4.3.2.4 Aircrafts

1) Outline

The flow of NOx and SOx emission estimation of aircraft for the year 2011 in the BMR is shown in Figure 4.3.2.8.

In the BAU Case, demand forecasts of the Airport Authority and the Department of Aviation are considered. The policy concerning the Bangkok International Airport is considered, in which the Second Bangkok International Airport (SBIA) will be used, however, the Don Muang Airport will not be operational in the year 2011.

The actual sulfur contents of jet fuel are the same as the one for the year 2000.

The NOx emission of aircraft by airport is estimated using the number of flights for the year 2011 by aircraft type in the Second Bangkok International Airport (SBIA) and the NOx emission factor in the LTO cycle based on USEPA. The number of flights of the Second Bangkok International Airport (SBIA) for the year 2011 is based on the data of the New Bangkok International Airport Co.,Ltd (NBIA).

Similarly, the SOx emission of aircraft by airport is estimated using the number of flights for the year 2011 by aircraft type in SBIA and the SOx emission factor in the LTO cycle based on USEPA.

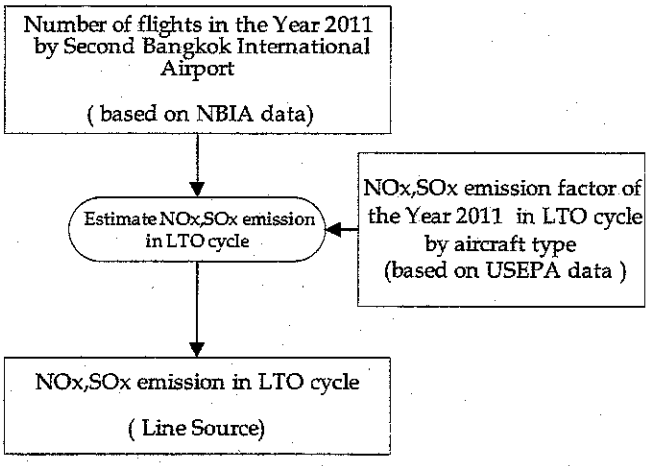


Figure 4.3.2.8 Flow of SOx and NOx emission estimation of aircraft for the Year 2011 in the BMR

2) Traffic Data

The annual aircraft movement in the Second Bangkok International Airport in the year 2011 is about 310,000 flights/year, as shown in Table 4.3.2.16. The location of airports is shown in Figure 4.3.2.2.

Table 4.3.2.16 Annual Aircraft Movements in the Year 2011

airport	Movement(Flight/year)		
Second Bangkok	International	Domestic	Total
International Airport	216,572	94,923	309,295

Source: NBIA
Note: Adjusted to movement of 2011 based on the NBIA forecasted movement of 2010

3) Emission Factor

The method to estimate the NOx and SOx emission of aircraft is the same as the one for the year 2000, which is based on the "Evaluation of Air Pollutant Emissions from Subsonic Commercial Jet Aircraft (USEPA)".

The sulfur contents and specific gravity of fuel for the year 2011 are the same as the ones for the year 2000, which are shown in Table 4.2.1.27.

4) Estimated Emission

The estimated NOx and SOx emission of aircraft for the Year 2011 in the Second Bangkok International Airport in the BMR are shown in Table 4.3.2.17.

The estimated NOx and SOx emission of aircraft in the Second Bangkok International Airport is about 21,000 ton/year and 770 ton/year respectively. 79% of NOx emission and 41% of SOx emission of aircraft is emitted during Take-off and Climb-out.

Table 4.3.2.17 Estimated NOx and SOx emission of airports in the BMR in the Year 2011

airport	NOx Emission(ton/year)				SOx Emission(ton/year)			
	Takeoff+ Climb-out	Approach	Taxing	Total	Takeoff+ Climb-out	Approach	Taxing	Total
Second Bangkok International Airport	16,743	2,241	2,032	21,017	316	142	309	767

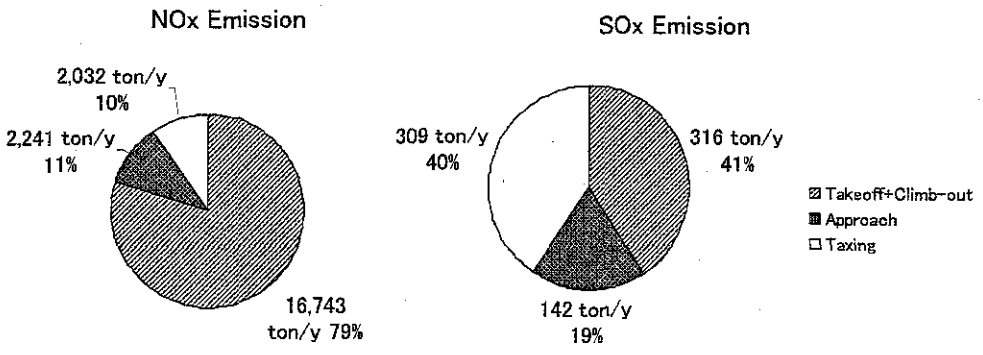


Figure 4.3.2.9 Estimated NOx and SOx emission of airport in the BMR in the Year 2011

4.3.2.5 NOx and SOx Emission of Mobile Sources for the Year 2011(BAU Case) in the BMR

The Summary of NOx emission of mobile sources for the Year 2011 in the BMR is shown in Table 4.3.2.18. The estimated total annual NOx emission of mobile sources is about 318,000 ton/year. The share of each province in the BMR in the total NOx emission is shown in Figure 4.3.2.10. The NOx emission of Bangkok is about 164,000 ton/year, which accounts for 52% of the total NOx emission of mobile sources in the BMR.

The share of each mobile source in the total NOx emission is shown in Figure 4.3.2.10. The share is 87% for vehicles on roads, 1% for ships, 6.6% for aircraft, 0.6% for railways and 4.5% for area sources like traffic in local areas.

Table 4.3.2.18 Estimated NOx Emission of Mobile Sources in the BMR in the Year 2011

Unit: ton/year

Province	Vehicles			Railway	Aircraft	Ships				Other	Total
	Gasoline	Diesel	LPG			Vessels	Long Tailed Boats	Express and Ferry boats	Fishing Boats	Area Sources	
Bangkok	22,789	102,250	252	1,013	21,017	3,014	141.7	215	0	13,098	163,790
Nonthaburi	4,000	23,640	44	34	0	0			0	473	28,192
Pathum Thani	6,105	29,656	67	355	0	0			0	164	36,347
Samut Prakan	5,212	25,976	59	0	0	0			249	225	31,720
Nakhon Pathom	4,006	37,579	62	295	0	0			0	169	42,112
Samut Sakhon	2,369	12,853	31	82	0	98			198	92	15,722
Total	44,480	231,954	515	1,779	21,017	3,112	141.7	215	446	14,222	317,883

