	SSW	16	F
3	24	NNW	5	0	-51	F	WSW	6	F
4	6	N	12	0	-52	F	NNW	11	F
5	4	N	17	0	-44	F	N	15	F
6	****	NNW	12	0	-31	F	N	13	F
7	****	NNW	8	7	-23	E	N	11	E
8	****	C	3	156	66	CCtN	N	6	B
9	29	SE	12	443	254	A	S	9	A
10	84	SSE	31	572	339	B	S	30	B
11	121	SSE	36	740	442	A	S	35	B
12	190	SSE	36	803	480	A	SSW	35	B
13	181	S	31	670	395	A	SSW	28	B
14	210	S	25	434	248	A	S	22	B
15	113	SSE	38	544	320	B	SSW	32	B
16	190	SSE	39	247	135	C	S	36	C
17	29	SE	45	180	79	C	SSE	34	C
18	9	ESE	38	94	17	DtN	SE	40	DtN
19	7	SE	31	4	-44	F	SSE	28	F
20	7	ESE	28	0	-43	F	SE	25	F
21	6	ESE	25	0	-42	F	SE	22	F
22	6	ESE	25	0	-48	F	SE	24	F
23	5	E	29	0	-50	F	SE	24	F
24	6	E	21	0	-44	F	E	14	F

(4) BOON LAY APARTMENT May 2nd SO_2 daily average : 60.4 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	7	WSW	57	0	-30	D3N	WSW	46	E
2	3	WSW	41	0	-30	E	WSW	29	F
3	2	SW	35	0	-31	E	WSW	30	E
4	10	SSW	25	0	-30	F	SW	31	E
5	14	SSW	13	0	-33	F	SSW	21	F
6	17	S	6	0	-30	F	SSW	16	F
7	13	C	3	0	-32	CD	S	9	F
8	7	NNW	11	21	-22	DtN	NNW	10	DtN
9	10	C	4	169	69	CCtN	C	4	CCtN
10	11	S	20	390	212	B	SSW	24	B
11	81	S	26	604	348	B	SSW	25	B
12	250	S	25	759	428	B	S	26	B
13	140	S	24	809	445	B	SSW	22	B
14	241	SSE	22	749	415	B	SSW	21	B
15	169	S	25	772	450	B	SSW	30	B
16	216	SSE	31	356	181	C	SSW	30	C
17	99	SSE	26	160	65	C	S	25	C
18	33	SE	23	244	103	C	S	18	C
19	39	SE	13	69	-10	E	S	18	E
20	14	SSE	13	0	-41	F	S	15	F
21	24	SSE	17	0	-40	F	SSE	18	F
22	17	SSE	20	0	-41	F	SSE	25	F
23	13	SSE	20	0	-41	F	SSE	20	F
24	19	SSE	14	0	-41	F	S	16	F

Table IV-2-13 Hourly SO_2 concentration and meteorological conditions of highest two days of daily averages (e)

(5) BUKIT TIMAH FIRE ST. October 29th SO_2 daily average : 43.0 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST
1	24	NW	8	6	-25	F	N	15	E
2	22	NNW	6	15	-27	F	N	14	E
3	15	C	3	3	-27	CC3N	N	14	E
4	9	NNW	6	1	-28	F	N	13	E
5	5	C	2	2	-37	CO	NE	14	F
6	8	SSE	6	2	-37	F	SSE	37	E
7	20	SE	7	2	-33	F	S	44	E
8	20	NW	7	96	34	DtN	WSW	26	DtN
9	27	W	9	269	127	A	WSW	35	C
10	25	SSW	9	****	****	****	SW	37	****
11	29	S	9	****	****	****	S	31	****
12	32	SSW	8	****	****	****	SSW	35	****
13	90	SW	8	****	****	****	S	28	****
14	97	SW	11	****	****	****	SSW	38	****
15	126	SSW	11	****	****	****	SW	43	****
16	102	SW	13	560	313	A	SW	38	8
17	40	SSW	9	322	156	A	SW	25	B
18	122	C	3	98	26	CCtN	SW	25	DtN
19	91	C	1	0	-44	CO	SW	22	F
20	30	C	2	0	-45	CO	WSW	18	F
21	31	C	1	0	-45	CO	WSW	11	F
22	27	C	0	1	-40	CO	W	7	F
23	22	C	0	2	-39	CO	NNW	9	F
24	17	C	0	0	-38	CO	N	8	F

