CHAPTER 6 MEASUREMENT OF TEMPERATURE

Temperature itself is not directly concerned with atmospheric diffusion, but the vertical distribution of temperature near the ground is closely concerned with diffusion of pollutants. As described in CHAPTER 5, the atmospheric stability is obtained more accurately from the vertical distribution of temperature.

The long term monitoring of vertical distribution of temperature is usually carried out by installing thermometers at different heights of the high tower and detect the inversion layer occurred in the sphere near to the ground mostly at night time. In case the high tower is used for such measurement, the maximum height will be around 200 meters. In order to measure the vertical distribution of temperature at higher place exceeding 200 meters, the low layer sonde is used, equipped with wireless telemeter in the balloon, which makes measurement possible for the height of about 2 km from the ground. However this system costs much for long term monitoring.

In this study, the continuous monitoring has been conducted at MP-1, installing thermometers at 1.5, 10, and 40 meters from the ground, for measuring the inversion layer which might have occurred near the ground. Unfortunately the data for 40 m high could not be obtained and so the vertical distribution of temperature has been analyzed by 1.5 and 10 m data.

The measurement has been conducted for one year, from July 15th 1981 to July 14th 1982, installing nickel resistance thermometers which measured and recorded instantaneous values of temperature. The daily check of instruments have been conducted by JTC and the maintenance has been carried out by Japanese team once every 3 months.

II-6-1 Measuring Methods of Temperature

For meteorological observation of temperature, the glass thermometer has been used since long, but for obtaining the data of time series progress of temperature, the metal resistance self recording thermometer has been used. At present, nickel resistance and thermister thermometers have been developed and widely used.

The resistance thermometer indicates temperature by electrical signal which is converted and automatically recorded by recorder. The sensor is installed with ventilating device which supply the fresh air to the sensor and it is designed to be covered by shelter to avoid the impact from direct solar radiation.

II-6-2 Thermometer Used in This Study

The thermometer used in this study is nickel resistance thermometer which is widely used in environmental monitoring stations of Japan.

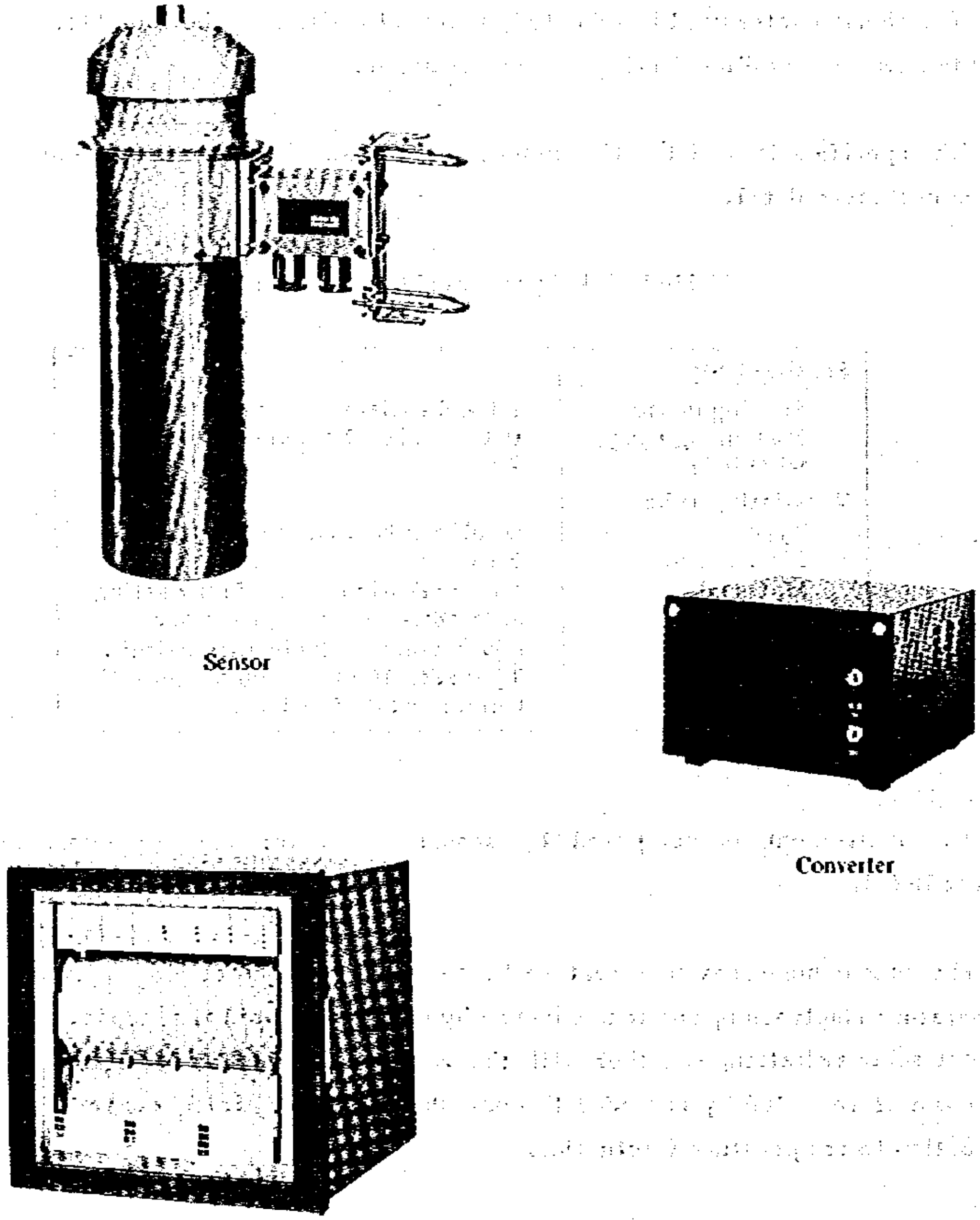
The specifications of the thermometer are shown in Table II-6-1 and the outview is shown in Picture II-6-1.

Table II-6-1 Specifications of thermometer

Sensing body	
Sensing device	Nickel resistance 100 at 0°C
Measuring range	0°C to +60°C accuracy ±0.5°C
Currency	5 mA
Ventilating tube	
Type	Double tube with ventilation
Flow speed	5 - 6 m/s
Materials	anti-corrosion aluminium casting anti-corrosion alumina-alloy
Painting	silver color melanin fuse painting
Fan motor	Type:FC-100B AC100 V 50/60 Hz Currency: 0.15/0.18 A

The instrument is composed by sensor, converter and recorder, as shown in Picture II-6-1.

The sensor measures temperature by fluctuation of electrical resistance caused by temperature fluctuation, and it is covered by shelter to avoid the impact from direct and indirect solar radiation, together with the ventilated air. The resistance fluctuation at the sensor is recorded by recorder through the converter which converts the resistance fluctuation to temperature fluctuation.


Sensor

Converter

Recorder

Picture II-6-1 Outview of thermometer

II-6-3 Measurement

The thermometer used in this study had been inspected by the Meteorological Agency of Japanese Government which is effective for 5 years. Therefore the calibration of instruments were not necessary during the survey period.

II-6-3-1 Installation

The thermometer is generally installed in flat open area where no obstacles like buildings and trees are located. The pole for installation of thermometer is erected on the firm foundation prepared by concrete arrangement. In this study, the thermometer have been installed at the same pole with the anemometer of MP-1.

II-6-3-2 Connection

Connection of cable is performed by the order of sensor, arrestor, converter and recorder. As described in the above, the sensor measures the temperature by resistance fluctuation. So the attention should be given to the length of cable between sensor and converter. Because the resistance of cable itself will give the impact on the sensitivity of sensor. Therefore the resistance of cable itself should not exceed 2 Ω, by adjusting the cable length between sensor and converter.

In this study, the length of cable was 13 m and the diameter of the cable was 2 mmϕ.

II-6-3-3 Loading of chart

The recorder for thermometer used in this study is the same type with SO_2 analyzer. The chart is loaded as described in II-3-3-3.

II-6-3-4 Calibration

As mentioned above, the instruments had been calibrated and inspected by the Japanese Authorities which is effective for 5 years. However, for the measurement of temperature difference, even the small error of measured value should be avoided, and so the regular adjustment has been performed once every 3 months. The adjustment has been conducted, using another standard thermometer (Assmann thermometer) for comparison.

II-6-3-5 Automatic measurement

Turn the function switch of converter to ON. After turning power supply switch of recorder to ON, adjust the recording pen to the present time on the chart, and automatic continuous measurement will be commenced.

II-6-3-6 Maintenance

For the sound and proper operation of thermometer, the maintenance is carried out according to the items and frequency mentioned in Table II-6-2.

Table II-6-2 Items and frequency for maintenance

Items		Frequency				
	Items & contents	Day	Week	1 Month	3 Month	Year
Sensor	(1) abnormal noise of air pump	x				
	(2) cleaning of shelter					x
Recorder	(1) chart advance, time slip of chart, ink shade	x				
	(2) replacement of chart			x		
	(3) ink supply		x			
Calibration	Adjustment after comparison by Assmann thermometer				x	
Power & cable	loose and or disconnection of cable	x				

II-6-4 Maintenance and Results of Measurement

The measurement of temperature has been conducted for one year, from July 15th 1981 to July 14th 1982, at 1.5 and 10 m high from the ground of MP-1 shown in Fig. II-1-1.

During the above period, the daily check and calibration have been carried out by JTC and Japanese team respectively.

II-6-4-1 Maintenance

(1) Daily check

According to the items and frequency mentioned in Table II-6-2, the thermometers installed at MP-1 have been daily checked by JTC. Items for daily check are as follows.

(a) confirmation of abnormal noise of air pump
(b) confirmation of chart advance
(c) confirmation of time slip of the chart
(d) confirmation of ink shade and supply of ink
(e) confirmation of loose or disconnection of cable

(2) Calibration

The calibration of thermometers have been carried out by Japanese team once every 3 months, for the sound and proper operation of instruments.

The calibration has been performed by setting Assmann thermometer at the side of installed thermometers, comparing the indicating values of each thermometer, and took note on the form shown in Table II-6-4, as the results of inspection.

The results of calibration of thermometers are shown in Table II-6-3 and the instruments are found satisfactory during the survey period.

Table II-6-3 Results of calibration of thermometers

Times	Thermometers	Values (°C)	Assmann values (°C)
1st Calib.	1.5 m 10.0 m	30.2 30.1	30.2 30.1
2nd Calib.	1.5 m 10.0 m	30.3 30.3	30.8 30.2
3rd Calib.	1.5 m 10.0 m	27.5 27.7	27.6 27.7
4th Calib.	1.5 m 10.0 m	30.2 29.4	30.4 29.4
5th Calib.	1.5 m 10.0 m	28.8 28.4	28.8 28.4

II-6-4-2 Temperature

(1) Reading of chart of thermometer

As shown in Fig. II-6-1, the instantaneous values of temperature at 1.5 m and 10 m high from the ground are recorded on the same chart by different colors of ink. Further, due to the replacement of electrical parts of the instruments, the ink colours have been changed on the way as shown in Table II-6-4.

Table II-6-4 Ink colour of recorder of thermometer

Height \ Survey period	From 01:00 of July 15th to 10:00 of October 30th 1981	From 11:00 of October 30th 1981 to 24:00 of July 14th 1982
1.5 m	Red	Black
10.0 m	Black	Red

The full scale of the chart is 0 to 60°C and the value of each exact full hour has been read by the unit of 0.1°C as the value of temperature.

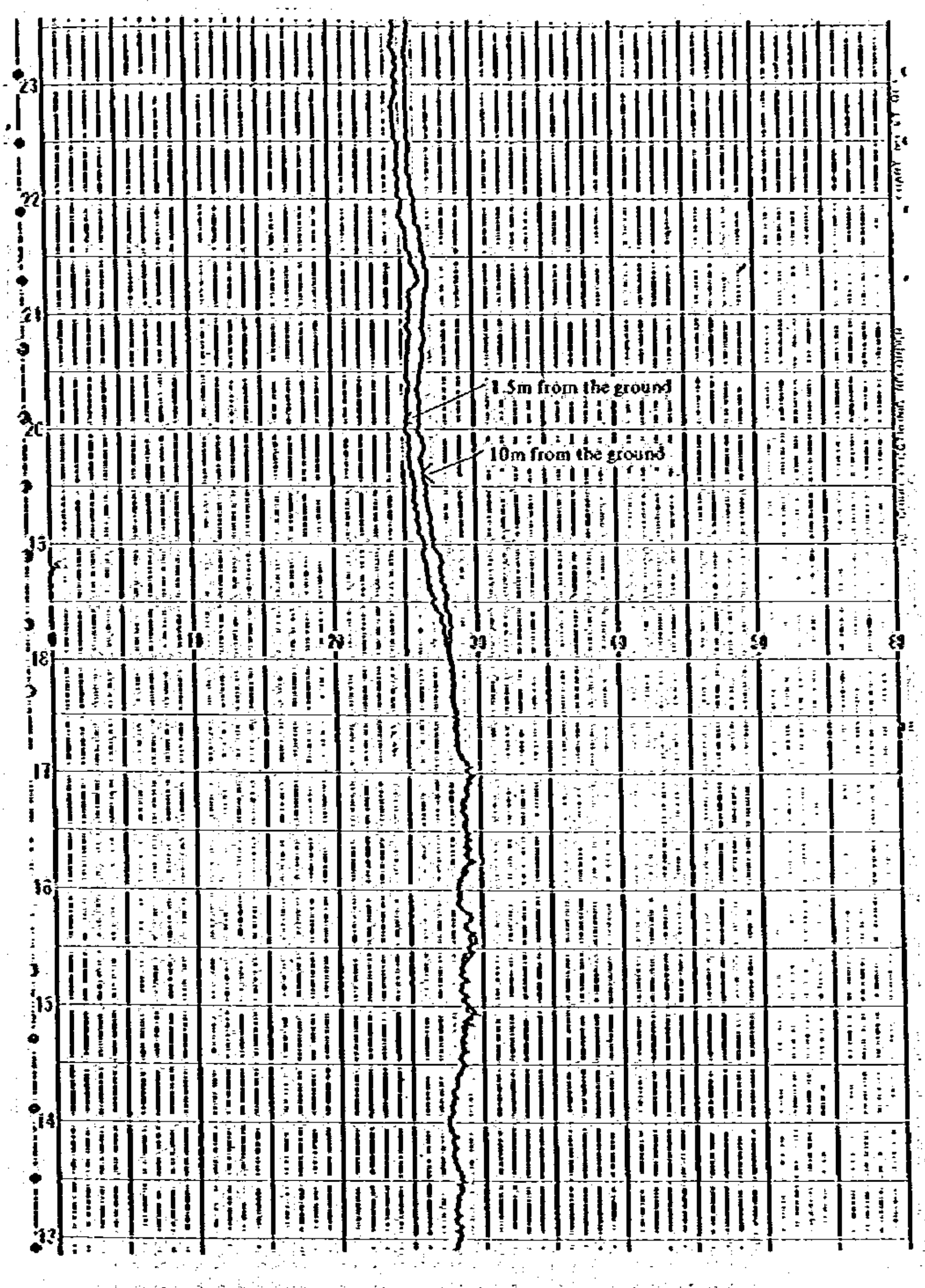


Fig. II-6-1 An example of recording of temperature

(2) Results of measurement

The effective measurement time of temperature measured at 1.5 and 10 m high from the ground were 8,753 hours for 1.5 m and 8,755 hours for 10 m, both of which are exceeding standard of effective monitoring stations in Japan.

The raw data of temperature measured at 1.5 m and 10 m high from the ground are shown in ANNEX and an example of recording is shown in Table II-6-5.

Table II-6-5 An example of recording of one hour value of temperature

SINGAPORE TEMP. 1.5M ST. 1
1981. 8. 100.0%

DAY	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H	24H	MEAN	MAX	MIN
1	250	247	245	248	240	240	242	272	288	259	261	295	282	289	290	290	284	281	275	268	255	254	251	249	265	295	240
2	245	242	241	242	241	240	245	268	250	245	250	269	272	290	295	295	297	288	266	270	257	255	250	242	260	295	240
3	243	239	237	238	240	241	249	272	287	290	293	300	298	301	303	300	300	292	283	278	269	270	255	250	272	303	237
4	248	246	245	245	255	251	260	280	283	294	300	300	308	303	298	300	299	294	262	273	260	252	249	246	274	308	245
5	242	241	241	241	243	242	245	272	282	291	300	295	300	305	310	308	305	291	285	272	265	262	258	259	273	310	241
6	253	255	252	262	269	271	272	283	292	299	308	309	315	309	310	310	308	297	286	282	276	265	254	251	283	315	251
7	249	243	245	243	259	259	268	278	290	298	300	310	319	311	319	312	308	297	286	262	280	275	278	274	283	319	243
8	271	270	268	269	252	262	253	279	290	300	295	310	310	315	310	309	303	293	286	287	282	264	269	264	284	315	252
9	261	255	262	263	258	247	246	272	289	290	295	295	300	310	305	302	300	292	282	280	284	289	287	270	281	310	246
10	259	253	245	243	242	241	249	275	291	298	304	305	302	298	298	297	295	290	279	272	268	256	251	247	273	305	241
11	246	242	248	248	246	244	249	280	284	300	310	310	320	315	318	312	308	289	284	282	280	277	269	267	280	320	242
12	267	248	243	245	248	259	268	279	290	294	307	314	320	321	313	309	302	290	282	279	278	275	273	265	282	321	243
13	260	254	241	240	241	249	249	278	283	293	300	311	301	315	311	317	309	298	287	281	277	262	257	253	278	317	240
14	268	265	265	258	259	250	250	274	290	300	309	318	319	318	319	313	310	299	289	283	280	272	268	265	285	319	250
15	253	255	261	252	261	260	254	272	290	295	303	310	319	316	314	310	310	300	293	284	279	279	272	270	284	319	252
16	267	253	263	251	246	258	258	277	289	295	302	310	308	315	312	313	302	297	288	284	280	279	275	274	283	315	246
17	269	269	263	261	267	266	268	279	288	292	300	310	314	304	305	310	307	293	285	280	277	275	272	269	284	314	261
18	259	248	245	246	244	246	214	233	243	238	247	270	292	305	305	303	300	287	276	272	272	270	252	246	263	305	214
19	247	251	244	239	233	233	242	271	279	294	300	299	300	310	310	305	299	289	283	279	272	265	253	250	273	310	233
20	250	245	243	242	242	242	248	249	261	264	283	302	300	292	292	290	298	284	276	273	259	262	255	256	267	302	242
21	251	251	251	243	258	253	262	279	283	283	297	300	299	292	301	300	298	291	282	275	272	270	268	252	275	301	243
22	249	244	248	243	240	241	246	279	290	298	309	310	319	319	320	314	300	295	290	272	265	252	252	241	277	320	240
23	248	243	242	238	236	235	239	258	290	303	302	319	310	287	298	312	310	300	289	282	273	272	270	268	276	319	235
24	268	252	249	245	243	247	246	262	252	269	299	284	292	278	288	290	284	278	274	277	273	246	249	255	267	299	243
25	258	260	245	245	259	262	261	267	270	278	290	287	292	288	295	289	285	287	271	273	269	262	248	245	270	295	245
26	241	236	238	234	235	232	235	275	290	295	303	303	304	280	277	272	273	271	267	255	265	252	253	240	264	304	232
27	240	237	238	230	228	228	234	263	292	292	300	302	299	275	249	243	242	240	232	231	230	230	228	227	250	302	227
28	225	222	222	222	223	222	224	249	271	290	293	295	287	298	295	290	299	289	275	272	262	258	253	248	262	299	222
29	242	240	238	235	235	236	238	272	282	292	300	304	307	290	302	305	298	288	277	272	267	271	257	249	271	307	235
30	243	240	237	232	232	231	232	275	290	295	298	310	298	315	304	300	295	291	272	278	273	271	256	250	272	315	231
31	249	246	245	244	240	241	247	270	285	295	299	299	308	319	309	301	294	287	279	275	275	274	265	260	275	319	240
MONTHLY																									274	321	214

UNIT : 0.1°C

Fig. II-6-2 shows monthly pattern of temperature and from the figure, the temperature of 10 m is higher about 0.3-0.4°C in each month.