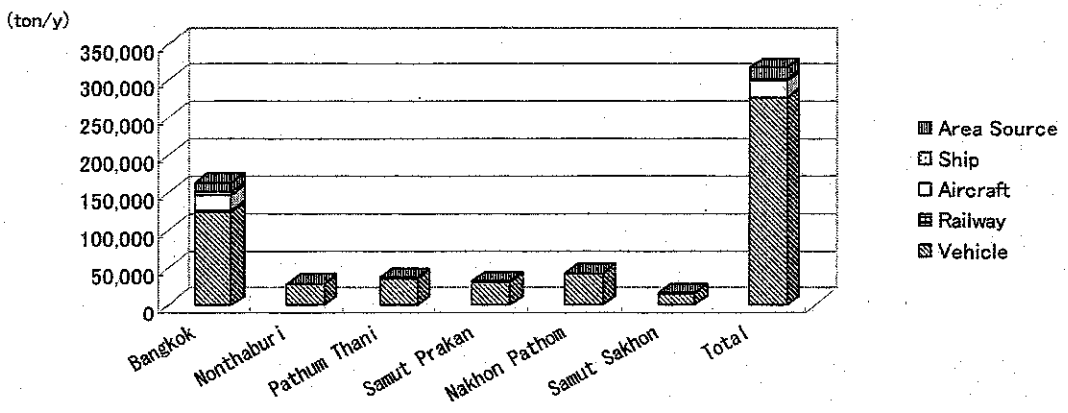


Figure 4.3.2.10 Estimated NOx Emission of Mobile Sources in the BMR in the Year 2011

The Summary of SOx emission of mobile source of the year 2011 in the BMR is shown in Table 4.3.2.19. The estimated total annual SOx emission of mobile source is about 6,100 ton/year. The share of each province in the BMR in the total SOx emission is shown in Figure 4.3.2.11. The SOx emission of Bangkok is about 4,400 ton/year, which accounts for 72% of the total SOx emission of mobile source in the BMR.

The share of each mobile source in the total SOx emission is shown in Figure 4.3.2.11. The share is 51% for vehicle on road, 33% for ship, 13% for aircraft, 0.2% for railway and 3% for area source like traffic in local area.

Table 4.3.2.19 Estimated SOx Emission of Mobile Sources in the BMR in the Year 2011

Unit: ton/year

Province	Vehicles			Railway	Aircraft	Ships				Other	Total
	Gasoline	Diesel	LPG			Vessels	Long Tailed Boats	Express and Ferry boats	Fishing Boats	Area Sources	
Bangkok	407	1,081	Neglected	9	767	1,707	2.6	210.9	0.0	198	4,382
Nonthaburi	65	234	Neglected	0	0	0			0	6	306
Pathum Thani	80	271	Neglected	3	0	0			0	0	354
Samut Prakan	78	254	Neglected	0	0	0			5	1	337
Nakhon Pathom	73	415	Neglected	3	0	0			0	0	490
Samut Sakhon	38	134	Neglected	1	0	59			4	0	235
Total	740	2,389	Neglected	15	767	1,766	2.6	211	8	205	6,105

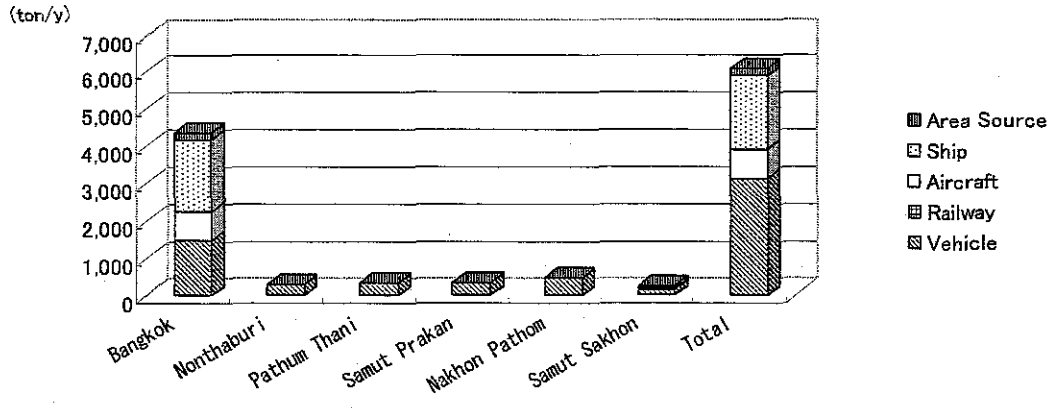


Figure 4.3.2.11 Estimated SOx Emission of Mobile Sources in the BMR in the Year 2011

4.3.2.6 Comparison of NOx and SOx Emission between the Year 2000 and 2011(BAU Case) in the BMR

The NOx emission of mobile sources for the year 2000 and 2011 in the BMR is shown in Figure 4.3.2.12.

The total NOx emission for the year 2011 decreases by 5 % on the Year 2000.

As for decrease of NOx emission by the mobile sector, although the NOx emission of diesel vehicles decreases by 14%, one of the gasoline vehicles increases by 24%, aircraft by about 73% and ships by about 2% respectively.

Since the vehicle-kilometer of diesel vehicles for the year 2011 increases by 44% in the Year 2000, the decrease of NOx emission of diesel vehicles is caused by the reduction of NOx emission factor of diesel vehicles like buses and heavy trucks due to the Euro3 emission standard enforcement.

The Euro3 emission standard enforcement requires lower sulfur fuel (gasoline: 150ppm, diesel oil: 350ppm). The fuel quality of gasoline and diesel oil should strictly comply with the fuel specification demands for the Euro3 emission standard.

As the engine modification and replacement might cause higher emission than the Euro3 emission standard, the compliance with the emission standard through I/M program should be executed.

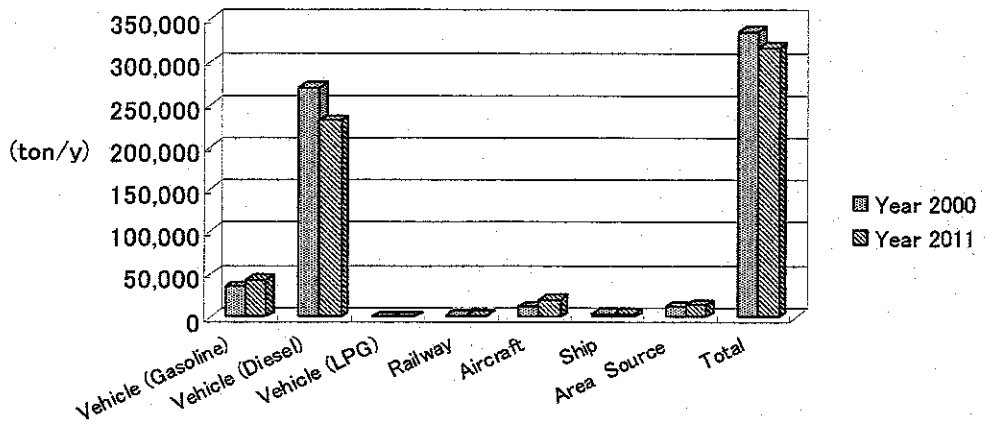


Figure 4.3.2.12 NOx Emission of Mobile Sources of the Year 2000 and 2011 in the BMR

The SOx emission and the fuel consumption of mobile sources for the Year 2000 and 2011 in the BMR are shown in Figure 4.3.2.13, 4.3.2.14.

The total SOx emission for the year 2011 is equal to the one for the year 2000.

As for increase of SOx emission by the mobile sector, although the SOx emission of gasoline vehicles decreases by 48%, one of diesel vehicles increases by 31%, aircraft by about 70% and ships by about 2% respectively.

Since the fuel consumption of gasoline vehicles for the year 2011 increases by 53% for the year 2000, the reduction of sulfur contents of gasoline (reduced percent :66%, from 382 ppm to 130 ppm) causes the decrease of SOx emission of gasoline vehicles.