(6) BUKIT TIMAH FIRE ST. March 1st SO_2 daily average : 38.3 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N (0.1 cal/cm²/h)	ST	WD	WV (0.1m/s)	ST
1	10	NNE	5	0	-55	F	N	19	F
2	7	N	5	0	-50	F	NNE	30	E
3	6	C	4	0	-45	CO	N	35	E
4	11	C	4	0	-39	CO	N	23	F
5	11	C	4	0	-31	CO	NNW	20	F
6	10	C	3	0	-31	CO	ESE	5	F
7	14	C	3	0	-33	CO	SSW	44	E
8	119	NNE	6	29	-10	DtN	E	18	DtN
9	193	N	14	198	100	C	N	29	C
10	31	N	19	383	214	B	N	30	C
11	123	N	16	630	361	B	N	26	B
12	91	NNW	10	718	419	B	N	17	B
13	33	NNW	7	501	298	A	N	19	B
14	29	WSW	9	762	448	A	N	23	B
15	45	S	5	133	69	B	NNW	18	C
16	17	NE	17	22	7	DtN	N	21	DtN
17	21	C	1	35	11	CCtN	N	24	DtN
18	16	C	2	105	48	CCtN	NNE	9	DtN
19	68	C	4	35	2	CC3N	NNE	18	E
20	12	C	3	0	-29	CC3N	NE	18	E
21	12	C	1	0	-29	CC3N	ENE	22	E
22	11	C	1	0	-25	CC3N	ENE	14	E
23	10	C	3	0	-22	CC3N	NE	24	E
24	19	C	4	0	-23	CC3N	NE	36	D3N

Table IV-2-13 Hourly SO_2 concentration and meteorological conditions of highest two days of daily averages (f)

(6) CHANGI AIRPORT May 8th SO_2 daily average : 21.5 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	7	W	7	0	-25	E	W	7	E
2	11	WSW	20	0	-19	E	WSW	20	E
3	9	WSW	51	0	-20	D3N	WSW	51	D3N
4	7	WSW	42	0	-21	D3N	WSW	42	D3N
5	21	WSW	28	0	-29	E	WSW	28	E
6	36	WSW	16	0	-30	F	WSW	16	F
7	26	NW	5	0	-24	E	NW	5	E
8	19	NW	8	28	-11	DCN	NW	8	DCN
9	29	SW	10	209	100	C	SW	10	C
10	25	SW	10	458	260	B	SW	10	B
11	22	NW	9	629	373	A	NW	9	A
12	50	E	18	****	****	****	E	18	****
13	34	SSE	42	****	****	****	SSE	42	****
14	23	S	46	****	****	****	S	46	****
15	15	S	50	****	****	****	S	50	****
16	16	S	48	****	****	****	S	48	****
17	18	S	42	****	****	****	S	42	****
18	19	S	30	304	151	C	S	30	C
19	23	S	19	98	0	E	S	19	E
20	32	SSW	12	0	-42	F	SSW	12	F
21	28	SW	9	0	-43	F	SW	9	F
22	17	C	3	0	-40	CD	C	3	CD
23	16	W	10	0	-40	F	W	10	F
24	12	WNW	11	0	-40	F	WNW	11	F