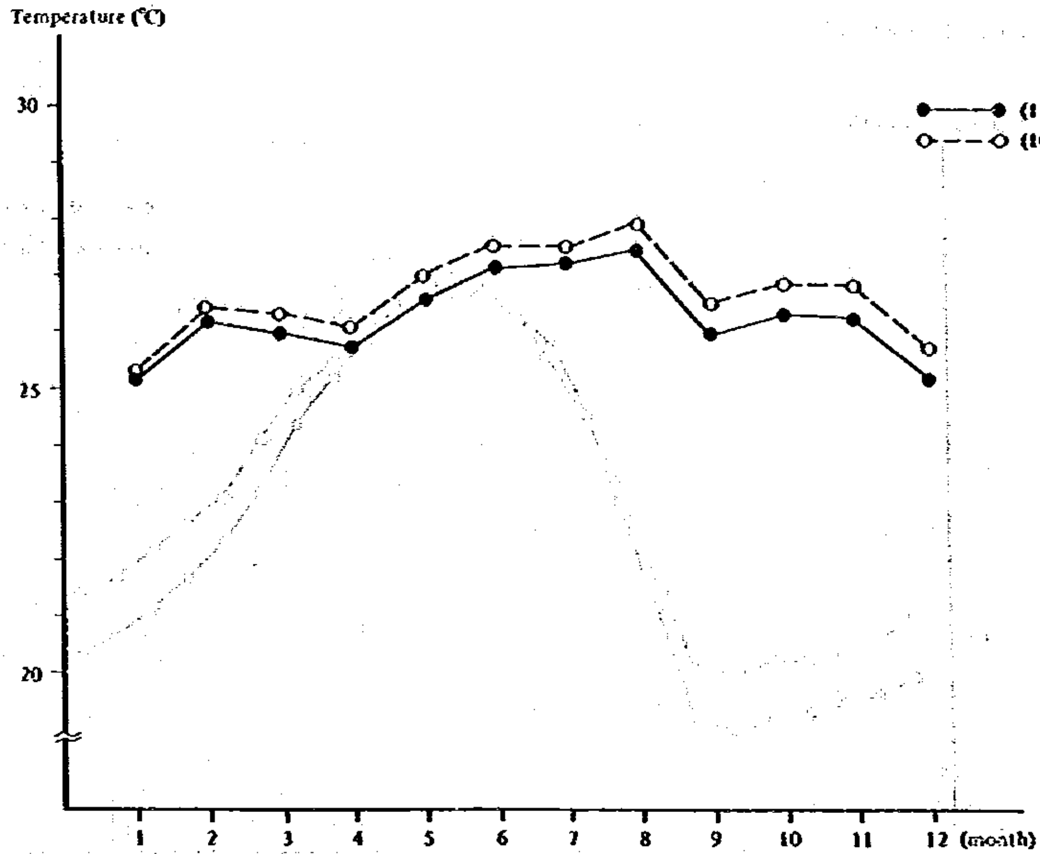


Fig. II-6-2 Monthly pattern of temperature

The hourly pattern of temperature is shown in Fig. II-6-3. From the figure, there found no difference between 1.5 m and 10 m in daytime, but the temperature of 10 m in nighttime is higher about 0.5-0.6°C than that of 1.5 m. It is due to the reflection from the ground.

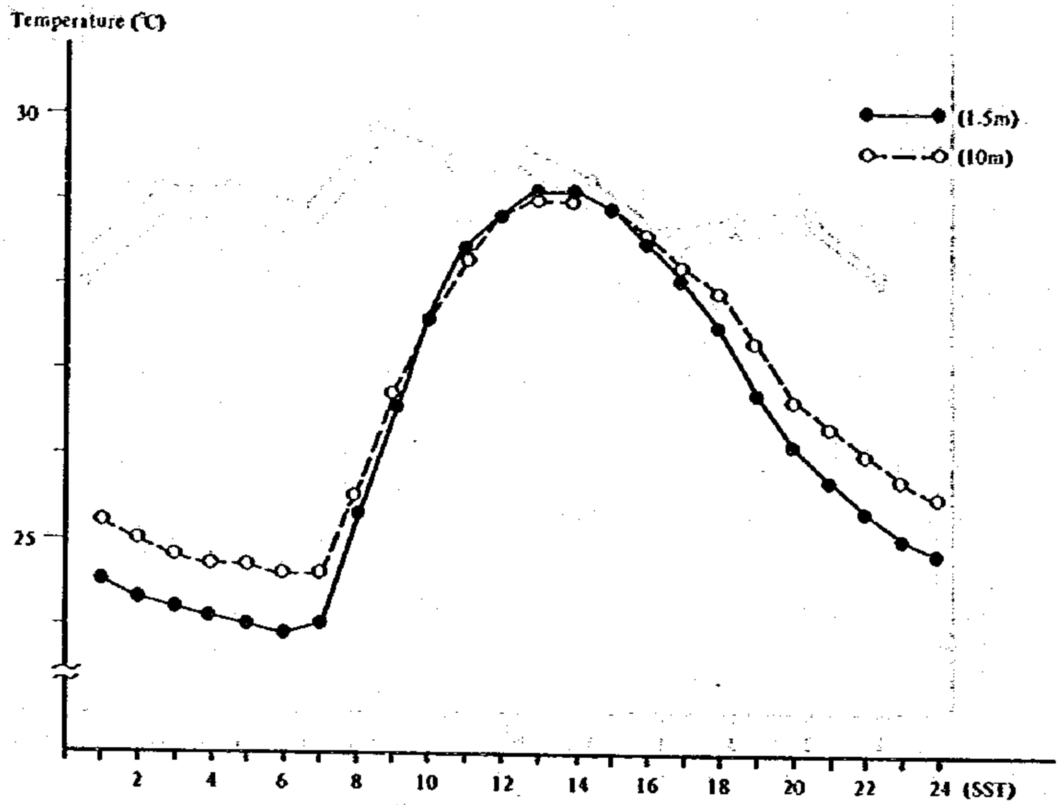


Fig. II-6-3 Hourly pattern of temperature

Table II-6-6 shows the average temperature of 1.5 m and 10 m classified by season and day/night. From the table, the temperature of 10 m is found higher about 0.3°C than that of 1.5 m.

Table II-6-6 Average temperature by season and day/night

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	25.2	26.6	27.5	24.3	25.8	28.0	24.8	26.3
10 m	28.4	25.9	27.0	27.6	24.8	26.1	28.0	25.5	26.6

CHAPTER 7 MEASUREMENT OF VERTICAL DISTRIBUTION OF WIND DIRECTION AND VELOCITY

In the atmospheric layer of up to about 2 km, the wind velocity is smaller in the lower layer due to fluid viscosity resistance of ground roughness and atmospheric fluid, by which the vertical slide of wind velocity and turbulence of wind are generated.

When the ground surface is heated by solar radiation, the convection is caused and wind turbulence is generated. The reaching height of convection is equal to the height of mixed layer. In the atmospheric boundary layer, the wind direction, velocity and temperature are largely fluctuating to the vertical directions and the wind turbulence is generally larger than free atmosphere of high sky. The diffusion of pollutants is in most cases limited in the boundary layers and so the measurement of vertical distribution of wind direction and velocity is one of the important factors in the environmental study.

In this study, the measurement of vertical distribution of wind direction and velocity has been conducted at two points within the survey area although the term was only limited to two days. The measurement has been carried out at MP-2 and MP-6, tracing the balloon by Theodolite upto the height of 2,000 meters, and recording the wind direction and velocity of each 100 meters, on June 23rd and 24th of June 1981.

II-7-1 Measuring Methods of Upper Layer Wind

There are two other methods to measure the atmospheric upper layer, which are (1) to install the anemometer at the high position of tower and (2) to release the captive balloon installed with the specially designed anemometer. However, when the tower is used, maximum height will not be more than 200 or 300 meters and in case of captive balloon, it will be not more than 500 meter. Therefore for the measurement of further higher layer, pilot balloon method is most common although there are some other methods which are using sonde, sonic lader and airplane.

II-7-2 Measurement of Vertical Distribution of Wind Direction and Velocity in This Study

In this study, the pilot balloon method has been employed, from the objectives of measurement and other economical reasons.

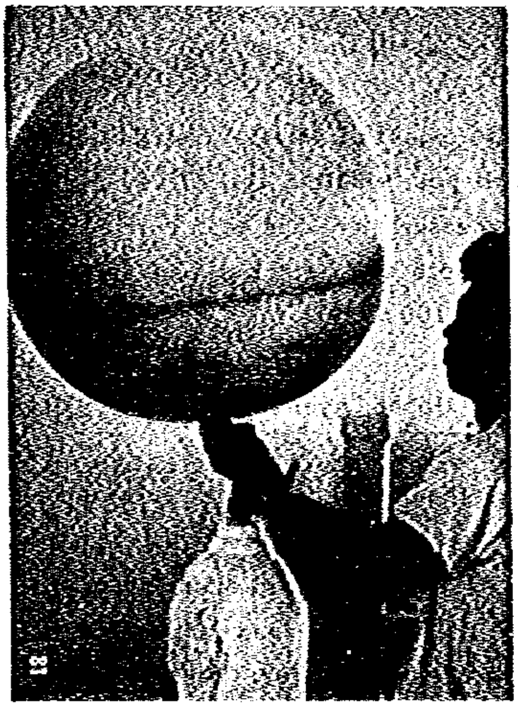
The method is to measure the wind direction and velocity from the relation between elevating height and floating distance of balloon, tracing by Theodolite the balloons adjusted to have the same elevating speed.

II-7-3 Measurement

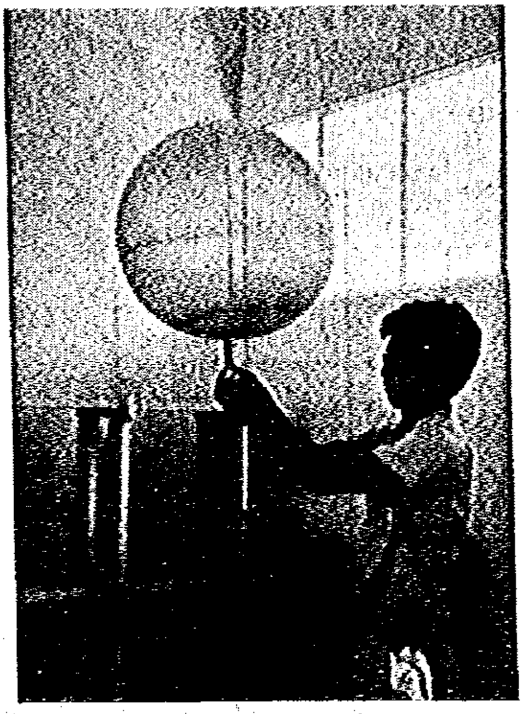
II-7-3-1 Gas charging

The rubber balloon is charged by helium gas as shown in Picture II-7-1, and adjust the helium gas volume by floating valve which has the weight of 55.7g, as shown in Picture II-7-2, until the balloon is kept in balance. (Picture II-7-3)

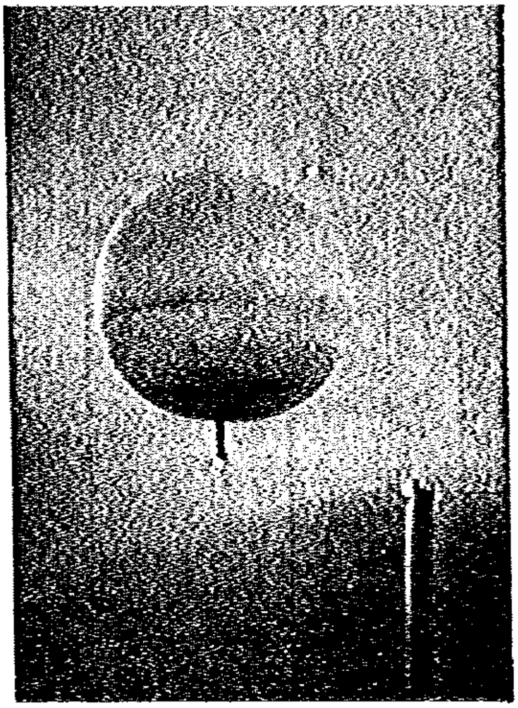
When the above charging processes are completed, the balloon has the buoyancy of 55.7g and its elevating speed is about 100 m/40 s in the atmosphere between the ground and 2 km high.



Picture II-7-1 Charging of helium gas



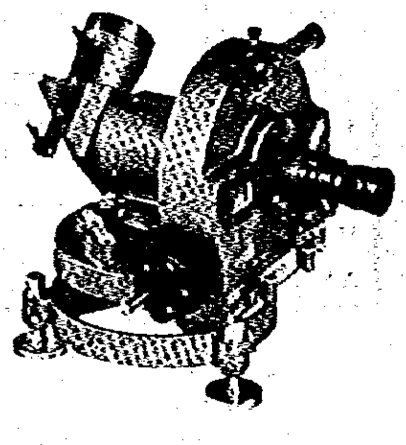
Picture II-7-2 Adjustment of buoyancy



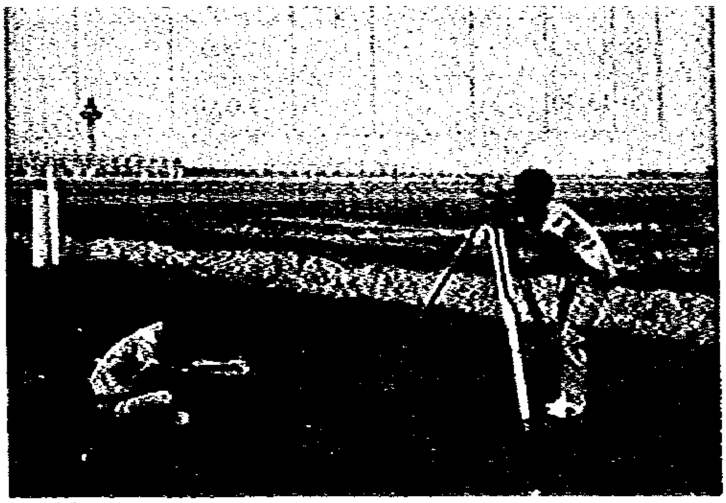
Picture II-7-3 Balanced state

II-7-3-2 Tracing of balloon by Theodolite

The Theodolite of Picture II-7-4 is kept on the three-legged stand and kept balance by the level. The fixing valve of magnetic needle is loosen and after adjusting the needle to be directed to the north, the telescope is directed to due north and adjust the angle indicator to zero. The released balloon is traced through telescope, noting altitude and azimuth angles of each 40 seconds on the form of Table II-7-1, as shown in Picture II-7-5. The specifications of Theodolite are shown in Table II-7-1.



Picture II-7-4 Theodolite



Picture II-7-5 Tracing balloon by Theodolite

Table II-7-1 Form for recording altitude and azimuth angles

PILOT BALLOON SURVEY RECORD

Site:

No.	Min. & sec.	Elevation angle	Azimuth angle	Height	Horizontal distance (m)	X coordinate	Y coordinate	Wind direction (°)	Wind velocity (m/s)
1	0:40				100				
2	1:20				200				
3	2:00				300				
4	2:40				400				
5	3:20				500				
6	4:00				600				
7	4:40				700				
8	5:20				800				
9	6:00				900				
10	6:40				1,000				
11	7:20				1,100				
12	8:00				1,200				
13	8:40				1,300				
14	9:20				1,400				
15	10:00				1,500				
16	10:40				1,600				
17	11:20				1,700				
18	12:00				1,800				
19	12:40				1,900				
20	13:20				2,000				

Survey No.	
Date	– – 81
Time	:
Name of surveyor	
Ground wind velocity	(m/s)
Cloud amount & form	
Weather	
Balloon weight	20 gr.
Buoyancy	55.7gr.
Ascending capacity	150 m/min.
Reason of survey suspension:	

Reasons of survey suspension

Sun	Disturbed by direct sun beam	Ent.	Entered into cloud
B.B	Balloon burst	Obst	Obstacled by cloud
A.G	Accident of ground instruments	O.S	Out of sight
D.G	Disturbed by ground obstacles	A.R	Another reason

Table II-7-2 Specification of Theodolite

Main telescope and finding telescope			
	Main telescope	Finding telescope	Tolerance
Effective dia of objective	45 m/m	13.5 m/m	±5%
Magnification	18.5 X	4 X	±5%
Resolving power	under 3.5"	under 12"	
Field of vision	2.5°	10.5°	±5%
Image	inverted	inverted	
Visual dia. of large hair ring	32'	2°	±10%
Visual dia. of small hair ring	12'	58'	±10%
Horizontal circle and vertical circle			
	Horizontal circle	Vertical circle	
Diameter	140 m/m	140 m/m	
Min. division	30'	30'	
Min. reading	30'	30'	

II-7-4 Elevating Speed of Balloon

The elevating speed of the balloon is deviating in a certain extent by the atmospheric status and height, but it is determined generally by weight and buoyancy of the balloon.

From several experiments, the equation has been obtained to express the elevating speed as a function.