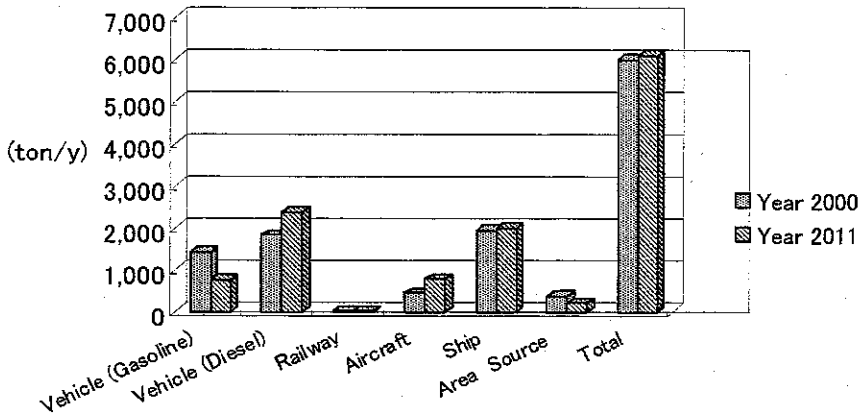


Figure 4.3.2.13 SOx Emission of Mobile Sources for the Year 2000 and 2011 in the BMR

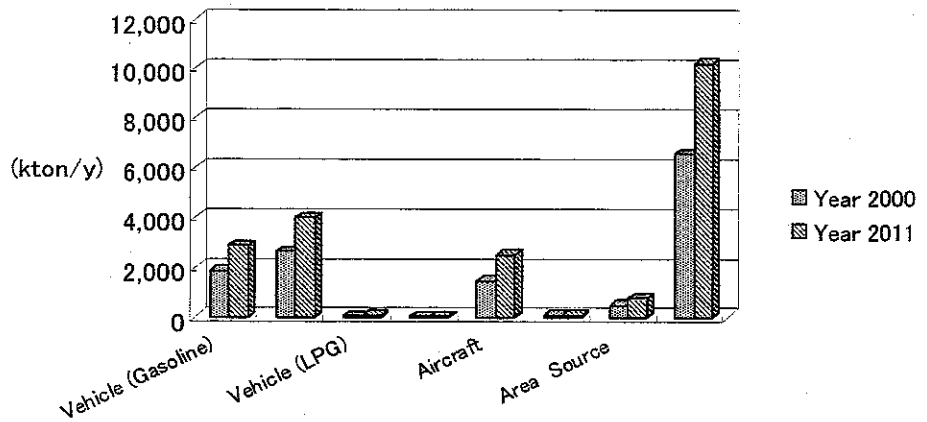


Figure 4.3.2.14 Fuel Consumption of Mobile Sources for the Year 2000 and 2011 in the BMR

Charpter 5

Inventory by Pollutants, SOx and NOx

5. Inventory by Pollutants, SOx and NOx

5.1 Emission Amount of Pollutants

The emission amount from stationary sources and mobile sources are described one by one in the previous chapters. The total emission amount of stationary sources and mobile sources are described in this section. The emission amount in the year 2011 is estimated based on the business as usual case, i.e. without introduction of a control strategy.

5.1.1 SOx Emission Amount of the Whole Thailand

5.1.1.1 Emission Analysis by Sector

The SOx emission amount of the whole Thailand by sector in the year 2000 and 2011 is summarized in Table 5.1.1.1 and illustrated in Figure 5.1.1.1.

The SOx emission amount is 344,000 ton/y in the year 2000, and 566,000 ton/y in the year 2011. The increase of emission amount is 65%. The manufacturing sector has the largest share both in the year 2000 and 2011. The share of the manufacturing sector exceeds 50% in both years. The power station has the second largest share both in the year 2000 and in the year 2011. The shares of the other sectors are not large. The share of the transportation sector is about 5% in the year 2000 and in the year 2011.

In order to study the control strategy for SOx reduction measures for the whole Thailand, the point is how to reduce the emission amount in the manufacturing sector and the power stations.

Table 5.1.1.1 SOx Emission Amounts of the Whole Thailand by Sector

Sector Type	Year 2000		Year 2011	
	SOx Emission (kton/y)	Share(%)	SOx Emission (kton/y)	Share(%)
Power Station	109	31.8	161	28.5
Agriculture	2	0.7	2	0.4
Mining and Construction	1	0.0	2	0.0
Manufacturing	177	51.4	324	57.3
Residential and Commercial	3	0.8	3	0.6
Refinery	34	9.8	49	8.7
Transportation	18	5.3	23	4.1
Total	344	100.0	566	100.0

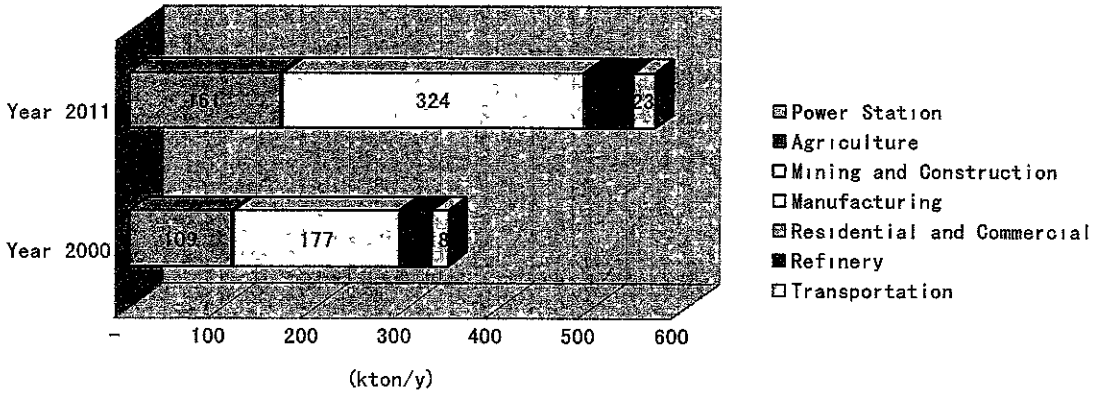


Figure 5.1.1.1 SOx Emission Amounts of the Whole Thailand by Sector

5.1.1.2 Emission Analysis by Fuel Type

The SOx emission amount of the whole Thailand by fuel type in the year 2000 and 2011 is summarized in Table 5.1.1.2 and illustrated in Figure 5.1.1.2.

SOx emission by fuel type shows that fuel oil, lignite and coal are major sources. The emission amount from fuel oil shows a significant change between the years 2000 and 2011. The share of fuel oil is about 50% in the year 2000 and will drastically decrease to 35% in the year 2011. The reason for this change is that power stations will reduce drastically the consumption of fuel oil. The change will have an important effect on the oil refining process, because the demand balance will shift from lighter oil (gasoline and others) to heavy oil (fuel oil). The share of lignite is about 20%, which is almost same in both years. Mae Moh power station utilizes 80% of lignite for the country in the year 2000. It will decrease to 70% in the year 2011.