(6) CHANGI AIRPORT November 3rd SO_2 daily average : 20.3 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	29	WSW	32	****	-29	D3N	WSW	32	D3N
2	39	SW	30	****	-24	D3N	SW	30	D3N
3	26	SW	30	****	-22	D3N	SW	30	D3N
4	30	SW	34	****	-17	D3N	SW	34	D3N
5	33	SW	36	****	-21	D3N	SW	36	D3N
6	33	SW	35	****	-19	D3N	SW	35	D3N
7	11	SW	34	****	-16	D3N	SW	34	D3N
8	14	SW	29	****	53	****	SW	29	****
9	24	SW	22	****	130	****	SW	22	****
10	37	SSW	22	****	238	****	SSW	22	****
11	29	SSW	19	****	251	****	SSW	19	****
12	28	SSW	11	****	314	****	SSW	11	****
13	37	NW	6	****	269	****	NW	6	****
14	10	NNW	18	****	201	****	NNW	18	****
15	5	NNW	15	****	160	****	NNW	15	****
16	4	NNW	18	****	113	****	NNW	18	****
17	4	NNW	17	****	40	****	NNW	17	****
18	11	WNW	15	****	-7	****	WNW	15	****
19	17	W	13	****	-20	E	W	13	E
20	28	WSW	13	****	-20	E	WSW	13	E
21	16	WSW	9	****	-22	E	WSW	9	E
22	9	WSW	10	****	-27	E	WSW	10	E
23	5	W	9	****	-23	E	W	9	E
24	7	W	8	****	-16	E	W	8	E

Table IV-2-13 Hourly SO_2 concentration and meteorological conditions of highest two days of daily averages (g)

(7) BEDOK POLICE STATION March 8th SO_2 daily average: 26.9 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	7	NW	10	0	-28	E	WNW	8	E
2	11	NW	13	0	-29	E	W	10	E
3	7	NW	9	0	-29	F	NW	9	E
4	6	NW	6	0	-28	E	NNW	6	E
5	6	NW	8	0	-28	F	W	7	E
6	6	NW	6	0	-32	F	W	12	F
7	14	NNW	7	0	-38	F	W	10	F
8	16	NW	13	22	-22	OLW	W	9	OLW
9	17	WNW	10	173	75	C	W	13	C
10	68	WNW	13	269	149	A	W	16	B
11	51	NW	12	169	90	C	WNW	14	C
12	46	C	4	328	191	CA	WNW	8	A
13	22	SW	6	393	228	A	W	10	B
14	51	WSW	11	420	248	B	WNW	10	B
15	28	SW	15	208	103	C	S	15	C
16	56	SSW	10	138	62	C	E	24	C
17	94	C	4	179	83	CCLW	E	27	C
18	40	SE	9	177	75	H	SE	23	C
19	28	ESE	12	70	5	F	E	26	E
20	21	ESE	14	0	-32	F	ESE	19	F
21	17	E	5	0	-40	F	ENE	20	F
22	12	NE	5	0	-30	F	NE	14	F
23	10	C	4	0	-26	CC3W	N	14	E
24	12	C	3	0	-27	CC3W	NW	6	E

(7) BEDOK POLICE STATION March 31st SO_2 daily average: 25.9 ppb

SST	SO_2 concentration and meteorological conditions						WD and WV at the representative station		
	SO_2 (ppb)	WD	WV (0.1m/s)	Q_H (0.1 cal/cm²/h)	Q_N	ST	WD	WV (0.1m/s)	ST
1	6	NNW	12	0	-48	F	NNW	8	F
2	5	NNW	11	0	-46	F	NW	6	F
3	6	NNW	8	0	-44	F	NNW	5	F
4	7	C	4	0	-40	CD	WNW	8	F
5	5	NNW	6	0	-32	F	W	13	F
6	4	NW	8	0	-20	E	SSW	15	E
7	7	WSW	11	1	-32	F	SW	11	F
8	13	SW	6	110	20	OLW	SW	7	OLW
9	30	WSW	5	320	157	A	S	12	B
10	44	C	4	355	185	CB	C	1	CB
11	58	C	4	448	255	CB	C	3	CB
12	67	SSW	8	662	396	A	S	14	B
13	60	S	12	840	504	B	SSE	38	B
14	26	SSW	12	751	451	B	SSE	42	B
15	44	SSW	14	601	350	B	SSE	37	B
16	52	SSW	15	605	346	B	SSE	24	B
17	47	SSW	13	430	227	B	NNE	20	B
18	46	SW	5	228	108	B	NNE	19	C
19	28	NE	11	30	-25	E	NNE	14	E
20	18	NE	11	0	-42	F	NE	14	F
21	15	NE	7	0	-47	F	NE	9	F
22	12	ENE	8	0	-45	F	NE	7	F
23	12	C	4	0	-45	CD	NNE	5	F
24	10	NNW	5	0	-44	F	N	9	F