The resistance of elevating balloon is represented by the equation

$$R = \xi \pi \rho r^2 V^2 \left(\frac{\nu}{rV}\right)^n \left(\frac{\kappa}{\rho V^2}\right)^{1-m} \qquad \text{Equation II-7-1}$$

where; ρ ---- air density

r ---- radius of balloon

ν ---- μ/ρ

μ ---- statical viscosity coefficient of air

κ ---- coefficient of elasticity of air at $\rho \frac{dP}{d\rho}$

V ---- transferring speed of balloon

ξ ---- constant for resistance of balloon surface

n, m ---- experimental constant

When gas density charged in balloon is σ, the empty weight of balloon is W, buoyant force is L, buoyancy is Q and these are expressed by the unit of gram and balloon is globe, the following equation for buoyancy is obtained.

$$Q = \frac{4}{3}\pi(\rho - \sigma)gr^3 \qquad \text{Equation II-7-2}$$

where: g --- acceleration of gravity

When the buoyant force of balloon and air resistance is balanced, the relation of Equation II-7-3 is resulted.

$$R = (Q - W)g = L \qquad \text{Equation II-7-3}$$

From the above 3 equations, the elevating speed of balloon is obtained as Equation II-7-4.

$$V = K_0 (1 - ats + b\Delta Ps - cZ)\left[\frac{L}{(L+W)^{\frac{2-n}{3}}}\right]^{\frac{1}{2m-n}} \qquad \text{Equation II-7-4}$$

where;

$$K_0 = \left[\left(\frac{4}{3}\right)^{2-n} \pi^{-(n+1)} (g\xi^{-1})^3 \left(\frac{g}{g - R\delta}\right)^{3(m-1)} \mu_0^{-3n} \times \rho_0^{-(3m-2n-2)} \left(1 - \frac{\sigma_0}{\rho_0}\right)^{2-n} \cdot P_0^{3(m-1)}\right]^{\frac{1}{3(2m-n)}}$$

$$a = \frac{2(n+1) - 3(m - \alpha_n T_0)}{3T_0(2m - n)}$$

$$b = \frac{2n - 1}{3P_0(2m - n)}$$

$$c = \frac{g(2n - 1)}{3RT_0(2m - n)} - a\delta$$

Z = height from the ground
R = atmospheric constant
δ = temperature decreasing rate
t = temperature by centigrade, $\Delta P = P - P_0$
P = atmospheric pressure
P_0 = 760 mmHg, T_0 = 273°

Mr. Y. Ishino has determined the constant value from the experiments and monitoring data as follows:

$$K_0 = 46.02,\ n = 1,\ m = 1.591,\ a = 0.0011,\ b = 0.0002,\ C = 0.000012.$$

In this calculation, unit is all based on m, g, min., °C. Therefore, as the empirical formula of Equation II-7-4, the Equation II-7-5 is obtained.

$$V = 46.02\,(1 - 0.0011\,ts + 0.0002\,\Delta Ps - 0.000012Z) \times \left[\frac{L}{(L+W)^{\frac{1}{3}}}\right]^{\frac{1}{2.182}} \qquad \text{Equation II-7-5}$$

The elevating speed V of the balloon is different by temperature, atmospheric pressure and height, but the error caused by these factors are small. Therefore, the buoyant force when atmospheric pressure is 760 mmHg and temperature is 0°C, is obtained by equation II-7-6.

$$V = 46.02\left[\frac{L}{Q^{\frac{1}{3}}}\right]^{\frac{1}{2.182}} \qquad \text{Equation II-7-6}$$

where;

L = buoyant force by gram

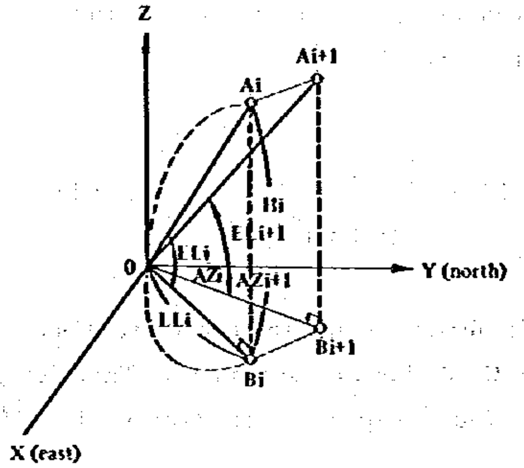
Q = L + W

W = empty weight of balloon

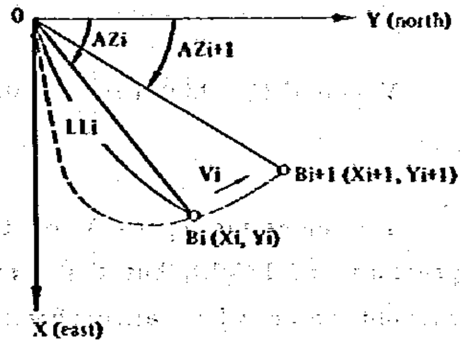
In this study, calculation has been based on equation II-7-6.

II-7-5 Calculation Methods of Wind Direction and Velocity

The average wind direction and velocity of each 100 meter layer are calculated from measured altitude and azimuth angles as follows:



Trajectory of pilot balloon (elevation)



Projection of pilot balloon trajectory onto the gound (plan figure)

Pilot balloon elevates by the speed of 100 m/40 s and reaches to Ai point after 1 second. The altitude and azimuth angles measured from the releasing point are AZi and Eli respectively. As the elevating speed of balloon is 100 m/40 s, the height Hi(Ai - Bi) is obtained by Equation II-7-7.

$$Hi = i \times \frac{100}{40} (m)$$ Equation II-7-7

The horizontal distance LLi (O-Bi) is obtained from altitude angle by Equation II-7-8.

$$LLi = Hi\ O^{o}tELi\ (m)$$ Equation II-7-8

The co-ordinates projected Ai point on the ground is obtained from horizontal distance LLi and azimuth angle AZi by equation II-7-9.

$$Xi = LLi \sin AZi$$ Equation II-7-9

$$Yi = LLi \cos AZi$$

The average wind velocity of after i + 1s from point i is obtained from Pythagorean theorem by Equation II-7-10.

$$V_i = \frac{\sqrt{(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2}}{40} \text{ (m/s)} \qquad \text{Equation II-7-10}$$

In transit observation, north is 0^o and measure azimuth angle in clockwise. Wind direction WDi is obtained by Equation II-7-11.

$$WD_i = \tan^{-1} \left(\frac{X_{i+1} - X_i}{Y_{i+1} - Y_i}\right) \qquad \text{Equation II-7-11}$$

II-7-6 Results of Measurement

AT two points of MP-2 and MP-6, the measurement of average wind direction and velocity of each 100 meter layer has been conducted on the 23rd and 24th of June 1981, during 08:00 to 17:00 hour, by pilot balloon and Theodolite upto the height of 2,000 meter from the ground. The results of measurement are described.

The horizontal trace charts of every exact full hour are shown in Fig. II-7-1-(1) to -(7).

The chart is plotted by average wind direction and velocity of each hour. Upper side of the chart is N and bottom side of chart is S. The direction between dot and dot in the chart is indicating wind direction of the respective layer. The distance between dot and dot indicates the wind velocity. From the figures, it is confirmed that the different wind is blowing between the ground and upper layer.

When vertical axis represents height and lateral axis represents time, the wind direction and velocity are plotted on the chart shown in Fig. II-7-2-(1) to -(4). In the chart, the upper side is N and bottom side is S, as same as Fig. II-7-1.

The wind direction is marked by (and the wind velocity is printed as number located just under the direction mark. Inside the surrounding solid line, the same type of wind is blowing. The wind velocity is found not increasing corresponding to the height. As the measurement term was only for two days, the tendency found in the charts will not be applied to the general tendency of vertical distribution of wind velocity of Singapore.

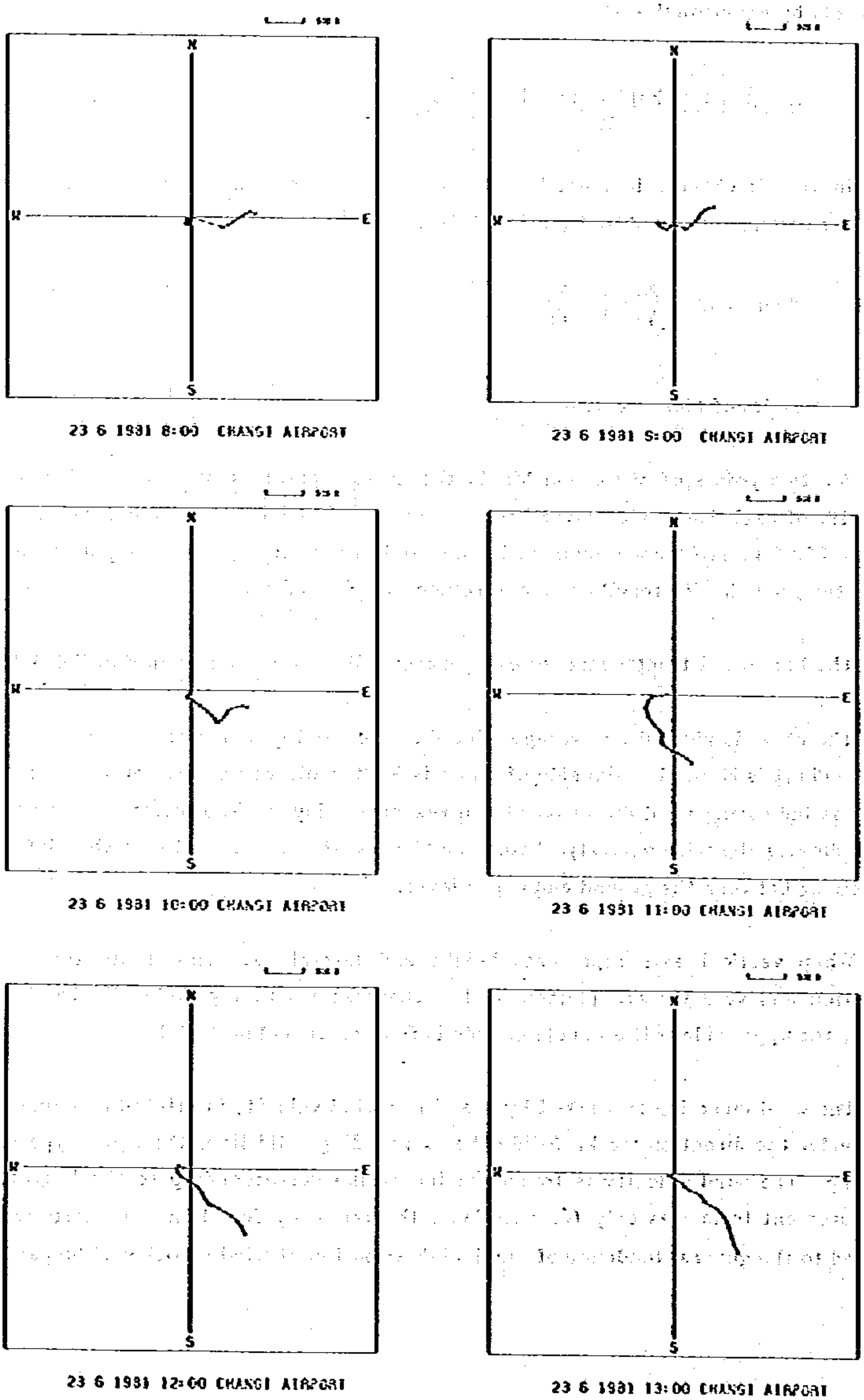
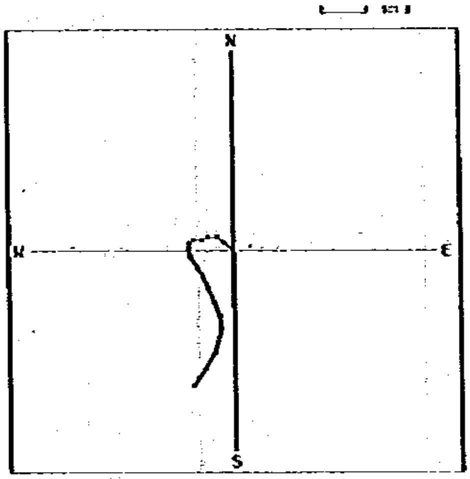
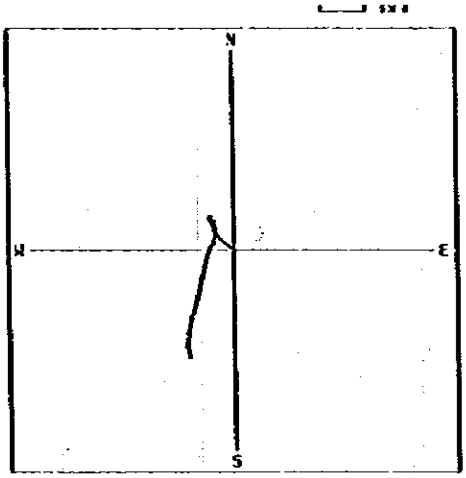


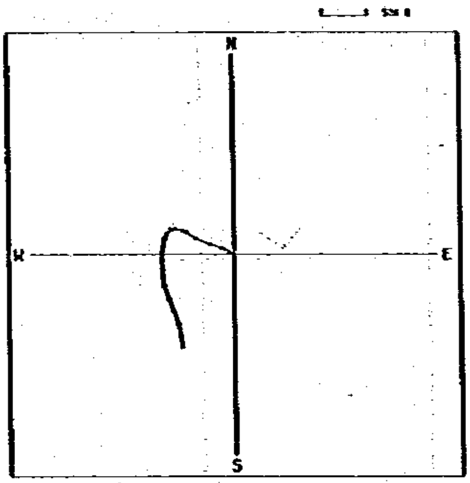
Fig. II-7-1-(1) Horizontal trace chart by pilot balloon



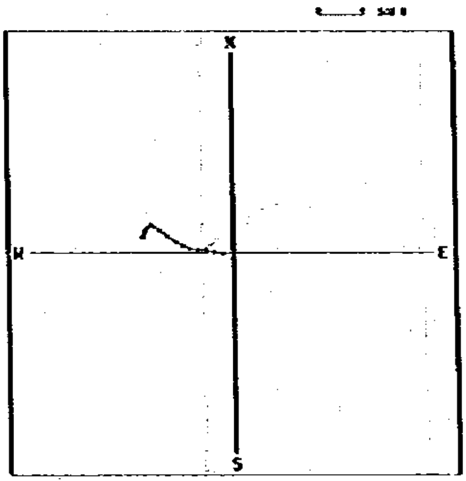
23 6 1981 14:00 CHANGI AIRPORT



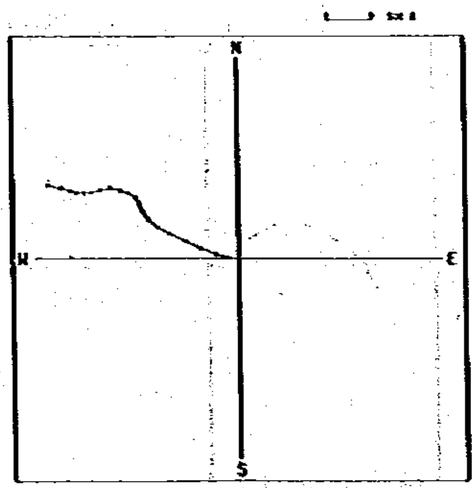
23 6 1981 15:00 CHANGI AIRPORT



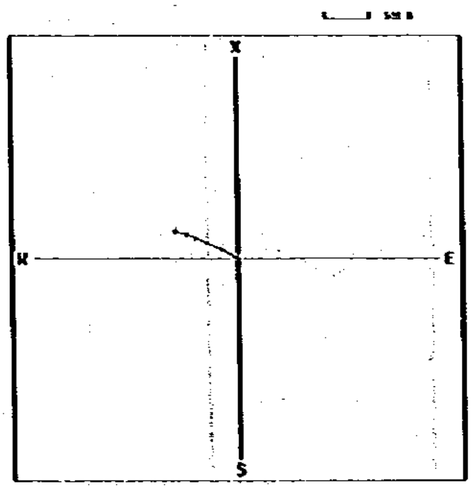
23 6 1981 16:00 CHANGI AIRPORT



23 6 1981 17:00 CHANGI AIRPORT



24 6 1981 8:00 CHANGI AIRPORT



24 6 1981 9:00 CHANGI AIRPORT

Fig. II-7-1-(2) Horizontal trace chart by pilot balloon

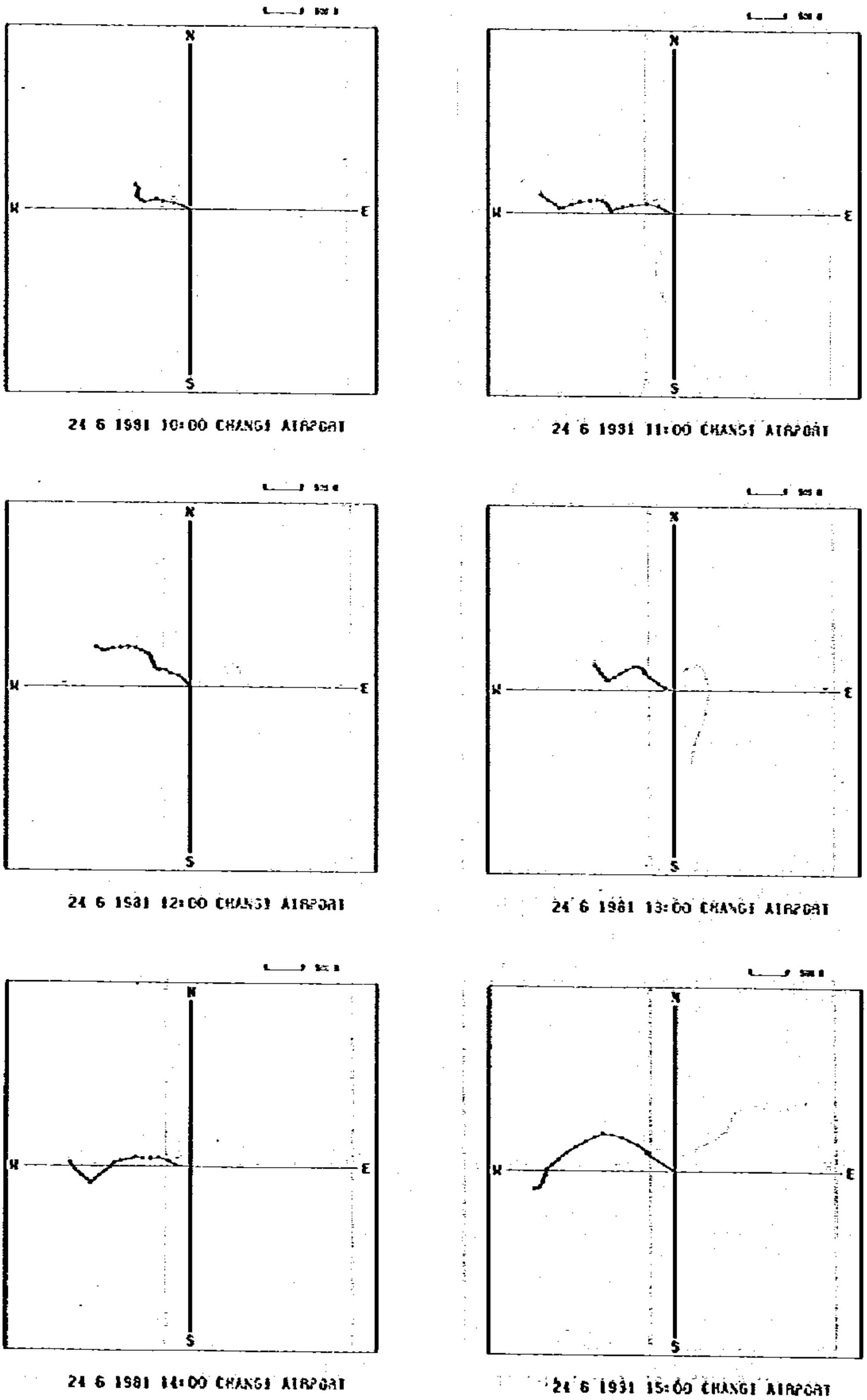
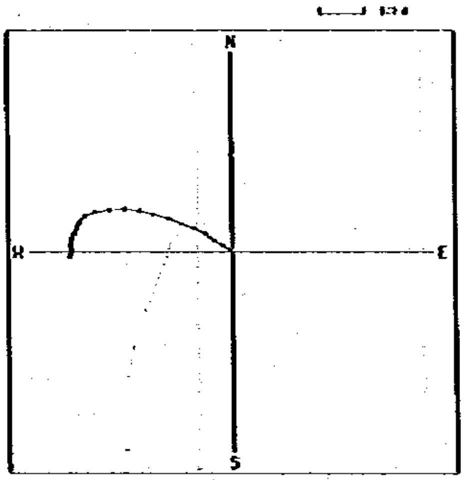
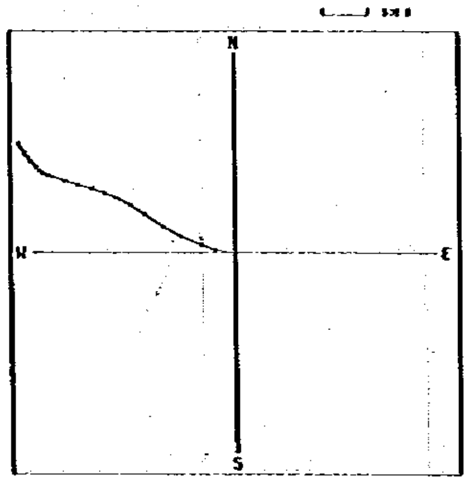