Table 5.1.1.2 SOx Emission Amounts of the Whole Thailand by Fuel Type

Fuel Type		Year 2000		Year 2011	
		SOx Emission (kton/y)	Share(%)	SOx Emission (kton/y)	Share(%)
Coal		23	6.7	151	26.6
Lignite		64	18.6	101	17.8
Natural Gas		1	0.4	2	0.3
Petroleum Products	Fuel Oil	178	51.8	198	34.9
	Gasoline	4	1.1	2	0.4
	High Speed Diesel	9	2.5	11	2.0
	Other Fuel	3	0.9	5	0.9
Non Fossil		4	1.1	5	0.8
Process		58	16.9	92	16.2
Total		344	100.0	566	100.0

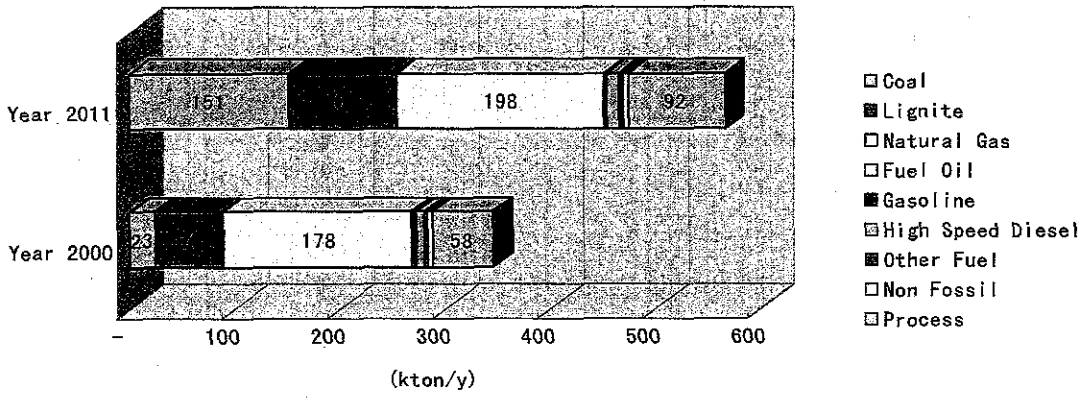


Figure 5.1.1.2 SOx Emission Amounts of the Whole Thailand by Fuel Type

In contrast, the share of coal is about 7% in the year 2000 and will drastically increase to 27% in the year 2011. The major reason for this increase is the emission from the coal firing power station projects. The projects will import low sulfur coal and install FGD with required efficiency. The consumption of coal will also increase drastically, and will result in high levels of SOx emission. This causes an increase of the total SOx emission amount in 2011.

Concerning emissions from processes, the majority of emissions are from refinery and cement. Refinery will expand its production proportional to the national demand for oil products, and SOx emission will increase. The situation is the same for the cement industry.

5.1.2 SOx Emission Amount of the BMR

5.1.2.1 Emission Analysis by Sector

The SOx emission amount of the BMR by sector in the year 2000 and 2011 is summarized in Table 5.1.2.1 and illustrated in Figure 5.1.2.1.

The SOx emission amount is 107,000 ton/y in the year 2000, and 113,000 ton/y in the year 2011. The increase of emission amount is 6%. It should be noted that the emission amount for the year 2011 is approximately same as the value for the year 2000.

The majority of SOx are discharged from stationary sources. The manufacturing sector has the largest share both in the year 2000 and 2011. The share of the manufacturing sector is about 70% in the year 2000, and will exceed to 90% in the year 2011. In contrast, the share of the power station sector is about 25% in the year 2000, and will drastically decrease to almost 0% in the year 2011. This is considered due to the effect of the fuel shift from fuel oil to natural gas at the power stations.

The share of the transportation sector is about 5% in the year 2000 and in the year 2011.

In order to study the control strategy for SOx reduction measures of the BMR, the point is how to reduce the emission amounts of the manufacturing sector.

Table 5.1.2.1 SOx Emission Amounts of the BMR by Sector

Sector Type	Year 2000		Year 2011	
	SOx Emission (kton/y)	Share(%)	SOx Emission (kton/y)	Share(%)
Power Station	28	25.8	0	0.1
Agriculture	0	0.2	0	0.2
Mining and Construction	0	0.4	1	1.0
Manufacturing	72	67.3	105	92.4
Residential and Commercial	0	0.2	0	0.2
Refinery	1	0.5	1	0.7
Transportation	6	5.6	6	5.4
Total	107	100.0	113	100.0

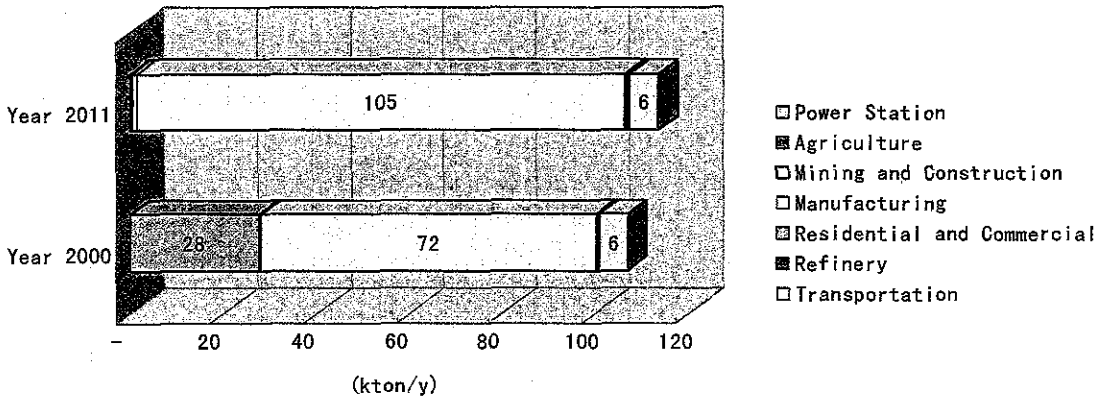


Figure 5.1.2.1 SOx Emission Amounts of the BMR by Sector

5.1.2.2 Emission Analysis by Fuel Type

The SOx emission amount of the BMR by fuel type in the year 2000 and 2011 is summarized in Table 5.1.2.2 and illustrated in Figure 5.1.2.2.

In the BMR, the major source of SOx emission is fuel oil. The share of fuel oil is about 90% in both years. For SOx reduction measures of the BMR, the point is how to reduce the emission amounts from fuel oil.

Table 5.1.2.2 SOx Emission Amounts of the BMR by Fuel Type

Fuel Type		Year 2000		Year 2011	
		NOx Emission (kton/y)	Share(%)	NOx Emission (kton/y)	Share(%)
Coal		2	1.5	2	2.1
Lignite		3	2.8	4	3.8
Natural Gas		0	0.1	0	0.1
Petroleum Products	Fuel Oil	96	90.1	100	88.2
	Gasoline	2	1.7	1	0.8
	High Speed Diesel	2	2.1	3	2.5
	Other Fuel	1	0.7	1	1.0
Non Fossil		1	0.5	1	0.7
Process		1	0.6	1	0.8
Total		107	100.0	113	100.0

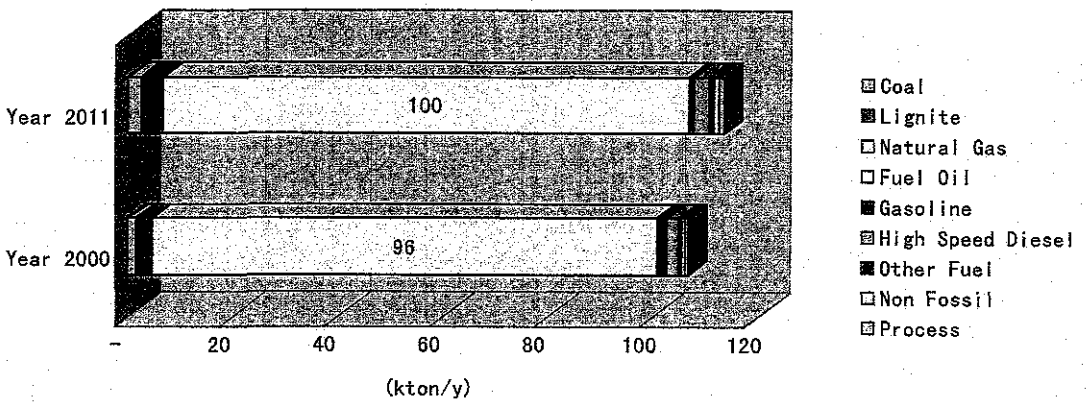


Figure 5.1.2.2 SOx Emission Amounts of the BMR by Fuel Type

5.1.3 NOx Emission Amount of BMR

The NOx emission amount of the BMR by sector in the years 2000 and 2011 is summarized in Table 5.1.3.1 and illustrated in Figure 5.1.3.1.

NOx emission amount is 398,000 ton/y in the year 2000, and 389,000 ton/y in the year 2011. The decrease of emission amount is 2%. It should be noted that the amount for the year 2011 will decrease compared to that for the year 2000.

The majority of NOx are discharged from the transportation sector. The emission from vehicles has largest share both in the years 2000 and 2011. The share of vehicles is about 80% in the year 2000, and will decrease to 75% in the year 2011. This decrease of share is caused by the reduction of NOx emission factor of vehicles due to the Euro3 enforcement.

The Euro3 emission standard enforcement requires lower sulfur fuel (gasoline: 150ppm, diesel oil: 350ppm). The fuel quality of gasoline and diesel oil should strictly comply with the fuel specification demands for the Euro3 emission standard. As the engine modification and replacement might cause higher emission than the Euro3 emission standard, it should be inspected through I/M program for the compliance with the Euro3 emission standard.

The share of the power station is 5% in the year 2000, and will decrease to 3% in the year 2011. This decrease of share is caused by the fuel shift from fuel oil to natural gas at the power stations.

In order to study the control strategy for NOx reduction measures of the BMR, the point is how to reduce the emission amounts from vehicles.

Table 5.1.3.1 NOx Emission Amounts of the BMR by Sector

Sector Type		Year 2000		Year 2011	
		NOx Emission (kton/y)	Share(%)	NOx Emission (kton/y)	Share(%)
Power Station		19	4.8	10	2.7
Agriculture		11	2.7	13	3.4
Mining and Construction		2	0.6	7	1.8
Manufacturing		28	7.0	37	9.6
Residential and Commercial		1	0.3	2	0 5
Refinery		1	0.2	1	0.3
Transportation	Vehicle	318	80 0	291	74.9
	Railway	2	0.4	2	0.5
	Aircraft	12	3.0	21	5 4
	Ship	4	1.0	4	1 0
Total		398	100.0	389	100.0

Note: vehicle emission of transportation sector includes that of area source.

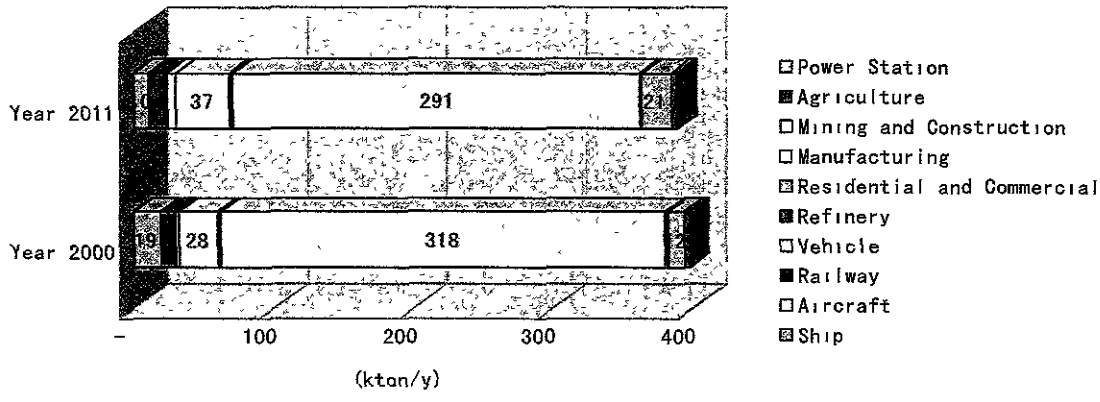


Figure 5.1.3.1 NOx Emission Amounts of the BMR by Sector

5.2 Summary of Emission Inventory

The emission amount of SOx for the whole Thailand will show a big increase in 2011 by the BAU case. Major sources of SOx are in the manufacturing sector and power stations. Also significant fuel sources are coal, lignite and fuel oil. In year 2000, the fuel oil share is the largest, and lignite is the second. In the year 2011, coal will be the second largest source after fuel oil, and the third source will be lignite. The emission amount by coal will be 6 times larger than the value for the year 2000, though coal will be imported and the sulfur content of them are regarded as low. In the whole Thailand, the focal points of the SOx emission control strategy will be these three fuels.

The emission amount of SOx of the BMR will show a slight increase in 2011 by the BAU case. Major sources of SOx are the manufacturing sector, which will account for over 90% in the year 2011. The significant fuel source is the fuel oil, which is dominant over all the others. In the BMR, focal points for the SOx emission control strategy will be how to reduce the emission amount from the facilities utilizing fuel oil.

In contrast, the emission amount of NOx of the BMR will slightly decrease in 2011 by the BAU case. Major sources of NOx are Mobile sources, especially vehicles, which will account for about 90% in the year 2011. In the BMR, the focal points for the NOx emission control strategy will be how to reduce the emission amounts from vehicles.

Charpter 6

Model Simulation

6. Model Simulation

6.1 ATMOS2

The ATMOS2 model can predict sulfur and particulate depositions and concentrations at regional scale and urban scale. The ATMOS2 model is a multi-layers forward trajectory Lagrangian puff-transport model [1]. The model was primarily developed for sulfur emission and dispersion model as part of the Regional Air Pollution Information System for Asia (RAINS-Asia) [2].

[1] Arndt, R. L., Carmichael, G. R., Streets, D. G., and Bhatti, N.: 1997, Sulfur dioxide emissions and sectorial contributions to sulfur deposition in Asia, Atmospheric Environment, vol.31, p1553-1572

[2] Carmichael, G. R. and Arndt, R. L.: 1995, ATMOS module - Long range transport and deposition of sulfur in Asia in RAINS ASIA: An assessment model for acid rain in Asia, The World Bank, p V-1 to V-58

6.1.1 Meteorological Data Processing

6.1.1.1 Original Data and Meteorological Pre-processors

The necessary meteorological input data to the ATMOS2 simulation model are lateral wind (u and v components), precipitation rate, and mixing layer height. The standard meteorological pre-processors called 'ncep_cut' and 'amp' developed by Dr. Giuseppe Calori have been kindly provided by Ms. Narisara Thongbooncho of Iowa University. These programs can process CDC/NCEP reanalysis data and create meteorological input data. The relationships among the original CDC/NCEP meteorological data, pre-processors and ATMOS2 input data are summarized in. Table 6.1.1.1. For an example, precipitation rate data (prate.2000.nc) for ATMOS2 are created from the NCEP original data (prate.sfc.gauss.2000.nc) by the ncep_cut program.