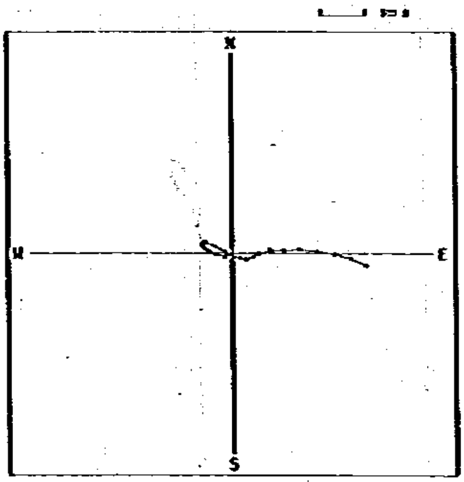
Fig. II-7-1-(3) Horizontal trace chart by pilot balloon



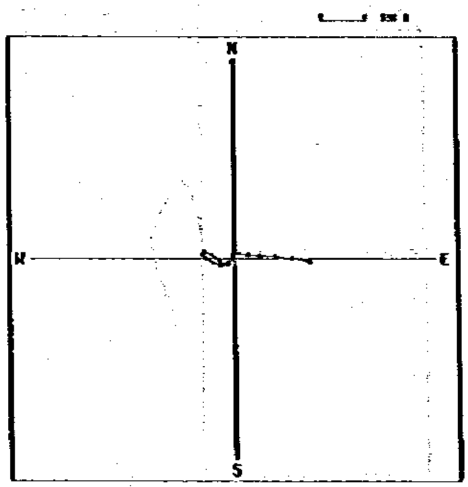
24 6 1981 16:00 CHANGI AIRPORT



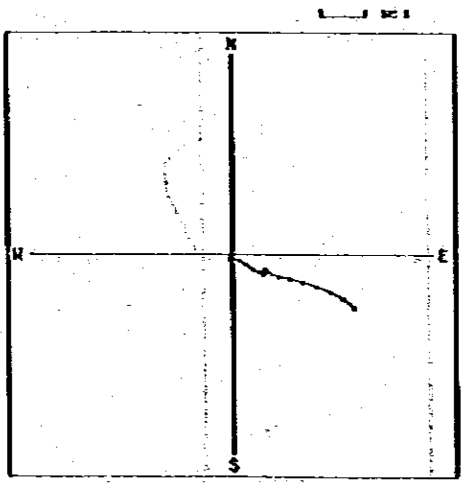
24 6 1981 17:00 CHANGI AIRPORT



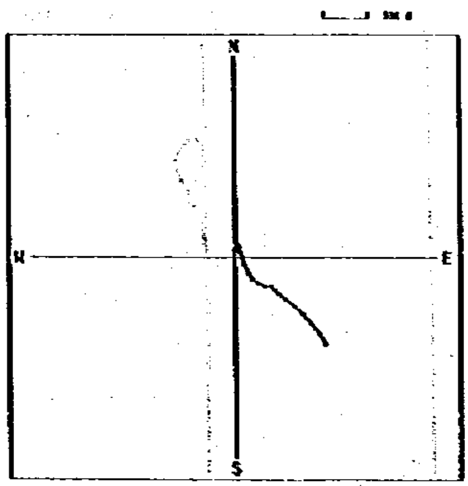
23 6 1981 8:00 J.T.C.



23 6 1981 9:00 J.T.C.



23 6 1981 10:00 J.T.C.



23 6 1981 11:00 J.T.C.

Fig. II-7-1-(4) Horizontal trace chart by pilot balloon

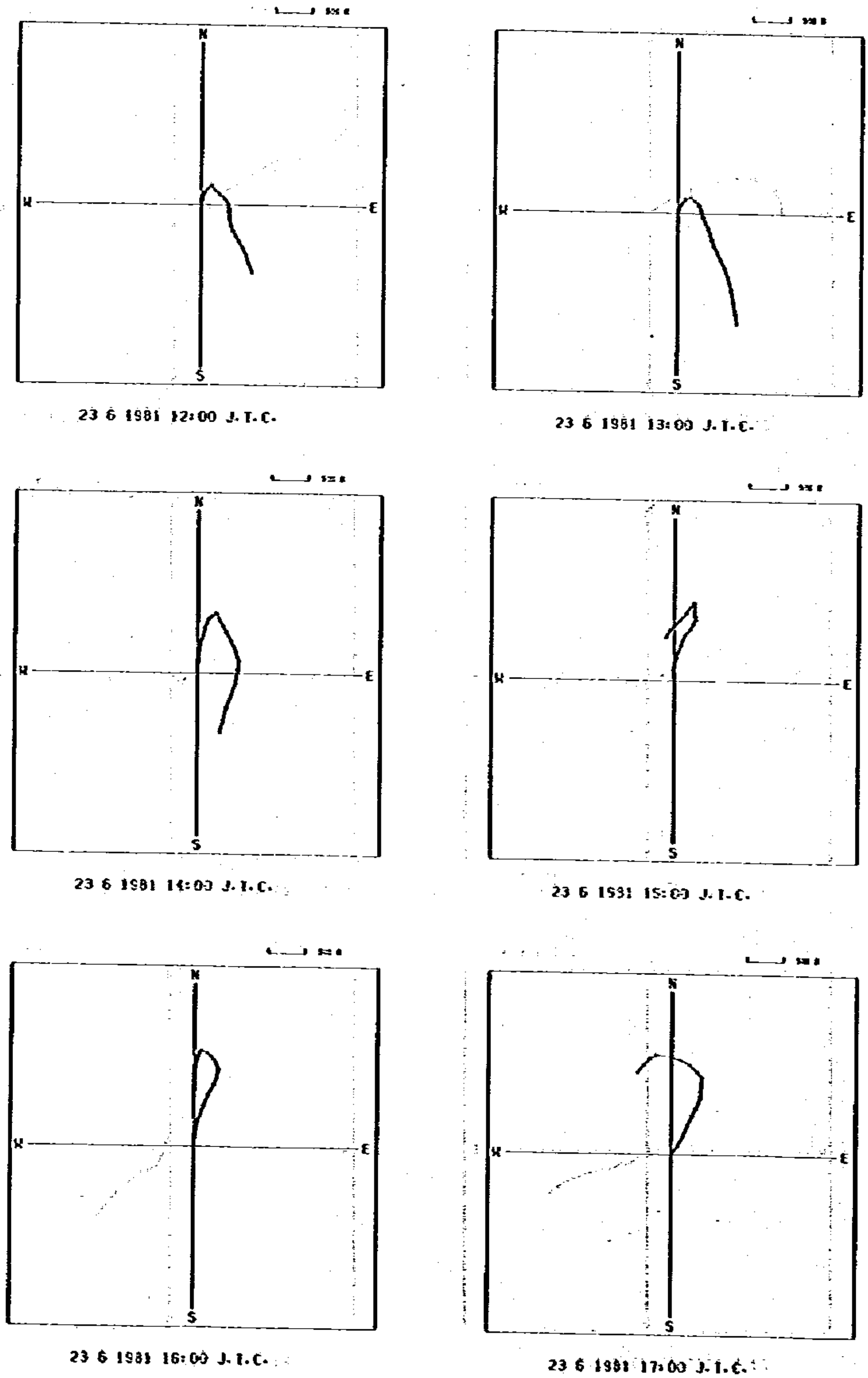
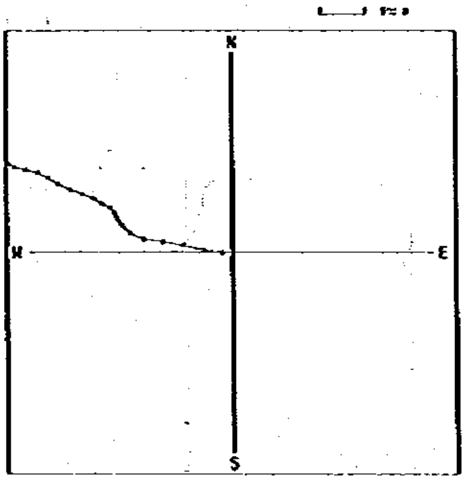
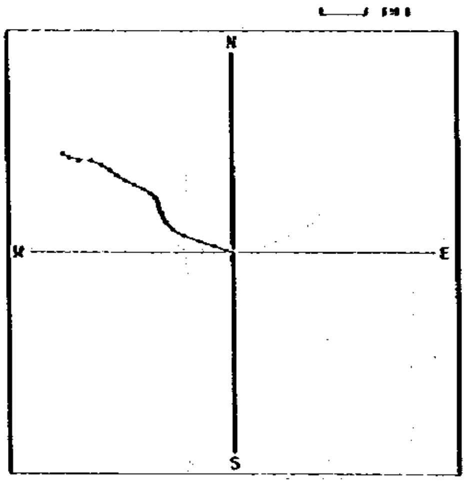


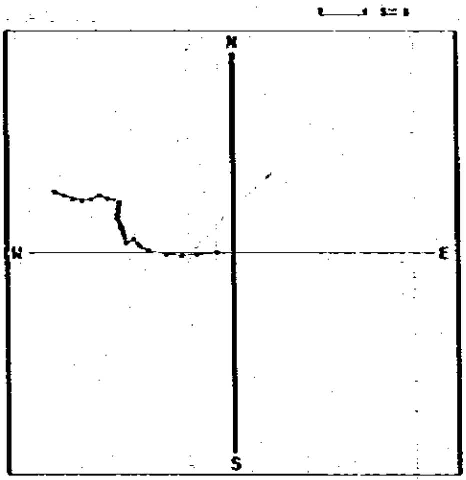
Fig. II-7-1-(5) Horizontal trace chart by pilot balloon



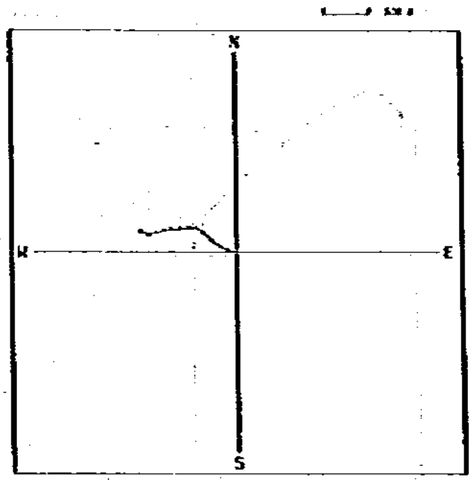
24 6 1981 8:00 J.T.C.



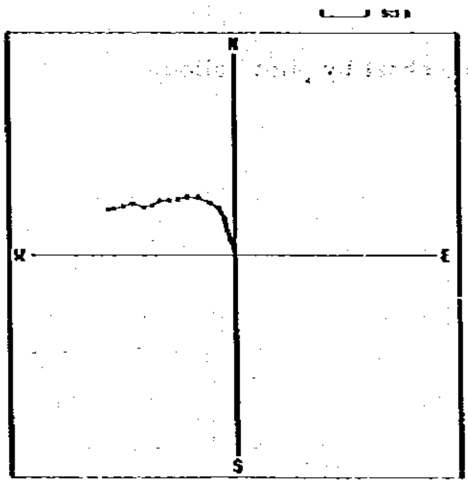
24 6 1981 9:00 J.T.C.



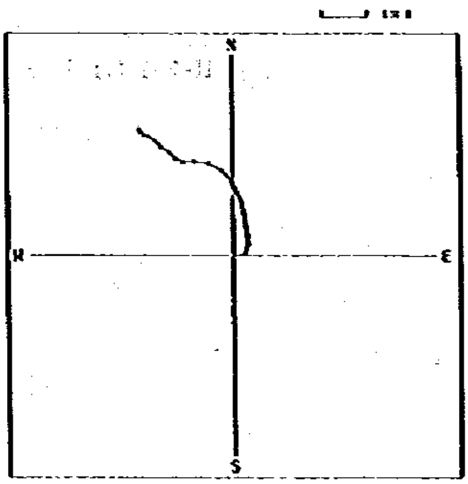
24 6 1981 10:00 J.T.C.



24 6 1981 11:00 J.T.C.



24 6 1981 12:00 J.T.C.



24 6 1981 13:00 J.T.C.

Fig. II-7-1-(6) Horizontal trace chart by pilot balloon

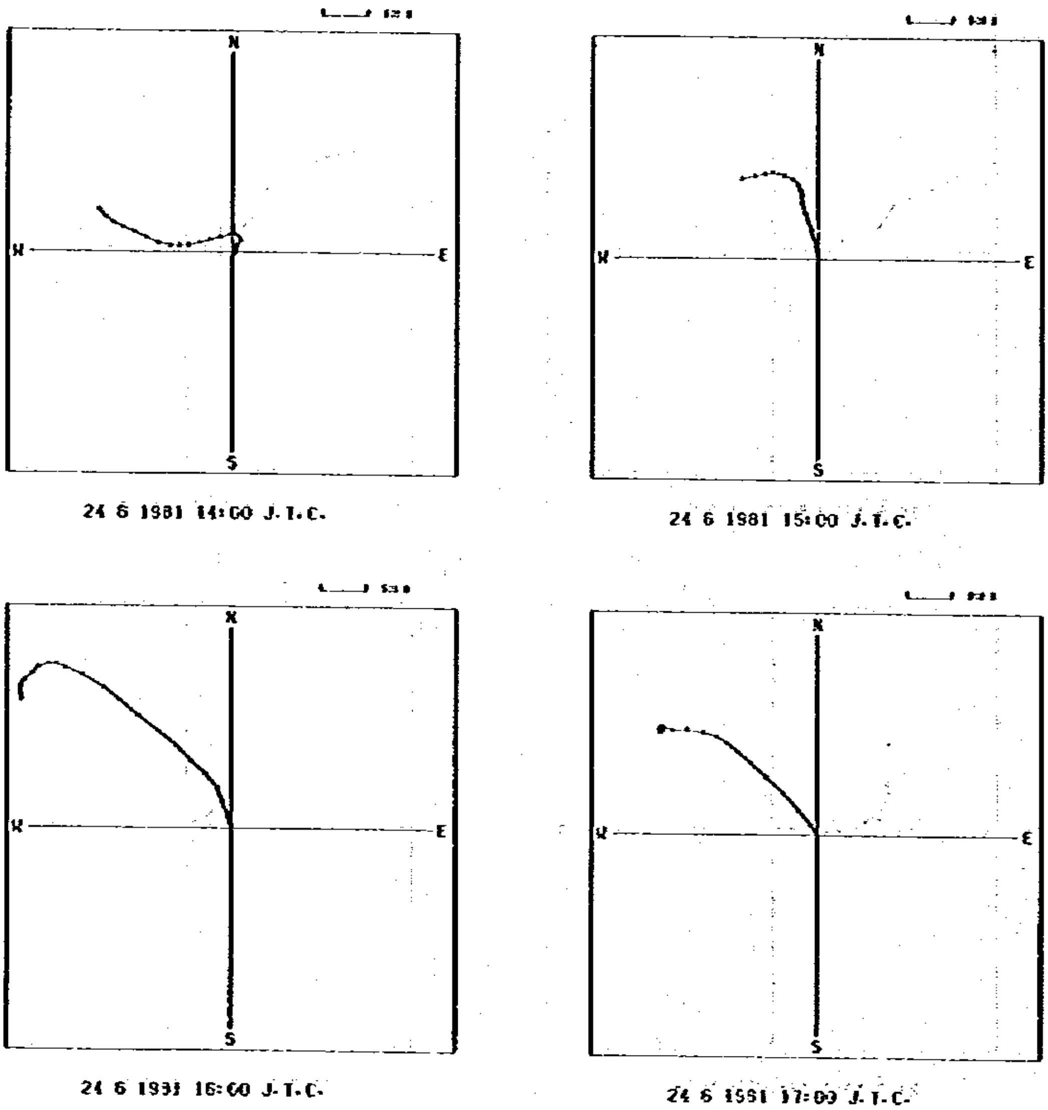


Fig. II-7-1-(7) Horizontal trace chart by pilot balloon

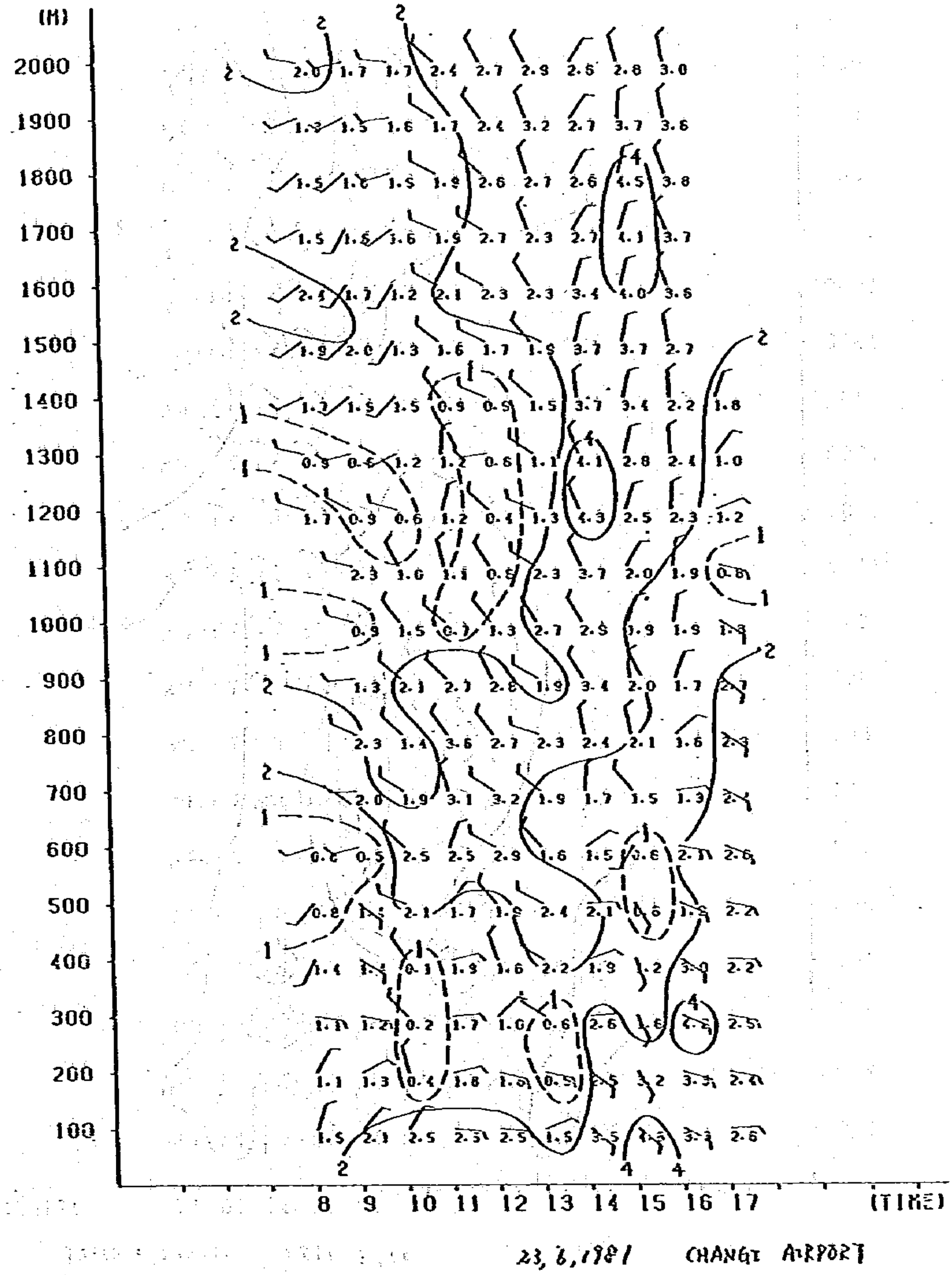


Fig. II-7-2-(1) Isopleth diagram of pilot balloon

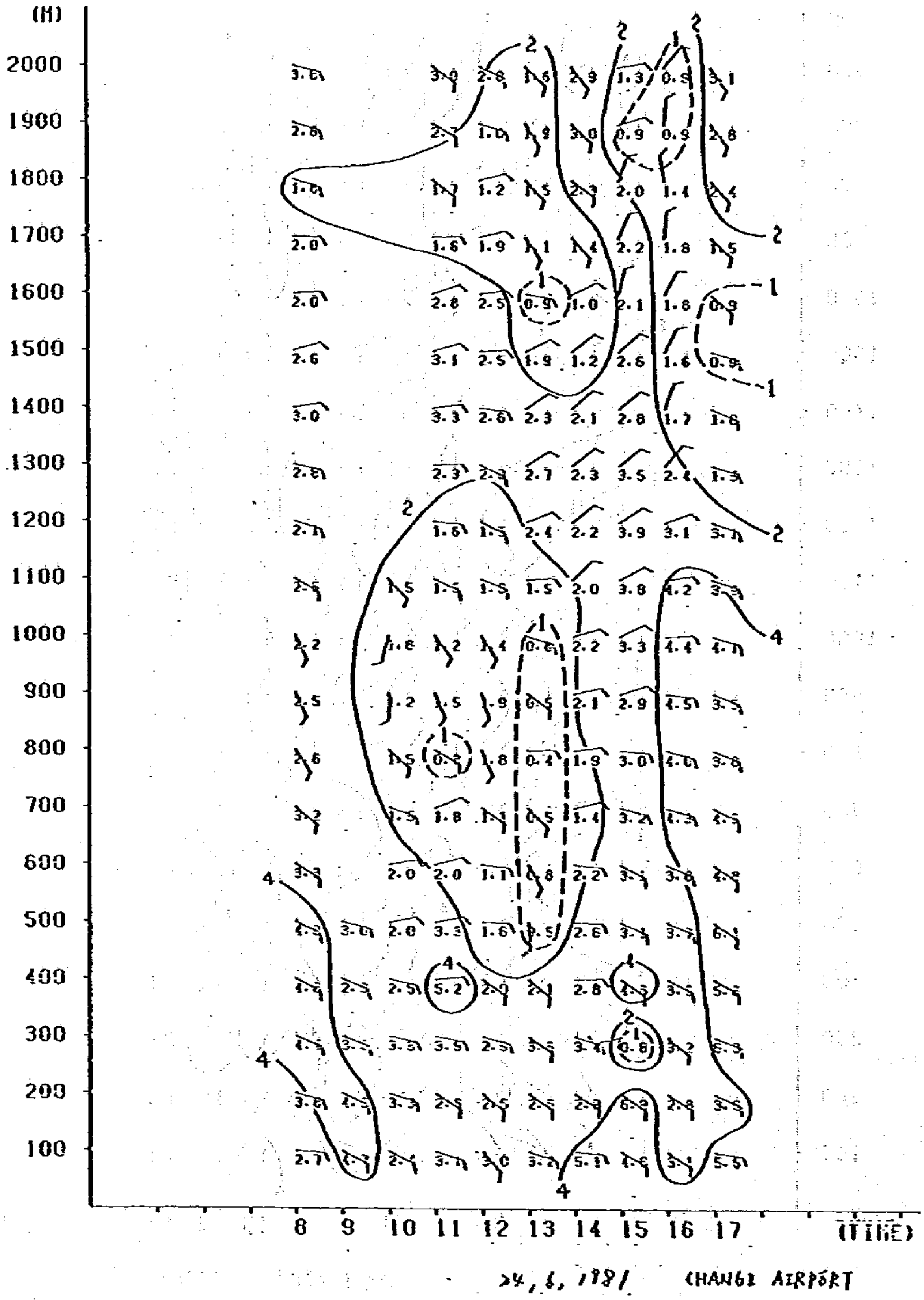
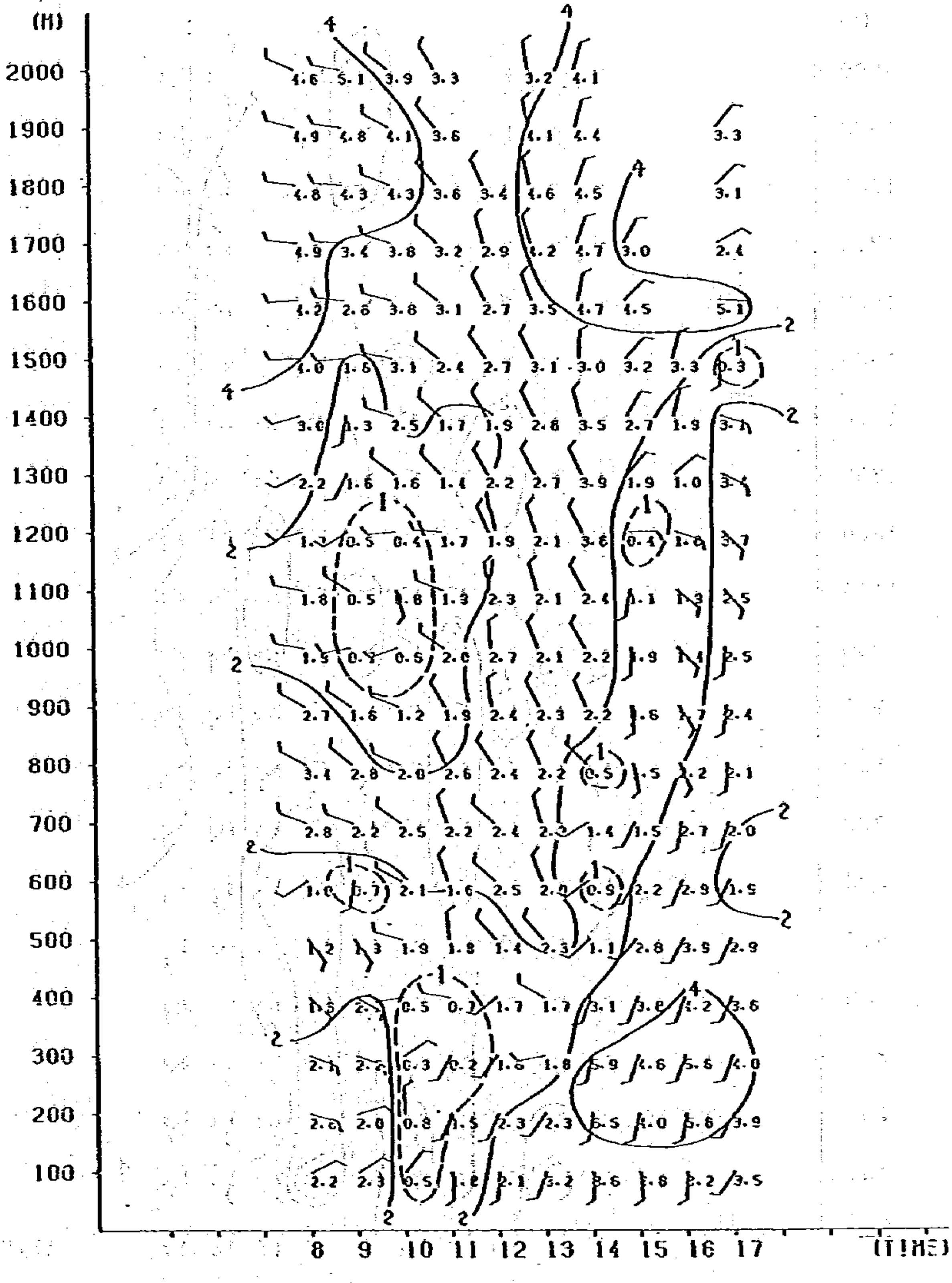
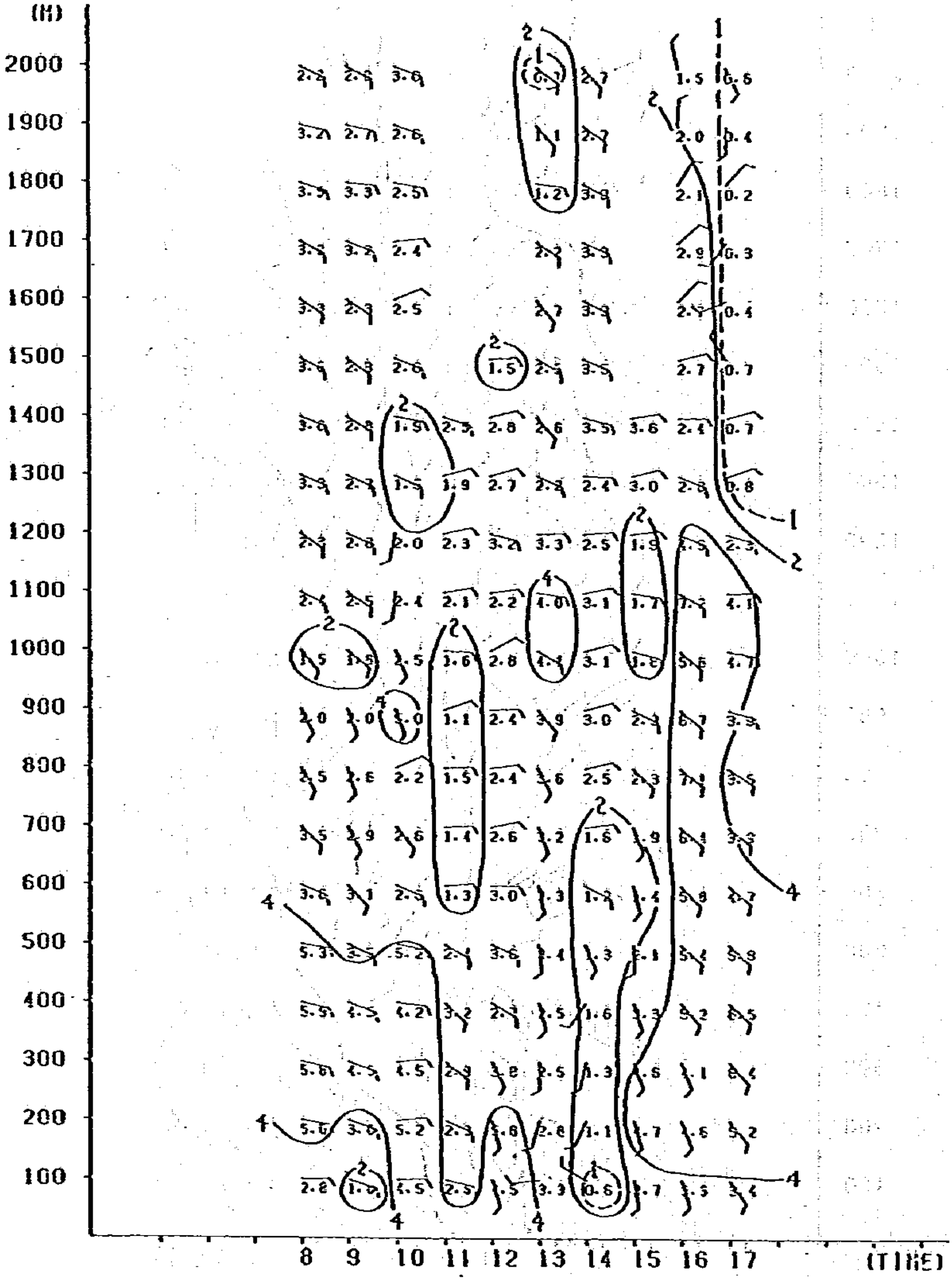


Fig. II-7-2-(2) Isopleth diagram of pilot balloon



23, 1, 1981   J.T.C.

Fig. II-7-2-(3) : Isopleth diagram of pilot balloon



24, 6, 1981 J.T.C.

Fig. II-7-2-(4) Isopleth diagram of pilot balloon

PART III SURVEY ON EMISSION SOURCES

The accurate emission sources data of the survey area is one of the important items for environmental assessment, as same as the data of ambient concentration of pollutants.

In this study, the survey on stationary sources and vessels' emission have been carried out and based on these data, the present (1981) and future (1990) SO_2 concentration have been estimated.

CHAPTER 1 COLLECTION OF EMISSIONS SOURCES DATA

For the estimation of SO_2 ambient concentration, the present emission from the existing factories and future emission from the proposed factories are to be estimated comprehensively.

In the first place, the present emission sources data have to be collected and the data thus obtained have to be compared with the data obtained from field survey, described in PART II. After the consistency of the above two data is confirmed, the estimation of total emission including future emission from the proposed factories is to be performed. Thus the survey on present and future emission sources are one of the important factors in the environmental assessment.

III-1-1 Stationary Sources

The present emission sources data have been collected by JTC from the existing factories, based on the form of questionnaire prepared by Japanese team.

The emission sources data are the important materials as the input data to evaluate the present ambient concentration and so JTC has been requested to collect as much data as possible. Items investigated and form for questionnaire are shown in Table III-1-1-(1) to -(4).

The questionnaire after modified have been sent by JTC to 61 factories and plants enumerated in Table III-1-2 and the detailed data of emission sources have been collected. Number of factories classified by type of industry, stacks and facilities are shown in Table III-1-3. Thus the data of 175 facilities and 131 stacks have been collected as the emission sources data of the present (1981).

Table III-1-1-(1) Questionnaire for emission sources' data

Serial number	Type of facility (a)	Facility's burning rate (b)	Facility's date of commencement of operation	Type of fuel and raw materials used by/with the facility (c)	Consumption rate (per hour) of fuel and raw materials (d)			Gravity of used fuel and raw materials (e)	Sulfur content of used fuel and raw materials (f)	Desulfurizing efficiency (g)	Remarks
					Rating max.	Operating max.	Normal				

Notes:

(a) Please list the facilities (e.g., Boiler, Gas Producer, Blast Furnace, Kiln, etc), see Annex I for a Classification of Facilities.

(b) Please state by Kcal/m^3/h for the burner combustion, and Kg/m^2/h for combustion of solid fuel or waste.

(c) Please list the fuels (e.g., Heavy Fuel Oil, LPG, PUB Gas, Electricity, etc) and raw materials (e.g., Iron Ore, Petroleum, Salt Cake, etc), see Annex II for a Classification of Fuels and Raw Materials.

(d) Please state by Kg/h, l/h, Nm^3/h for solid, liquid, gaseous fuel and raw materials respectively.

(e) Please state to two decimal points, e.g., 1.15.

(f) Please state in percentage to two decimal points.

(g) Please state the desulfurization efficiency (in percentage) only for the facilities where such desulfurization units are installed.

Table III-1-1-(2) Questionnaire for emission sources' data

Serial number of stack	Height of stack (a)	Inner diameter at the top of stack (b)	Flue gas volume from stack (c)			Flue gas tempera-ture (d)	Flue gas SO_2 concen-tration (e)	Type of facilities connected to stack (f)
			Rating max.	Operating max.	Normal			

Notes:
(a) Please state the stack height (in metre) from the ground level.
(b) Please state the the diameter for round stack, and length of 2 sides for square/rectangular stack.
(c) Please state the the gas volume (in Nm^3/h) from the stack.
(d) Please state the gas temperature (in °C) from the stack.
(e) Please state the SO_2 concentration (in ppm) in the gas from the stack.
(f) Please state the type and serial number of facilities connected to stack.