Table 6.1.1.1 Data and Pre-Processors

	prate.2000.nc precipitation rate	lwind.2000.nc u, v-wind	hmix.2000.nc mixing height
CDC/NCEP Data			
air.2000.nc (multi-pressure level temperature)	---	O	O
uwnd.2000.nc (multi-pressure level u-wind)	---	O	---
vwnd.2000.nc (multi-pressure level v-wind)	---	O	---
prate.sfc.gauss.2000.nc (surface level precipitation rate)	O	---	---
shtfl.sfc.gauss.2000.nc (surface level sensible heat flux)	---	---	O
pres.sfc.2000.nc (surface level pressure)	---	O	O
uwnd.sig995.2000.nc (surface level u-wind)	---	O	O
vwnd.sig995.2000.nc (surface level v-wind)	---	O	O
air.sig995.2000.nc (surface level temperature)	---	O	O
Pre-processors			
ncep_cut	O	O	O
amp	X	O	O

6.1.1.2 Meteorological Pre-Processing Algorithms

1) Grid System Conversion

The grid system used in the ATMOS2 input data is the Cartesian grid system with 2.5 degree spans in longitude and latitude directions, and some of the original NCEP data use the non-Cartesian grid system called Gaussian grid system. In the 'ncep_cut' pre-processor, the meteorological values of each Cartesian grid point are calculated by the

2-dimensional lateral interpolation. Only the 'ncep_cut' pre-processor is used for creating the precipitation rate data (prate.2000.nc) for ATMOS2. If the original data adopt the Cartesian grid, the 'ncep_cut' just extracts the data for the simulation target domain.

2) Vertical Interpolation of Wind

The u and v components of winds are reanalyzed for the multi-pressure levels, and the values at the middle height of each vertical layer have to be calculated. At first, the height of the pressure levels are calculated with the surface pressure and temperatures at surface and the pressure levels. Next, the values at the certain heights can be calculated by the vertical linear interpolation. The 'amp' pre-processor conducts these calculations.

3) Mixing Layer Height Estimation

The estimation method of mixing layer height estimation is the most complicated procedure included in the 'amp'.

The estimation follows the steps below.

1. Friction velocity (u_*) and Monin-Obukhov length (L) are calculated for the daytime and the nighttime.
2. Convective mixing layer height and mechanical mixing layer height are calculated for the daytime and the higher estimation of them is used as mixing height over land.
3. Mechanical mixing height is estimated for the nighttime over land.
4. Mixing height over sea is estimated from the heights over land with the weights of inverse of $(distance)^2$.

(1) Friction Velocity and Monin-Obukhov Length Estimation in the Daytime

Initial estimations of friction velocity (u*) and Monin-Obukhov Length (L) are calculated by the following equation.

$$u_* = \kappa u \ln\left(\frac{z_0}{z}\right)$$

$$L = \frac{-\rho c_p u_*^3 T}{\kappa g H}$$

u_*: friction velocity

κ : von Karman constant

u: wind speed at height z above ground

z_0: surface roughness length

ρ :air density

c_p: specific heat under constant pressure

T: mean temperature

g: gravity

H: sensible heat flux

Subsequent iterative estimation for u* and L use the equation for stability corrections to the logarithmic profiles for momentum, ψ_m.

$$u = \frac{u_*}{\kappa}\left[\lambda n\left(\frac{z}{z_0}\right) - \psi_m\right]$$

For unstable conditions, the stability corrections denoted in the above equation, ψ_m is as follows.

$$\psi_m = 2\lambda n\left[\frac{1+\phi_m^{-1}}{2}\right] + \lambda n\left[\frac{1+\phi_m^{-2}}{2}\right] - 2\arctan\left(\phi_m^{-1}\right) + \frac{\pi}{2}$$

$$\phi_m = \left(1 - 15\frac{z}{L}\right)^{-\frac{1}{4}}$$

Iteration continues until the error of the Monin-Obukhov length estimation becomes below 0.5 %.

(2) Friction Velocity and Monin-Obukhov Length Estimation in the Nighttime

A first estimate of temperature scale, θ_*, is obtained by the following equation.

$$\theta_{*1} = 0.09\left(1 - 0.5N^2\right)$$

N: cloud cover

A second estimate of θ_* is made from the profile equation for temperature.

$$\theta_{*2} = \frac{TC_{DN}u^2}{4\beta_m zg}$$

$$C_{DN} = \frac{\kappa}{\lambda n\left(z/z_0\right)}$$

β_m: constant (=4.7)

The next step is to set θ_* to the smaller of θ_{*1} and θ_{*2}. From the relationship for the sensible heat flux, H;

$$H = -\rho c_p u_* \theta_*$$

The u* can be calculated as the solution to the following equation.

$$u_* = \frac{C_{DN}u}{2}\left[1 + \left(1 - \left(\frac{2u_O}{C_{DN}^{1/2}u}\right)^2\right)^{1/2}\right]$$

$$u_O = \left(\frac{\beta_m zg\theta_*}{T}\right)^{1/2}$$

(3) The Daytime Mixing Height Estimation

The daytime convective mixing height is calculated from the sensible heat flux the and vertical potential temperature profile. The convective mixing height at time t+dt can be estimated from its value at time t in a stepwise manner.

$$h_{t+dt} = \left[h_t^2 + \frac{2H(1+E)dt}{\gamma \rho c_P} - \frac{2d\theta_t h_t}{\gamma} \right]^{1/2} + \frac{d\theta_{t+dt}}{\gamma}$$

$$d\theta_{t+dt} = \left[\frac{2\gamma E H dt}{\rho c_P} \right]^{1/2}$$

γ : potential temperature lapse rate in the layer above h_t

d θ : temperature jump at the top of the mixing layer

E: constant (=0.15)

The mechanical mixing height is estimated by the following equation:

$$h = \frac{Bu_*}{[fN_B]^{1/2}}$$

f: Coriolis parameter ($=10^4 s^{-1}$)

B: constant ($=2^{1/2}$)

N_B: Brunt-Vaisala frequency in the stable layer aloft (s^{-1})

$$N_B = \left[\left(\frac{g}{\theta} \right) \gamma \right]^{1/2}$$

Finally, the daytime mixing height could then be taken as the maximum of the convective and mechanical values.

(4) The Nighttime Mixing Height Estimation

During the nighttime, mechanical turbulence determines the mixing height and the following empirical equation is used.

$$h = B_2 u_*^{3/2}$$

B_2: constant (=2400)

6.1.1.3 Precipitation Rate

1) Comparison of Precipitation Data

The precipitation rate is the most important meteorological data for acid deposition simulation. During the First Field Work, hourly precipitation data of around 50 stations were collected from the Airviro on-line monitoring system. On the other hand, the Meteorological Department conducted the precipitation rate observation in Thailand.

Adding to them, the precipitation amounts were also recorded at the acid deposition monitoring stations.

Then, these three sets of precipitation amount data are compared at the 4 acid monitoring stations and the data of the Meteorological Department showed good coincidence with the records of the acid monitoring stations. One of the examples from the TMD (Meteorological Department, 'Meteo' (rectangular symbols)) and Bangkok (OEPP, 'Acid' (circle symbols)) stations are shown in Figure 6.1.1.1.

Another important founding is less amount of the recorded precipitation such as in April, September and so on. So, the recorded precipitation amount at each acid deposition monitoring station is used for the simulation compared with the measured deposition amount in section 5.1.4.