Table III-1-1-(3) Reference for Questionnaire

ANNEX 1 : CLASSIFICATION OF FACILITIES

Boiler
Boiler (for utility)
Boiler (for air-conditioning)
Gas Producer
Gas Heating Furnace
Roasting Furnace
Roasting Furnace (for refining of copper, lead, zinc)
Sintering Furnace
Sintering Furnace (for refining of copper, lead zinc)
Calcining Furnace
Calciner (for manufacturing phosphorus, phosphoric acid, & phosphoric fertilizer)
Galciner (for manufacturing sodium tripolyphosphate)
Pellet Baking furnace
Blast Furnace
Blast Furnace (for refining of copper, lead, zinc)
Converter
Converter (for refining of copper, lead, zinc)
Open Heart Furnace
Metal Smelting Furnace
Melting Furnace (for refining of copper, lead, zinc)
Smelter (for manufacturing phosphorus, phosphoric acid, and phosphoric fertilizer)
Smelter (for manufacturing lead pigment)
Metal Rolling Furnace
Metal Heat Treatment Furnace
Metal Forging Furnace
Petroleum Heating Furnace
Catalyst Regenerator
Sulfur Recovering Furnace
Kiln
Cement Kiln
Brick Kiln
Lime Kiln
Alumine Kiln
Pottery Kiln
Glass Melting Furnace

Table III-1-1-(4) Reference for Questionnaire

ANNEX 2 : CLASSIFICATION OF FUELS AND RAW MATERIALS

FUEL

Heavy Fuel Oil
Crude Oil
Naphtha
Light Oil
Kerosene
Black Liquor
Coal
Coke
LPG
LNG
Cracking Gas of Naphtha
Coke Oven Gas
Blast Furnace Gas
Converter Gas
Off Gas
Town Gas
Rich Gas
Petroleum Refinary Gas
Electricity
Waste Oil
Digestion Gas
Hydrogen
Methancl
Wood
Acrylic Acid Waste
Acrylic Acid Off Gas

Table III-1-1-(4) Reference for Questionnaire (Cont'd)

ANNEX 2: CLASSIFICATION OF FUELS AND RAW MATERIALS

RAW MATERIAL

Iron Ore
Recovered Sulfur
Petroleum for Refining
Salt Cake (Sodium Sulfate)
Sulfur for manufacturing Sulfuric Acid
Reactor
Reactor (for manufacturing phosphorus, phosphoric acid and phosphoric fertilizer)
Reactor (for manufacturing sodium tripolyphosphate)
Reactor (for manufacturing lead pigment)
Direct Heating Furnace
Aggregate Dryer
Raw Cement Material Dryer
Raw Brick Material Dryer
Casting Mold Dryer
Detergent Dryer
Dryer
Dryer (for refining of copper, lead, zinc)
Dryer (for manufacturing sodium tripolyphosphate)
Dryer (for manufacturing lead pigment)
Active Carbon Manufacturing Furnace
Electrolytic Refining Furnace of Aluminium
Concentrator (for manufacturing phosphorus, phosphoric acid and phosphoric fertilizer)
Reverberatory Furnace (for manufacturing lead pigment)
Coke Oven

Table III-1-2 List of factories collected emission data

Names of factory and enterprise
DRAGON POLY-FOAM INDS (S) PTE LTD
DUNLOP SINGAPORE SDN BHD
BERLI JUCKER (S) COSMETICS (PTE) LTD
METAL PRINTERS (S) PTE LTD
HITACHI KOKI (S) PTE LTD
WESTERN RUBBER (PTE) LTD
TECK CHIANG METAL MFR PTE LTD
REPCO MANUFACTURING PTE LTD
CERAMIC WORKS (PTE) LTD
UIC CHEMICALS PTE LTD
UIC MARCHON (PTE) LTD
INTERNATIONAL STEEL ROPES (PTE) LTD
MALAYSIA STEEL PIPE MANUFACTURING CO (PTE) LTD
CALTEX (ASIA) LTD
TROPICAL TIMBER INDS LTD
ANGLO AMERICAN CORPN SDN BHD
SIGMA METAL CO LTD
TOHO RUBBER PROCESSING CO PTE LTD
SINGAPORE FOLEX CORPN PTE LTD
EVERGREEN TIMBER PRODUCTS CO (PTE) LTD
BEECHAM (MANUFACTURING) SINGAPORE PTE LTD
YEOW SAN (POLYFOAM) PTE LTD
HUME INDUSTRIES (S) LTD
THE CHEMICAL CORPORATION OF SINGAPORE PTE LTD
SERVALL CASTINGS PTE LTD
BROADWAY ENTERPRISES (PTE) LTD
SINGAPORE NAGAI PTE LTD
PLASPAC (PTF) LTD
HERCULES RUBBER & CHEMICAL INDS (PTE) LTD
B & O INDS PTE LTD
GREENLAND TIMER INDS PTE LTD
CROWN ALLIANCE PTE LTD
SINGAPORE CLAY PRODUCTS (PTE) LTD
METALS & ORES PTE LTD
FIRST ROLLING MILLS (S) PTE LTD

Table III-1-2 List of factories collected emission data (Cont'd)

Names of factory and enterprise
SINGAPORE ADHESIVES & CHEMICALS PTE LTD
NATIONAL IRON & STEEL MILLS LTD
BP SINGAPORE
SINGAPORE GLASS MANUFACTURER PTE LTD
SINGAPORE WOOD INDUSTRIES PTE LTD
SUNLIGHT TIMBER PODUCTS CO (PTE) LTD
SOUTHERN WOOD PRODUCTS (PTE) LTD
INTERNATIONAL WOOD PRODUCTS LTD
JURONG PLYWOOD CO (PTE) LTD
SIME DARBY OLEO CHEMICALS LTD
ASIAN PLYWOOD CO PTE LTD
STARLIGHT TIMBER PRODUCTS CO LTD
MITSUBOSHI BELTING SINGAPORE PTE LTD
MAXIM DYEING & FINISHING FTY PTE LTD
HORIZON PAPER INDUSTRIES PTE LTD
MANUFACTURE ELEMENT PREFABRICATE PTE LTD
HONGKONG DYEING AND WEAVING (S) LTD
MOBIL OIL SINGAPORE PTE LTD
SINGAPORE REFINING CO PTE LTD
SHELL COMPANIES IN SINGAPORE
ESSO SINGAPORE PRIVATE LIMITED
SENOKO POWER STATION
PASIR PANJANG POWER STATION
JURONG POWER STATION
SUGAR INDUSTRY OF SINGAPORE LTD
RDC BRICKWORKS TILE WORKS

Table III-1-3 Number of factories, stacks and facilities classified by type of industry

Type of industry	Number of factories	Number of stacks	Number of facilities
Electric Power Ind.	3	6	17
Petroleum	4	47	68
Petrochemical	1	1	2
Chemicals	8	13	15
Pharmaceutical	3	3	4
Rubber	4	4	5
Non-Metalic	3	4	4
Food	1	1	2
Textile	3	4	7
Miscellaneous	3	7	8
Machine Tools	1	1	2
Iron & Steel	1	5	5
Fabricated Metal	6	14	14
Consumer/Industrial Electric Ind.	1	6	7
Others	19	15	15
TOTAL	61	131	175

As for the emission sources' data for the future (till 1990), the collection of information by questionnaire was found impossible, and so the following arrangements have been made.

(1) Coal firing power stations and integrated steel mill which will be sited in Pulau Seraya and Tekong. The factors related to the emission of pollutants had been mentioned in SCOPE OF WORK and Minutes of Meetings.

(2) For the existing factories in 1981, the growing rate up to 1990 FY estimated by EDB (Economic Development Board) has been applied as shown in Table III-1-4.

(3) For the expanding plan of the existing power plants, the information has been given by PUB (Public Utility Board) as shown in Table III-1-5.

Table III-1-4 Growing rate of production output classified by type of industry (1981 - 1990)

Type of industry	Growing rate
Electric Power Ind.	as developing plan
Petroleum	1.55 %
Petrochemical	9.20
Chemicals	3.40
Pharmaceuticals	3.95
Rubber	1.54
Non-Metalic	1.66
Food	2.49
Textiles	1.53
Miscellaneous	1.96
Machine Tools	4.27
Iron & Steel	2.49
Fabricated Metal	2.49
Consumer/Industrial Electrical Ind.	3.40

(from EDB information)

Table III-1-5 Outline of facilities under expanding plan

Name of factories	Proposed commis-sioning date	Facilities
Seneko Power Station-Phase III	June 1983	250 MW x 1 (oil firing)
	December 1983	250 MW x 1 (oil firing)
Seraya Power Station	1987	250 MW x 2 (oil firing)
	1988	250 MW x 1 (oil firing)
	1990	250 MW x 3 (coal firing)
Tekong Power Station	1990	350 MW x 2 (coal firing)
Tekong Integrated Steel Mill	1990	Grate Kiln
	1990	Reheating Furnace
Sumitomo Petrochemical	1983	Boiler x 2 (oil firing)

III-1-2 Vessels

Emission volume of SO_2 from the vessels corresponds to the operation status (anchoring, loading, entered, cleared and navigation), type of vessels and their tonnage. Therefore the data collected for vessels' emission is necessary to be classified by type, tonnage, entered, cleared and navigation.

In this study, the basic information has been obtained from PSA (Port of Singapore Authority) through JTC as shown in Tables III-1-6 and III-1-6-7. The estimation of the future status of the vessels are described in the next chapter of this report.

Table III-1-6 Number of vessels entered and cleared classified by type of vessels

TYPE OF VESSELS ENTERED

All Vessels (in Number)

Type of vessel		1980 Annual	1980 2nd Qtr	1980 Jan/Jun	1981 1st Qtr	1981 2nd Qtr	1981 Jan/Jun
All types	Number	24,877	6,164	12,425	6,193	6,577	12,770
	'000 NRT	155,167	37,367	75,352	38,337	44,268	82,605
Coastor & Freighter	Number	13,407	3,355	6,807	3,220	3,440	6,660
	'000 NRT	41,592	10,401	21,056	9,858	10,628	20,486
Semi-Container & Container	Number	1,880	458	917	535	566	1,101
	'000 NRT	19,166	4,648	9,287	5,221	5,536	10,757
Tanker	Number	5,192	1,294	2,552	1,309	1,379	2,688
	'000 NRT	79,737	18,903	37,573	19,844	24,408	44,252
Bulk Carrier	Number	1,000	266	525	209	273	482
	'000 NRT	11,334	2,690	5,774	2,328	2,764	5,092
Others	Number	3,398	791	1,624	920	919	1,839
	'000 NRT	3,338	725	1,662	1,086	932	2,018

TYPE OF VESSELS CLEARED

All Vessels (in Number)

Type of vessel		1980 Annual	1980 2nd Qtr	1980 Jan/Jun	1981 1st Qtr	1981 2nd Qtr	1981 Jan/Jun
All types	Number	24,820	6,191	12,392	6,136	6,547	12,683
	'000 NRT	155,369	37,886	75,305	37,305	43,671	80,976
Coastor & Freighter	Number	13,393	3,368	6,804	3,200	3,409	6,609
	'000 NRT	41,497	10,421	21,027	9,893	10,499	20,392
Semi-Container & Container	Number	1,883	455	915	533	573	1,106
	'000 NRT	19,206	4,537	9,197	5,195	5,580	10,775
Tanker	Number	5,167	1,304	2,536	1,283	1,374	2,657
	'000 NRT	80,189	19,476	37,770	19,059	23,734	42,793
Bulk Carrier	Number	991	266	513	205	274	479
	'000 NRT	11,187	2,729	5,675	2,098	2,990	5,088
Others	Number	3,386	798	1,624	915	917	1,323
	'000 NRT	5,290	723	1,654	1,060	868	1,928

Table III-1-7 Number of vessels entered and cleared classified by tonnage

VESSELS ENTERED BY CAPACITY OF VESSEL (IN NRT)

Capacity of vessel (in NRT)	All Vessels (in Number)					
	1980			1981		
	Annual	2nd Qtr	Jan/Jun	1st Qtr	2nd Qtr	Jan/Jun
All Capacity	24,877	6,164	12,425	6,193	6,577	12,770
Under 1,000	8,806	2,158	4,353	2,237	2,287	4,524
1,000 - 1,999	2,568	654	1,320	650	689	1,339
2,000 - 3,999	2,385	843	1,703	846	938	1,784
4,000 - 5,999	3,440	890	1,775	772	823	1,595
6,000 - 7,999	2,386	578	1,201	586	624	1,210
8,000 - 9,999	941	235	463	237	283	520
10,000 - 14,999	1,387	329	671	376	383	759
15,000 - 19,999	373	92	177	109	119	228
20,000 - 29,999	471	119	248	114	122	236
30,000 - 39,999	555	139	260	145	138	283
40,000 and above	565	127	254	121	171	292

VESSELS CLEARED BY CAPACITY OF VESSEL (IN NRT)

Capacity of vessel (in NRT)	All Vessels (in Number)					
	1980			1981		
	Annual	2nd Qtr	Jan/Jun	1st Qtr	2nd Qtr	Jan/Jun
All Capacity	24,820	6,191	12,392	6,136	6,547	12,683
Under 1,000	8,793	2,169	4,344	2,189	2,293	4,482
1,000 - 1,999	2,550	647	1,307	655	673	1,328
2,000 - 3,999	3,378	849	1,711	855	935	1,790
4,000 - 5,999	3,444	898	1,780	767	808	1,575
6,000 - 7,999	2,379	580	1,189	582	624	1,206
8,000 - 9,999	932	237	461	243	281	524
10,000 - 14,999	1,386	334	668	367	394	761
15,000 - 19,999	360	88	173	107	120	227
20,000 - 29,999	465	121	242	116	118	234
30,000 - 39,999	552	137	260	144	136	280
40,000 and above	572	131	257	111	165	276

CHAPTER 2 ESTIMATION OF SO_2 EMISSION

Based on the emission sources' data obtained from stationary sources and vessels, SO_2 emission volume have been estimated as described hereunder.

III-2-1 Stationary Sources

III-2-1-1 Estimation methods of SO_2 emission

(1) The present

Sulfur contained in the fuel is oxidized in the process of combustion and most of them are discharged as SO_2. Therefore, SO_2 volume emitted from the stationary sources are calculated from fuel consumption rate and sulfur contents of fuel of each facility by following equations.

$$Q_s = W \times \frac{S}{100} \times \frac{64}{32} \quad \text{(when unit of sulfur is weight \%)}$$

$$= W \div \text{gravity} \times \frac{S}{100} \times \frac{64}{22.4} \quad \text{(when unit of sulfur is volume \%)}$$

Where; Q_s : yearly SO_2 emission volume (kg/year)
W : yearly fuel consumption rate (kg/year)
(= hourly fuel consumption rate x yearly operation hours)
S : Sulfur content of fuel (%)
(64 : SO_2 molecular weight
32 : mulecular weight of sulfer
22.4 : volume of 1 mol in normal combustion)

In this study, SO_2 emission volume has been calculated by the above equation. However, SO_2 emission from Sulfur Plant Incinerator, Sulfur Acid Plant, Kiln & etc., are not obtainable from the equation, because SO_2 generated by combustion is absorbed into the products by the reaction of the production processes. For these exceptional cases, SO_2 emission is usually estimated from SO_2 concentration and gas volume measured by the respective facility and by the following equation.

$$Q_s = G \times C_s \times 10^{-6} \times \frac{64}{22.4}$$

where; Q_s : yearly SO_2 emission volume (kg/year)

G : yearly flue gas volume (Nm^3/year)

(= measured gas volume [Nm^3/hr] x yearly operation hour [hr/year])

C_s : measured SO_2 concentration (ppm)

In this study, the collected data indicated zero for SO_2 measured concentration in these exceptional facilities and so the emission volume were calculated as zero. As for the flue gas volume, the indicated values in questionnair have been adopted and when the values are not indicated, calculated values were adopted which were calculated from fuel consumption rate, theoretical gas volume and other factors.

Further, in order to confirm the accuracy of indicated values, the comparison with the calculated values has been performed and when some doubts are found in the indicated values, the calculated values were adopted. Table III-2-1 shows the results of comparison between indicated and calculated values.

Table III-2-1 Comparison of indicated and calculated values of flue gas volume

Name of factories	Stack No.	Type of facilities	Flue gas volume (Nm^3/hr)		Ratio Ind./Cal.	Indi. value adopted	Remarks
			Indicated	Calculated			
10. UIC CHEMICALS	1	Boiler	465	254	1.83		Difference with theoretical gas volume is too large. Calculated value adopted.
	2	Dryer	26,663	6,307	4.23	x	Generally gas volume is larger than theoretical volume in dryer.
11. UIC MARCHON	1	Sulfer plant	1,141	-		x	Theoretical gas volume uncalculatable
	2	Boiler	442	530	0.83	x	
24. THE CHEMICAL CO	2	Acid plant	2,800	-		x	Theoretical gas volume uncalculatable
32. CROWN ALLIANCE	1	Melting furnace	543	1,972	0.28		Difference with theoretical gas volume is too large. Calculated value adopted.
34. METALS & ORES	1	Metal heating furnace	22	186	0.12		- ditto -
	2	Boiler	17	954	0.02		- ditto -
	3	Dryer	4	371	0.01		- ditto -
	4	Metal heating furnace	334	3,339	0.10		- ditto -
	6	Boiler	10	318	0.03		- ditto -
39. SINGAPORE GLASS	1	Glass melting furnace	6,834	37,313	0.18		- ditto -
50. HORIZON PAPER	1	Boiler	7,903	18,596	0.42		- ditto -
53. MOBIL OIL	1	Heating furnace	28,336	35,173	0.81	x	
	2	Heating furnace	17,801	20,979	0.85	x	
	3	Heating furnace	10,313	11,999	0.86	x	
	4	Heating furnace	4,392	5,176	0.85	x	
	5	Heating furnace	16,027	18,940	0.85	x	
	6	Heating furnace	2,574	3,456	0.74	x	
	7	Heating furnace	2,362	3,132	0.75	x	
	9	Heating furnace	202,556	236,979	0.85	x	
	10	Heating furnace	72,306	95,407	0.76	x	
	11	Generating boiler	44,053	49,476	0.89	x	
	12	Sulfur plant	2,177	1,890	1.15	x	
	13	Flare stack	330	-		x	Theoretical gas volume uncalculatable
	14	Flare stack	330	-		x	- ditto -
	15	Heating furnace	88,750	122,734	0.72	x	
	16	Generating boiler	24,177	26,070	0.93	x	

Table III-2-1 Comparison of indicated and calculated values of flue gas volume (Cont'd)

Name of factories	Stack No.	Type of facilities	Flue gas volume (Nm^3/hr)		Ratio Ind./Cal.	Indi. value adopted	Remarks
			Indicated	Calculated			
55. SHELL	1	Heating furnace	106,560	134,657	0.79	x	
	2	Heating furnace	124,920	157,847	0.79	x	
	3	Heating furnace	2,160	2,693	0.80	x	
	4	Heating furnace	11,520	14,588	0.79	x	
	5	Heating furnace	195,840	248,142	0.79	x	
	6	Heating furnace	94,680	119,994	0.79	x	
	7	Heating furnace	191,520	242,681	0.79	x	
	8	Heating furnace	69,840	88,499	0.79	x	
56. ESSO	1	Heating furnace	93,297	128,424	0.73	x	
	2	Heating furnace	5,829	5740	1.03	x	
	3	Heating furnace	3,936	2,916	1.35	x	
	4	Heating furnace	16,065	15,085	1.06	x	
	5	Heating furnace	91,719	102,261	0.90	x	
	6	Heating furnace	1,766	1,342	1.32	x	
	7	Heating furnace	83,092	72,769	1.14	x	
	8	Generating boiler	7,244	4,322	1.68	x	
	9	Generating boiler	98,508	94,618	1.04	x	
57. SENEKO POWER STATION	1	Generating boiler	919,368	943,683	0.97	x	
	2	Generating boiler	1,859,478	1,867,629	1.00	x	
58. PASIR PANJANG POWER STATION	1	Generating boiler	404,295	336,829	1.20	x	
	2	Generating boiler	404,295	336,829	1.20	x	
59. JURONG POWER STATION	1	Generating boiler	661,017	822,616	0.80	x	
	2	Generating boiler	846,102	1,066,463	0.79	x	
61. SUGAR INDUSTRY	1	Boiler	23,400	59,360	0.39		Difference with theoretical gas volume is too large.
62. RBC BRICKWORKS	1	Boiler	3,731	8,745	0.43		Difference with theoretical gas volume is too large. Calculated value adopted.
	2	Kiln	25,973	18,253	1.42	x	Generally gas volume is larger than theoretical volume in kiln.
	3	Kiln	25,973	18,253	1.42	x	- ditto -
	4	Kiln	38,959	17,808	2.19	x	- ditto -

The calculated values of flue gas volume have been obtained by the following equations.

$$G_h = W \times K \times \frac{21}{21-O_2}$$ (when unit of theoretical gas coefficient is [Nm^3/kg])

$$= W \div \text{gravity} \times K \times \frac{21}{21-O_2}$$ (when unit of theoretical gas coefficient is [Nm^3/l] or [Nm^3/Nm^3])

where; G_h : calculated value of flue gas volume (Nm^3/hr)

W : fuel consumption rate in normal condition (kg/hr)

K : theoretical gas coefficient (Nm^3/kg) or (Nm^3/l) or (Nm^3/Nm^3)

O_2 : residual oxygen concentration (%)

The supplementary explanation on the above equation is given as follows:

"Theoretical gas coefficient" is the assumed gas volume generated when a unit of fuel is completely burnt by the theoretical volume of air (minimum air for complete combustion of fuel), and it is calculated from combustion reaction of combustible elements contained in the fuel, such as carbon, hydrogen, sulfur and so on.

Table III-2-2 shows equations for combustion reaction of combustible elements, combustion gas volume and so on.