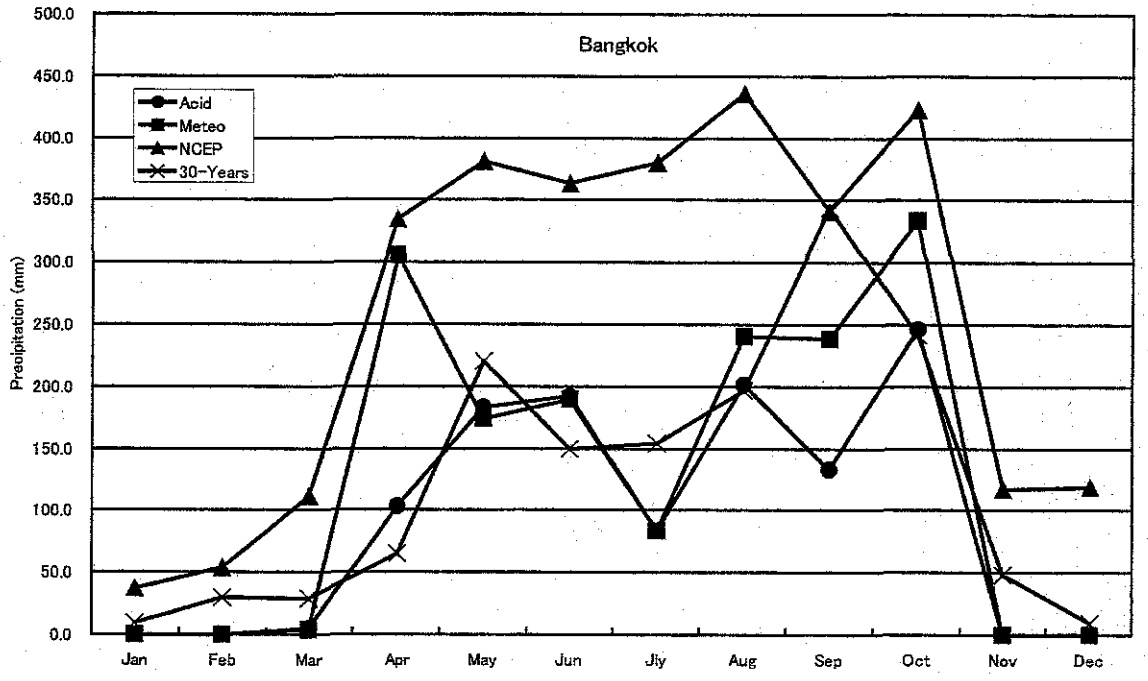


Figure 6.1.1.1 Monthly Precipitation Amount

Compared with the 30-years mean values (cross symbols), the precipitation amounts for the year 2000 (rectangular symbols) show some differences in April, July, and September.

The CDC/NCEP data was made by the reanalysis of the observation data and the reanalysis data is expected to be beyond the observation data because they excluded abnormal data and interpolate missed observation. The utilization of CDC/NCEP data is one alternative for the input to ATMOS2. However, the CDC/NCEP data (triangle symbols) show an overestimate tendency throughout a year. Then the local precipitation data (Meteorological Department

precipitation data (CDC/NCEP reanalysis data) are for the other grids in the simulation domain.

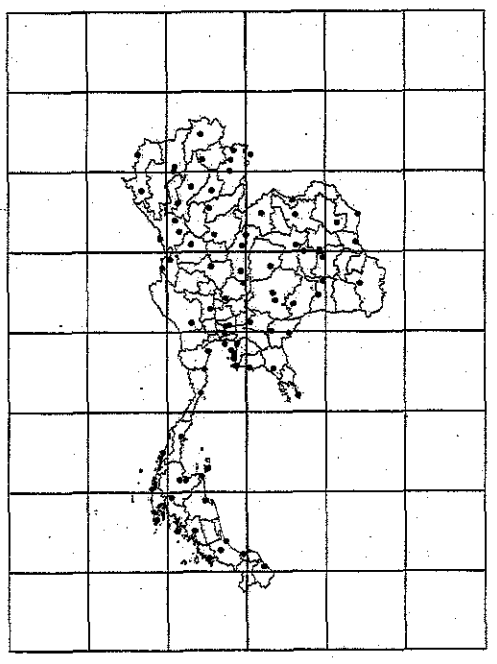
2) Combination of Local and Global Precipitation Data

The observation stations of the Meteorological Department for the precipitation rate for the year 2000 are shown in Figure 6.1.1.2 and the CDC/NCEP annual precipitation amounts for East Asia (ATMOS2 meteorological field) are in Figure 6.1.1.3.

In Thailand, local precipitation data within each grid are averaged for each grid point value. The grid system in Figure 6.1.1.2 is defined as the center point of the grids and correspond to the CDC/NCEP grid points.

Finally, precipitation fields in Thailand for the original CDC/NCEP data in Figure 6.1.1.4 are changed as in Figure 6.1.1.5, and the combined precipitation data which were used for year 2000 and 2011 simulations are in section 5.1.4 and 5.1.5.

Simulation flow diagram is shown in Figure 6.1.1.6. For the simulation to compare the results with the monitoring data is conducted with the combined precipitation data at the acid deposition monitoring stations and of CDC/NCEP data. After the calibration of the simulation model, the combined precipitation data of Thailand Meteorological Department and CDC/NCEP data of year 2000 are used for the simulation of year 2000, year2011 BaU, and year 2011 control case.



Note: Circles: Precipitation observation stations by the Meteorological Department
Grids: Grid system with 2.5 degrees sizes