Table III-2-2 Combustion factors of combustible elements contained in fuel

Combustible elements		Combustion reaction equation Weight kg based molecular weight Volume Nm^3 based molecular weight	Combustible element 1kg									
			Combustion byproducts			Oxygen consumption		Residual nitrogen		Combustion gas	
Name	Symbol		Name	Symbol	Volume	Symbol	Volume	Symbol	Volume	Symbol	Volume
Carbon	C	$C + O_2 = CO_2$ 12kg, 32kg, 44kg 22.4, 22.4Nm^3	Carbonic acid gas	CO_2	3.667kg 1.867Nm^3	O_2	2.667kg 1.867Nm^3	N_2	8.78kg 7.02Nm^3	CO_2 & N_2	12.45kg 8.89Nm^3
		$C + \frac{1}{2}O_2 = CO$ 12kg, 16kg, 28kg $\frac{1}{2}$ x 22.4, 22.4Nm^3	Carbon monoxide	CO	2.333kg 1.867Nm^3	O_2	1.333kg 0.933Nm^3	N_2	4.39kg 3.51Nm^3	CO & N_2	6.72kg 5.38Nm^3
Hydrogen	H	$H + \frac{1}{2}O_2 = H_2O$ 2kg, 16kg, 18kg $\frac{1}{2}$ x 22.4, 22.4Nm^3	Water vapor	H_2O	9kg 11.2Nm^3	O_2	8kg 5.6Nm^3	N_2	26.34kg 21.07Nm^3	H_2O & N_2	35.34kg 32.27Nm^3
Sulfur	S	$S + O_2 = SO_2$ 32kg, 32kg, 64kg 22.4, 22.4Nm^3	Sulfur dioxide	SO_2	2kg 0.7Nm^3	O_2	1kg 0.7Nm^3	N_2	3.29kg 2.63Nm^3	SO_2 & N_2	5.29kg 3.33Nm^3

The theoretical gas coefficient is obtainable from elemental composition of each fuel as shown in Table III-2-2. In this study, the calculated theoretical flue gas coefficient shown in Table III-2-3 has been employed. Further, the coefficient mentioned in the table is the flue gas volume which include water vapour.

Table III-2-3 Theoretical flue gas coefficient classified by type of fuels

Type of fuel	Theoretical flue gas coefficient	Unit
Heavy oil	10.6	Nm^3/l
Diesel oil	10.0	Nm^3/l
Heavy naphtha	8.8	Nm^3/l
Reduced Crude	10.6	Nm^3/l
Crude oil	10.2	Nm^3/l
Tail gas	13.9	Nm^3/Nm^3
Gas	14.4	Nm^3/kg
Others (wood)	4.2	Nm^3/kg

In the actual combustion, more air than theoretical volume is supplied for complete combustion. Therefore the flue gas volume should be corrected with the factor of excess air and $\frac{21}{21 - O_2}$ is the correction coefficient. O_2 is oxygen concentration contained in flue gas, and in this study, the assumed values classified by type of facilities shown in Table III-2-4 have been employed.

Table III-2-4 Residual oxygen classified by type of facilities

Type of facilities	Residual oxygen (%)
Petroleum Heating Furnace	7.0
Boiler (Power Generation)	5.0
Boiler	7.0
Sulfur Plant Incinerator	13.0
Flare Stack	6.0
Gas Producer	6.0
Oil Combustion Furnace	6.0
Thermal Fluid Heater	15.0
Sadium Silicate Furnace	6.0
Sulphuric Acid Plant	10.0
Metal Heating Furnace	9.0
Reheating Furnace	9.0
Kiln	16.0
Dryer	15.0
Burner	13.0
Glass Melting Furnace	13.0
Smelter	14.0
Zn. Smelter	18.0

(2) Future

Future (1990) SO_2 emission volume has been estimated both from the present emission sources and the new emission sources which will be sited by 1990.

Future emission volume of SO_2 from the existing sources has been estimated by multiplying the growing rate (EDB data) of each industry with their oil consumption rate and the same equations for calculation of SO_2 emission volume, described in III-2-1-1, have been applied. In the calculation, consideration has been given to APU regulation that industries or facilities commissioned after 1975 are compulsory to use the oil containing sulfer less than 2% with the exception of SENEKO Power Station.

The growing rate of each industry based on EDB data during the period from 1981 to 1990 is shown in Table III-2-5. The growing rate of electric power industry and petroleum were not based on EDB data, because the detailed information on future developing plan of power stations have been given by PUB and as for the petroleum industry had to make the corrected estimation under the recent international oil situations.

Table III-2-5 Growing rate of production classified by type of industry (1981 - 1990)

Type of industry	Growing rate	Remarks
Electric Power Ind.	-	Data given by PUB
Petroleum	1.55 %	corrected to 1.00%
Petrochemical	9.20	
Chemicals	3.40	
Pharmaceuticals	3.95	
Rubber	1.54	
Non-Metalic	1.66	
Food	2.49	
Textiles	1.53	
Miscellaneous	1.96	
Machine tools	4.27	
Iron & Steel	2.49	
Consumer/Industrial Electrical Industry	3.40	

The new emission sources under developing plans which will be sited by 1990 are shown in Table III-2-6.

The emission volume of SO_2 from these new sources have been estimated by the same methods applied for the present.

Table III-2-6 Outline of new sources

Name of facility	Proposed date of commissioning	Outline
Seneko Power Station-Phase III	June 1983	250 MW x 1 (oil burning)
	December 1983	250 MW x 1 (oil burning)
Seraya Power Station	1987	250 MW x 2 (oil burning)
	1988	250 MW x 1 (oil burning)
	1990	250 MW x 3 (coal firing)
Tekong Power Station	1990	350 MW x 2 (coal firing)
Tekong Integrated Steel Mill	1990	Grate Kiln (coal firing)
	1990	Reheating Furnace (coal)
Sumitomo Petrochemical	1983	Boiler x 2 (oil firing)

III-2-1-2 Results of estimation of emission volume

The estimation of SO_2 emission volume results as 226,362 ton/year for the present (1981) and 480,019 ton/year for the future (1990) which is almost 2.1 times of the present.

Estimated SO_2 emission volume classified by factories and enterprises is shown in Table III-2-7, the emission volume classified by type of industry is shown in Table III-2-8 and the volume classified by type of factories is shown in Table III-2-9.

From Table III-2-8, it is found that power stations and oil refinary hold 98% for the present and 97.6% for the future. Among them, power stations hold the majority of the emission volume which are 77.1% of the present and 68.2% of the future.

From Table III-2-9, the same tendency is confirmed that the emission volume from boiler for power generation and petroleum heating furnace for oil refinery are estimated to emit 97.9% of the present and the boiler for power generation, petroleum heating furnace and kiln of the integrated steel mill are estimated to emit 96.4% of the total volume in the future.

Fig. III-2-1 shows ranked diagram of SO_2 emission volume from stationary sources of the present by mesh. From the figure, it is clearly found that the factories and plants are concentrating in Jurong area located in the south west side of Singapore main island.

Table III-2-7 SO_2 emission volume classified by factory and enterprise

No.	SO_2 emission volume Present (1981) (ton/year)	Future (1990) (ton/year)	Names of factory and enterprise
1	25.9	238.5	DRAGON POLY-FOAM INDS (S) PTE LTD
2	34.0	52.5	DUNLOP SINGAPORE SDN BHD
3	10.1	29.5	BERLI JUCKER (S) COSMETICS (PTE) LTD
4	0.0	0.0	METAL PRINTERS (S) PTE LTD
5	0.0	0.0	HITACHI KOKI (S) PTE LTD
6	2.4	3.7	WESTERN RUBBER (PTE) LTD
7	4.2	10.5	TECK CHIANG METAL MFR PTE LTD
8	0.9	1.8	REPCO MANUFACTURING PTE LTD
9	0.0	0.0	CERAMIC WORKS (PTE) LTD
10	10.0	33.9	UIC CHEMICALS PTE LTD
11	9.1	31.0	UIC MARCHON (PTE) LTD
12	0.9	2.4	INTERNATIONAL STEEL ROPES (PTE) LTD
13	21.7	54.0	MALAYSIA STEEL PIPE MANUFACTURING CO (PTE) LTD
14	1.3	4.6	CALTEX (ASIA) LTD
15	0.0	0.0	TROPICAL TIMBER INDS LTD
16	0.0	0.0	ANGLO AMERICAN CORPN SDN BHD
17	5.6	39.0	SIGMA METAL CO LTD
18	61.1	94.3	TOHO RUBBER PROCESSING CO PTE LTD
19	0.0	0.0	SINGAPORE FOLEX CORPN PTE LTD
20	0.0	0.0	EVERGREEN TIMBER PRODUCTS CO (PTE) LTD
21	2.8	10.9	BEECHAM (MANUFACTURING) SINGAPORE PTE LTD
22	24.3	171.3	YEOW SAN (POLYFOAM) PTE LTD
23	56.1	139.8	HUME INDUSTRIES (S) LTD
24	85.2	289.8	THE CHEMICAL CORPORATION OF SINGAPORE PTE LTD
25	0.0	0.0	SERVALL CASTINGS PTE LTD
26	137.8	312.6	BROADWAY ENTERPRISES (PTE) LTD
27	0.0	0.0	SINGAPORE NAGAI PTE LTD
28	0.3	0.5	PLASPAC (PTF) LTD
29	4.6	7.0	HERCULES RUBBER & CHEMICAL INDS (PTE) LTD
30	0.0	0.0	B & O INDS PTE LTD
31	0.0	0.0	GREENLAND TIMER INDS PTE LTD
32	21.1	34.9	CROWN ALLIANCE PTE LTD

Table III-2-7 SO_2 emission volume classified by factory and enterprise (Cont'd)

No.	SO_2 emission volume Present (1981) (ton/year)	Future (1990) (ton/year)	Names of factory and enterprise
33	215.9	386.6	SINGAPORE CLAY PRODUCTS (PTE) LTD
34	40.7	218.8	METALS & ORES PTE LTD
35	12.4	48.0	FIRST ROLLING MILLS (S) PTE LTD
36	11.3	38.4	SINGAPORE ADHESIVES & CHEMICALS PTE LTD
37	1,529.4	3,838.6	NATIONAL IRON & STEEL MILLS LTD
38	1.8	6.1	BP SINGAPORE
39	401.8	666.1	SINGAPORE GLASS MANUFACTURER PTE LTD
40	0.0	0.0	SINGAPORE WOOD INDUSTRIES PTE LTD
41	0.0	0.0	SUNLIGHT TIMBER PODUCTS CO (PTE) LTD
42	0.0	0.0	SOUTHERN WOOD PRODUCTS (PTE) LTD
43	0.0	0.0	INTERNATIONAL WOOD PRODUCTS LTD
44	0.0	0.0	JURONG PLYWOOD CO (PTE) LTD
45	179.5	610.9	SIME DARBY OLEO CHEMICALS LTD
46	0.0	0.0	ASIAN PLYWOOD CO PTE LTD
47	0.0	0.0	STARLIGHT TIMBER PRODUCTS CO LTD
48	18.9	80.8	MITSUBOSHI BELTING SINGAPORE PTE LTD
49	39.4	60.3	MAXIM DYEING & FINISHING FTY PTE LTD
50	343.7	671.9	HORIZON PAPER INDUSTRIES PTE LTD
51	0.0	0.0	MANUFACTURE ELEMENT PREFABRICATE PTE LTD
52	114.9	175.9	HONGKONG DYEING AND WEAVING (S) LTD
53	5,623.0	5,529.6	MOBIL OIL SINGAPORE PTE LTD
54	8,131.3	8,131.3	SINGAPORE REFINING CO PTE LTD
55	20,974.0	20,974.0	SHELL COMPANIES IN SINGAPORE
56	12,508.3	12,508.3	ESSO SINGAPORE PRIVATE LIMITED
57	89,229.5	13,1142.9	SENOKO POWER STATION
58	21,518.1	21,518.1	PASIR PANJANG POWER STATION
59	63,761.9	63,761.9	JURONG POWER STATION
61	1,029.1	2,563.5	SUGAR INDUSTRY OF SINGAPORE LTD
62	158.2	309.3	RDC BRICKWORKS TILE WORKS
63	-	78,907.2	SERAYA POWER STATION
64	-	32,000.0	TEKONG POWER STATION
65	-	90,102.9	TEKONG INTEGRATED STEEL MILL
66	-	4,204.8	SUMITOMO PETROCHEMICAL
TOTAL	226,362.5	480,018.5	

Table III-2-8 SO_2 emission volume classified by type of industry

Type of industry	Present (1981) Number of factory	Number of stack	Number of facility	SOx volume (t/y)	& %	Future (1990) Number of factory	Number of stack	Number of facility	SOx volume (t/y)	& %	Additional SOx volume
Electric Power Ind.	3	6	17	174,509.5	77.1	5	10	27	327,330.1	68.2	152,820.6
Petroleum	4	47	68	47,236.6	20.9	4	47	68	47,143.1	9.8	
Petrochemical	1	1	2	25.9	0.01	2	2	4	4,443.3	0.9	4,204.8
Chemicals	8	13	15	436.0	0.2	8	13	15	1,327.3	0.3	
Pharmaceuticals	3	3	4	37.2	0.02	3	3	4	211.7	0.04	
Rubber	4	4	5	102.1	0.05	4	4	5	157.5	0.03	
Non-Metalic	3	4	4	638.8	0.3	3	4	4	1,087.6	0.2	
Food	1	1	2	1,029.1	0.5	1	1	2	2,563.5	0.5	
Textiles	3	4	7	154.6	0.1	3	4	7	236.7	0.04	
Miscellaneous	3	7	8	502.8	0.2	3	7	8	983.0	0.2	
Machine Tools	1	1	2	18.9	0.01	1	1	2	80.8	0.02	
Iron & Steel	1	5	5	1,529.4	0.7	2	7	7	93,941.5	19.6	90,102.9
Fabricated Metal	6	14	14	100.9	0.04	6	14	14	293.7	0.06	
Consumer/Industrial Electrical Ind.	1	6	7	40.7	0.02	1	6	7	218.8	0.05	
Others	19	15	15	0.0	0.00	19	15	15	0.0	0.00	
TOTAL	61	131	175	226,362.4	100.0	65	138	189	480,018.5	100.0	247,128.2

Remarks: Future SO_2 emission volume includes present.

Table III-2-9 SO_2 emission volume classified by type of facility

Type of facility	Present (1981)			Future (1990)			
	Number of facility	SO_2 volume (t/y) & %		Number of facility	SO_2 volume (t/y) & %		Additional SO_2 volume
Petroleum Heating Furnace	52	40,464.4	17.9	52	40,326.0	8.4	
Boiler (Power Generation)	25	181,110.9	80.0	35	333,979.4	69.6	152,820.5
Boiler	52	2,265.6	1.0	52	9,858.9	2.1	4,204.8
Sulfur Plant Incinerator	3	1.9	0.00	3	2.1	0.00	
Flare Stack	2	2.3	0.00	2	2.3	0.00	
Gas Producer	2	16.6	0.01	2	16.6	0.00	
Oil Combustion Furnace	4	151.3	0.1	4	151.3	0.03	
Thermal-Fluid-Heater	1	1.8	0.00	1	6.1	0.00	
Sadium Silicate Furnace	1	85.2	0.04	1	289.8	0.06	
Sulphuric Acid Plant	1	0.0	0.00	1	0.0	0.0	
Metal Heating Furnace	9	62.0	0.03	9	279.3	0.06	
Reheating Furnace	3	1,365.4	0.6	4	5,904.0	1.2	2,502.9
Kiln	9	382.7	0.2	10	88,402.2	18.4	87,600.0
Dryer	4	10.4	0.00	4	35.0	0.00	
Burner	1	18.4	0.01	1	62.7	0.01	
Glass Melting Furnace	1	401.8	0.2	1	666.1	0.1	
Smelter	3	21.3	0.01	3	35.3	0.00	
Zn. Smelter	1	0.5	0.00	1	1.3	0.00	
Others	1	0.0	0.00	1	0.0	0.0	
TOTAL	175	226,362.4	100.0	187	480,018.5	100.0	247,128.2

Remarks: Future SO_2 emission volume include present.

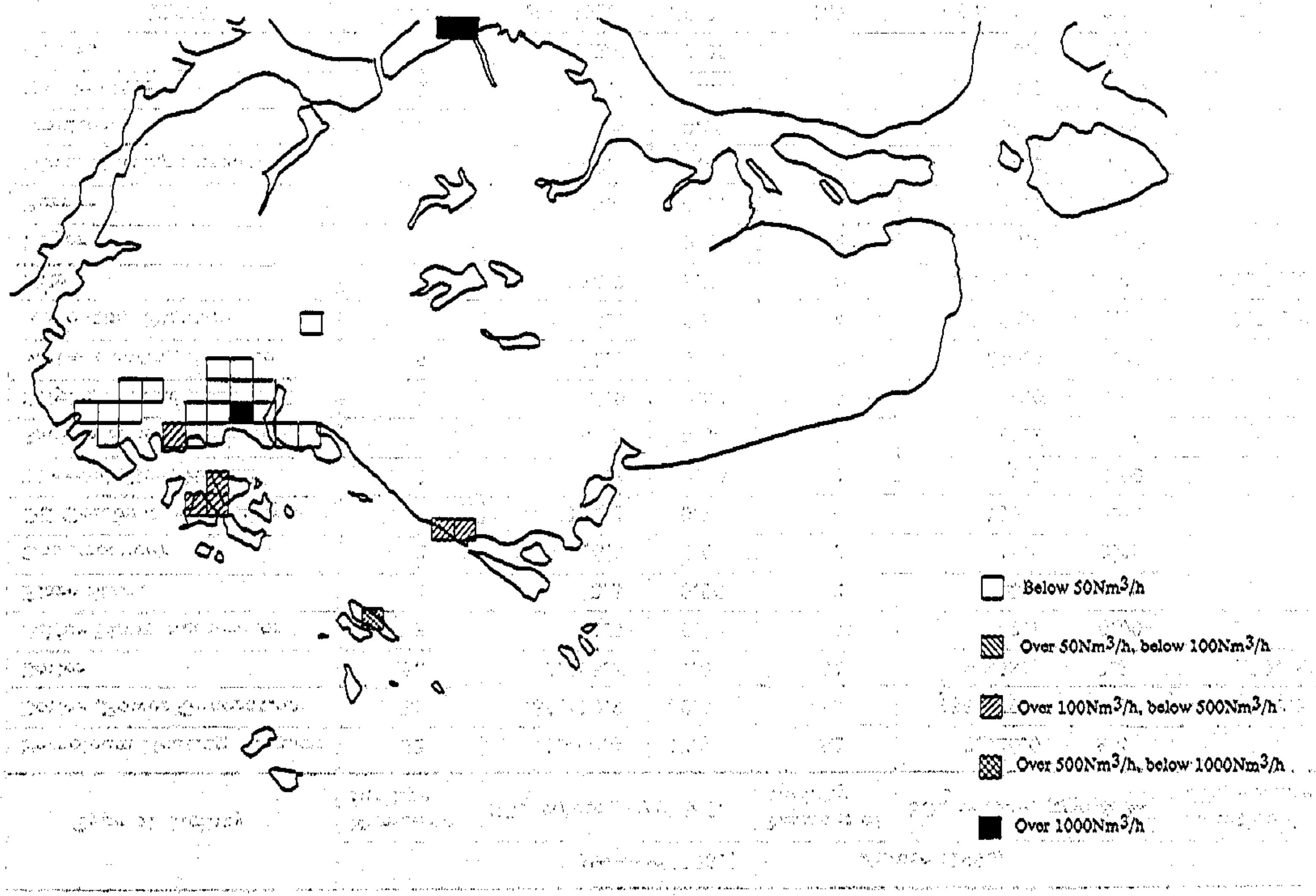


Fig. III-2-1-(1) Ranked diagram of yearly average SO_2 emission volume by mesh (present stationary)

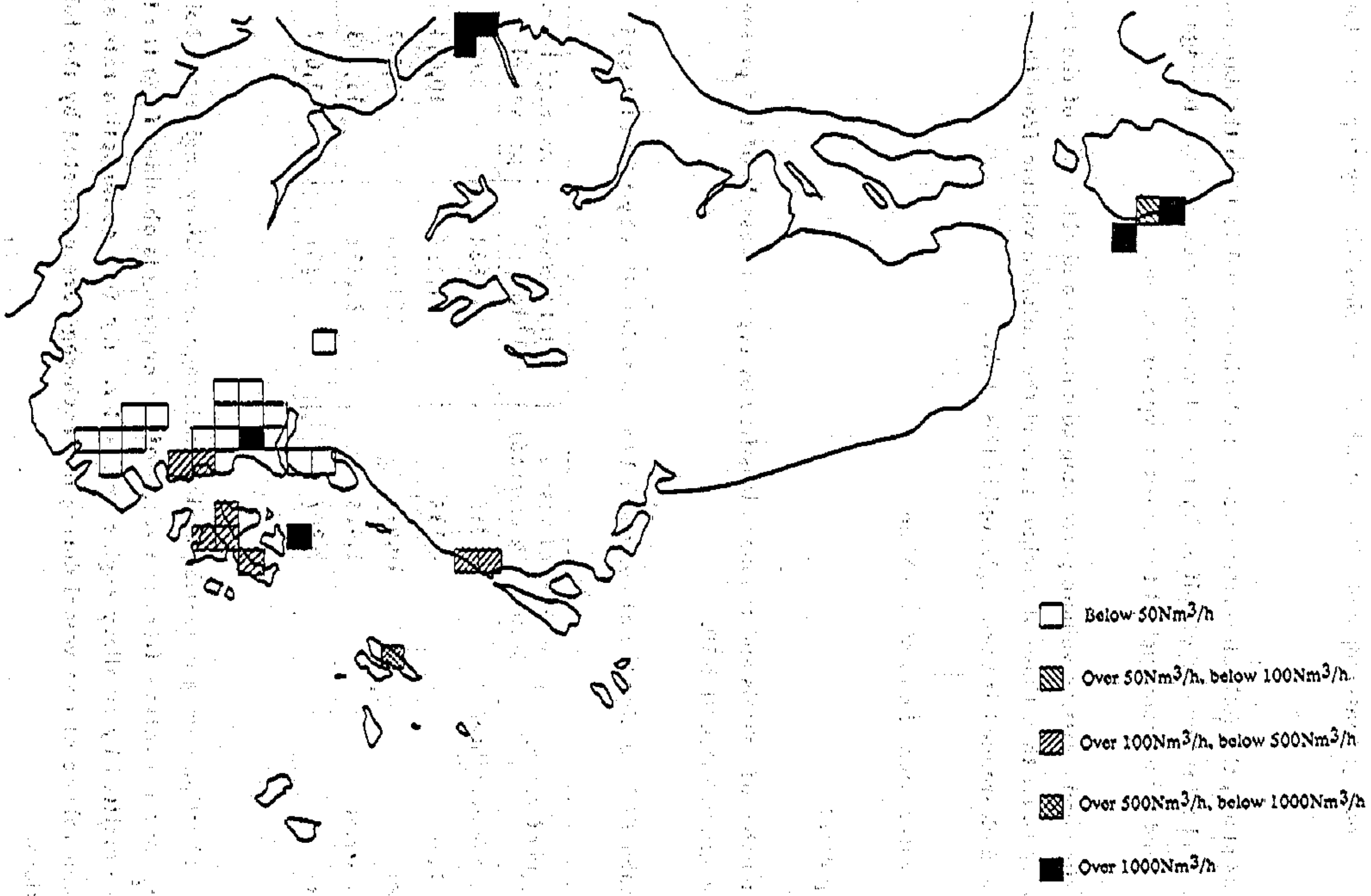


Fig. III-2-1-(2) Ranked diagram of yearly average SO_2 emission volume by mesh (future stationary)

III-2-2 Emission from Vessels

SO_2 emission volume from the vessels are usually estimated from the data on vessels statuses (anchorage, entered, and cleared) which are classified by type and tonnage of vessels.

In this study, the full information was not obtainable and so from the data on number of vessels and total tonnage classified by type of vessels, each average tonnage has been calculated and those were applied to the total type of vessels.

The time and emission volume pertaining to entering and clearance of the vessels are usually very small than those of anchorage, and the emission volume from the vessels in entering and clearance has been neglected in this study.

III-2-2-1 Estimation of emission volume

(1) The present

The number of vessels and tonnage classified by type of vessels of the present (1981) are shown in Table III-2-10.

Table III-2-10 Number of vessels and tonnage classified by type of vessel

Type of vessel	Number of vessel (entered & cleared)	Total tonnage (10^3 ton)	Average tonnage per vessel
Coaster & Freighter	26,458	81,884	3,095
Container	4,138	41,438	10,014
Tanker	10,616	171,628	16,167
Bulk Carrier	1,914	21,252	11,103
Others	7,207	7,257	1,007

The combustion engine operating during anchorage is auxiliary engine and boiler and so SO_2 emission volume from one vessel of one entering is obtained from the total of volume emitted by auxiliary engine and boiler. The fuel consumption rate and SO_2 emission volume of one vessel during her anchorage are estimated by the following equations.

(a) Auxiliary engine

Fuel consumption rate (kg/vessel) =

0.165 x rated power (PS) x load factor x anchoring hour (H)

SO_2 emission volume =

fuel consumption rate (kg/vessel) x sulfur content (%) x $\frac{1}{100} \times \frac{64}{32}$

Flue gas volume (Nm^3/vessel) =

5.46 x rated power (PS) x load factor x anchoring hour (H)

(b) Auxiliary boiler

Fuel consumption rate =

rated fuel consumption rate (kg/v.) x load factor x anchoring hour (H)

SO_2 emission volume =

fuel consumption rate (kg/v.) x sulfur content (%) x $\frac{1}{100} \times \frac{64}{32}$

Flue gas volume =

fuel consumption rate x theoretical gas volume (Nm^3/kg)

In the above equation, the rating power (PS) means the rating power of auxiliary engine installed in the vessel and the values have been obtained by the equations mentioned in Table III-2-11. The rating power of the auxiliary boiler is also obtained by the equation mentioned in Table III-2-11.

The anchoring hour is the number of hours required for one entering of one vessel and the values mentioned in Table III-2-12 have been applied. The values of sulfur content mentioned in Table III-2-12 have also been applied.

Load factor means the average load rate of auxiliary engine and boiler during anchorage. As for the load rate of auxiliary engine, the values were set up as 0.63 for time of loading work and 0.39 for non-loading time, and estimated percentage of loading work time during anchorage was set up as 0.23. So the average load rate of the vessel under loading work is:

$$0.39 + (0.63 - 0.39) \times 0.23 = 0.445$$

The average load rate of auxiliary boiler was set up as 0.5.

As the theoretical flue gas volume, 11.7 Nm^3/kg for heavy oil has been applied.

Table III-2-11 Rated fuel consumption rate of auxiliary engine and boiler classified by type of vessel

Type of vessel	Rating power & number of auxiliary engine	Rated fuel consumption rate of auxiliary boiler
Coaster & Freighter	$7.7 X^{0.4} \times 2$	$0.1 X^{0.79}$
Container	$2.2 X^{0.6} \times 2$	$0.1 X^{0.79}$
Tanker	$10 X^{0.37} \times 2$	$0.69 X^{0.76}$
Bulk Carrier	$7.7 X^{0.4} \times 2$	$0.10 X^{0.79}$
Others	$1.5 X^{0.63} \times 3$	-

Table III-2-12 Table of coefficient of vessels

Type of vessel	Number of vessel (entered & cleared)	Total tonnage (10^3 t)	Average tonnage (t/v.)	Main engine rated power (PS)	Auxiliary rated power (PS/e.)	Auxiliary boiler fuel consumption (kg/hr)	Load rate (anchorage)		Anchoring hour (H)	Sulfur content		Stack height (m)	Flue gas temp. (°C)
							Aux. E.	Aux. B.		Main & aux.	Aux. boiler		
Coaster & Freighter	26,458	81,884	3,095	3,529	192	57	0.445	0.5	47	1.0	1.6	20	300
Container	4,138	41,438	10,014	14,433	553	145	0.39	0.5	34	1.0	1.6	20	300
Tunker	10,616	171,628	16,167	10,598	361	1,090	0.445	0.5	30	1.0	1.6	20	300
Bulk Carrier	1,914	21,252	11,103	8,096	320	157	0.445	0.5	34	1.0	1.6	20	300
Others	7,207	7,257	1,007	2,456	117	-	0.39	0.5	3	1.0	1.6	20	300

(2) The future

The data on future status of the vessels have not been obtained and so the future emission volume from the vessels have been estimated by the followings.

The number of tanker assumed as the same with the present. For the other types of vessels except the tanker, the growing rate of industrial production (EDB data) has been adopted in estimation. Besides the above, the additional correction to cover the requirements from the newly sited factories have been made by the following equation.

$$\text{Necessary number of vessels} = \frac{\text{Fuel consumption rate (ton)}}{\text{Carrying capacity of one vessel (ton)} \times \text{loading rate}}$$

In the above equation, the carrying capacity of the vessel was assumed as 2 times of total tonnage and the average tonnage of the vessel was assumed as the same with the present. The loading rate of tanker and bulk carrier were assumed as 0.85 and 0.65 respectively.

The number of vessels classified by type of vessels are shown in Table III-2-13.

Table III-2-13 Number of vessels classified by type of vessel (future)

Type of vessel	Number of vessel (entered & cleared) in future	Number of vessel required for newly sited factories
Coaster & Freighter	69,055	
Container	10,800	
Tanker	10,791	175
Bulk Carrier	5,918	923
Others	18,810	

Remarks: Number of vessels required for newly sited factories are included in the future number of vessels.

III-2-2-2 Results of estimation of emission volume

SO_2 emission volume from the vessels have been estimated as 3,917 ton/year for the present and 5,705 ton/year for the future (1990) which corresponds 1.5 times of the present. SOx emission volume classified by type of vessels are shown in Table III-2-14.

Table III-2-14 SOx emission volume classified by type of vessel

Type of vessel	Present (1981)		Future (1990)	
	SOX emission volume (ton/year)	(%)	SOX emission volume (ton/year)	(%)
Coaster & Freighter	743.5	19.0	1,936.8	33.9
Container	213.3	5.4	555.6	9.7
Tanker	2,861.5	73.1	2,908.7	51.0
Bulk Carrier	97.0	2.5	299.5	5.2
Others	1.8	0.1	4.7	0.1
Total	3,917.1	100.0	5,705.3	100.0

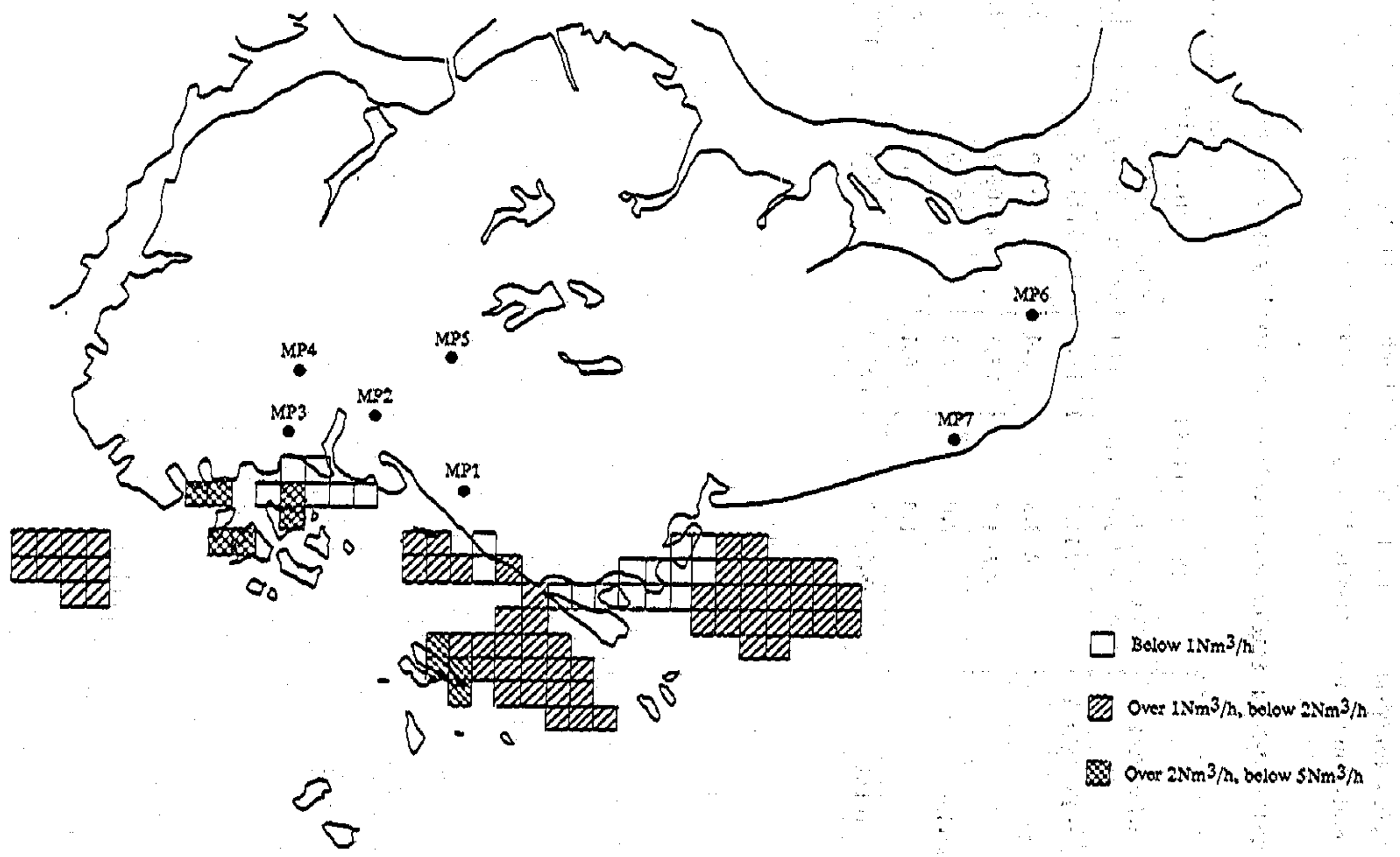


Fig. III-2-2-(1) Ranked diagram of yearly average SO_2 emission volume from vessels (present)

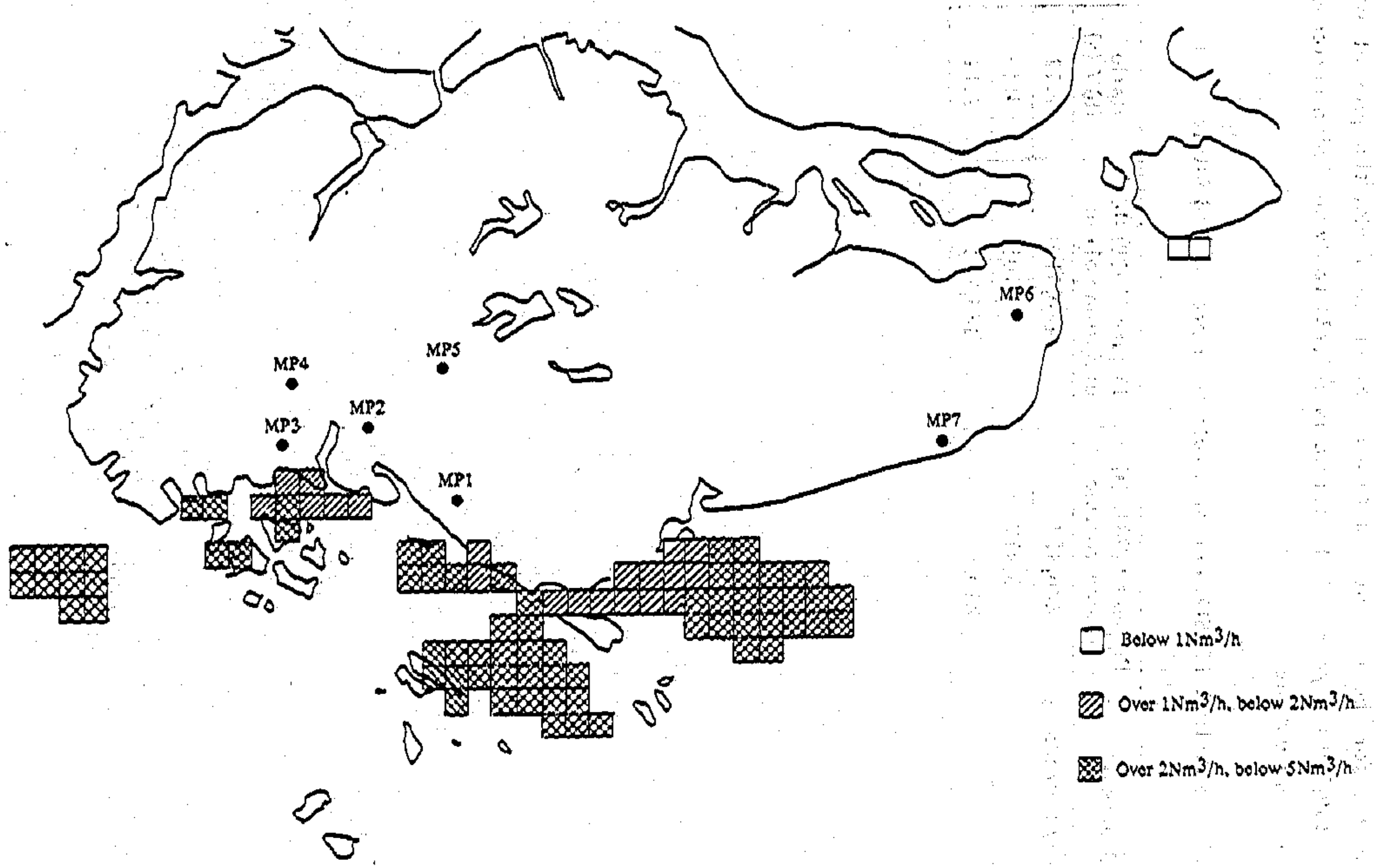


Fig. III-2-2-(2) Ranked diagram of yearly average SO_2 emission volume from vessels (future)

III-2-3 Conclusion of SO_2 Emission Volume

Table III-2-15 shows the total volume of SO_2 emitted from stationary sources and vessels estimated for the present and future. From the table, the present volume is estimated as 230,279 ton/year and the future is 485,724 ton/year which correspond 2.11 times of the present volume.

Table III-2-15 SO_2 emission volume of present and future.

Source	Present (1981) (a) emission volume	Future (1990) (b) emission volume	Ratio (b) / (a)
Stationary sources	226,362	480,019	2.12
Vessels	3,917	5,705	1.46
Total	230,279	485,724	2.11