Figure 6.1.1.2 Precipitation Observation Stations

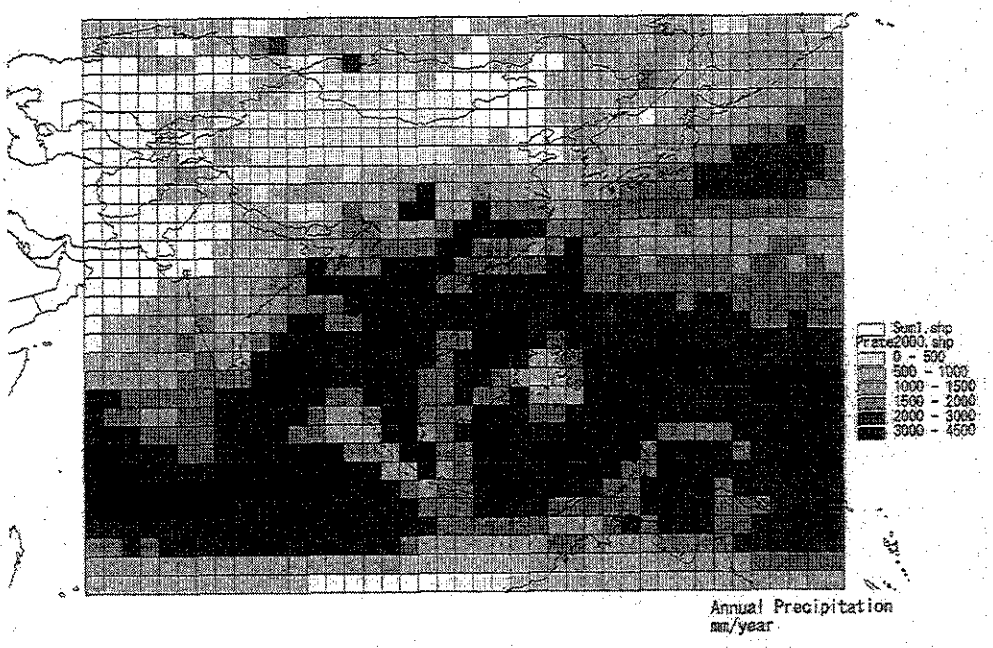


Figure 6.1.1.3 CDC/NCEP Precipitation Data in East Asia

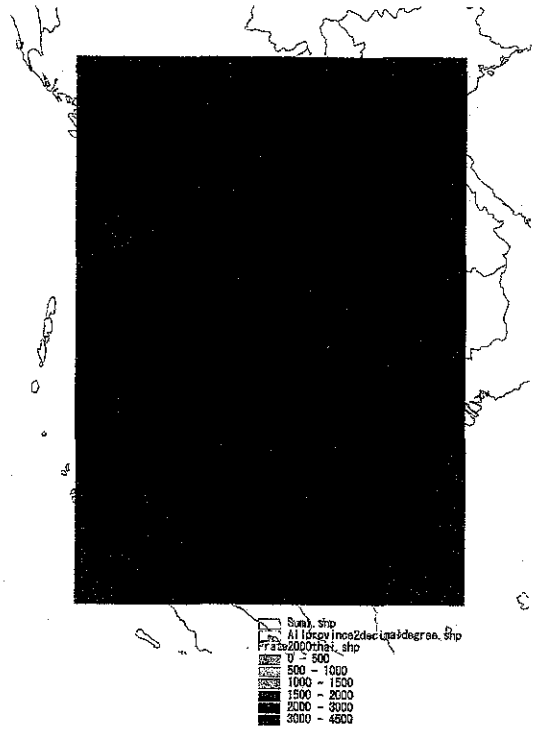


Figure 6.1.1.4 CDC/NCEP Precipitation around Thailand

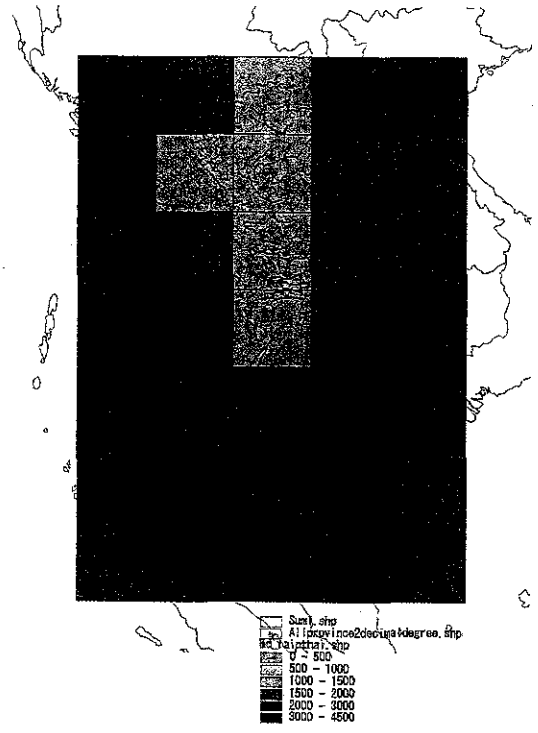


Figure 6.1.1.5 Combined Precipitation around Thailand

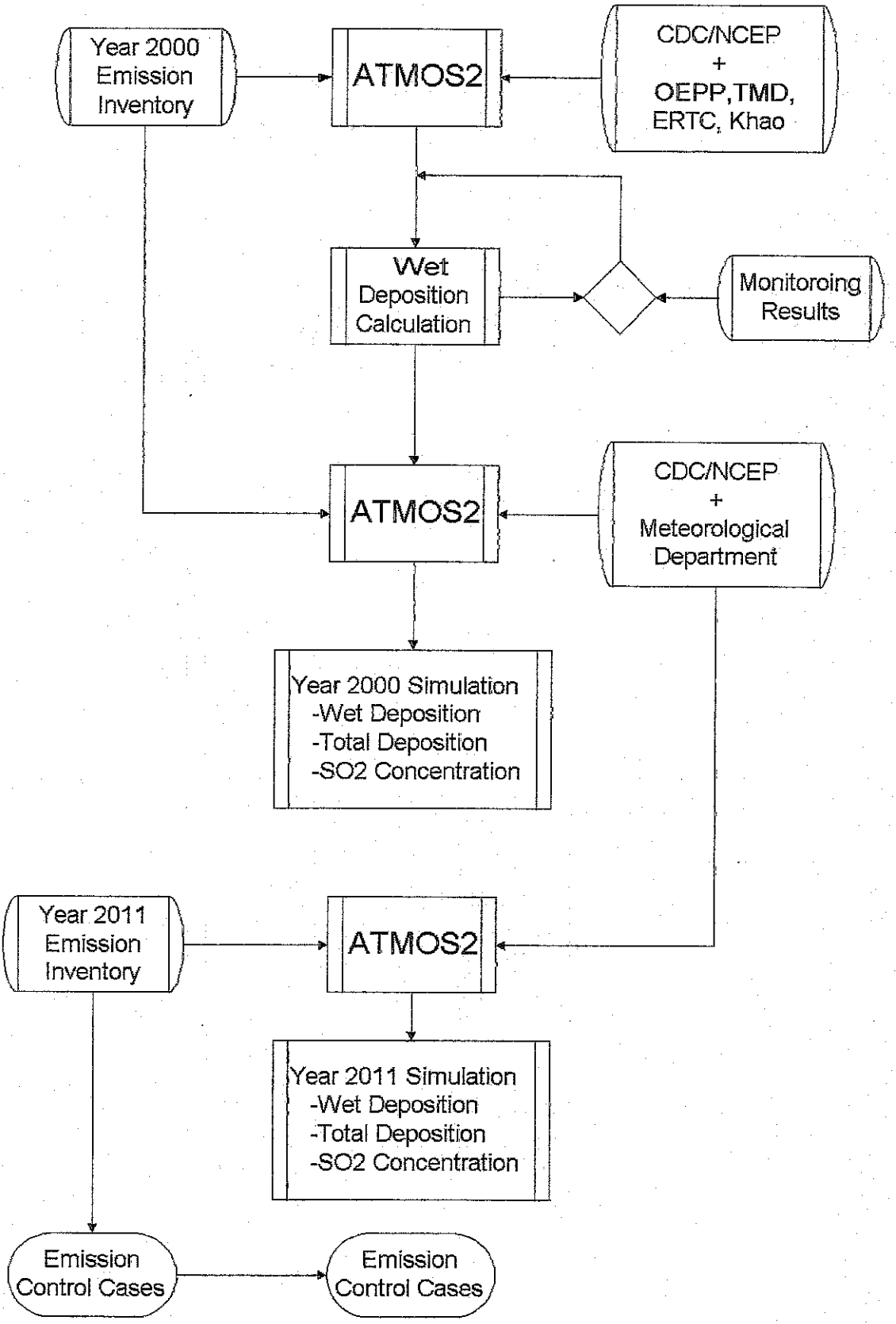


Figure 6.1.1.6 Simulation Flow Diagram

6.1.2 Pollutant Emission Processing

6.1.2.1 Grid System and Processing Method

1) Grid System

The longitude and latitude grid system in decimal degrees is adopted for the ATMOS2 simulation because the longitude and latitude system is used in the ATMOS2 program. Some of the pollutant emission data compiled in the UTM coordinates are converted to the longitude and latitude system.

For the improvement of the simulation, pollutant emissions are compiled into two types of grid systems with different resolutions. One is the urban grid system with 0.1 degree by 0.1 degree, and another is the regional grid system with 1.0 degree by 1.0 degree.

2) Processing Method

The GIS software, 'ArcView 3.2 a' was used and some scripts (programs) were developed for the pollutant emission data processing. Equivalent software is also installed in the PCD.

Stationary and mobile pollutant source data are compiled in point and line types and some categories are compiled as each province total amount. On the other hand, pollutant source types of ATMOS2 are large point sources and area sources with 1 degree by 1 degree size or 0.1 degree by 0.1 degree. Because ATMOS2 assumes the large point source as very high stack with a height such as 200 meters, all of the sources in Thailand are compiled as area sources.

Stationary point sources and some of the mobile point sources such as ports, airports are compiled into area sources based on their exact locations. Mobile line sources such as highway vehicle traffic etc. are divided with the intersected ratio of each link length into each grid as area source. Provincial total emission amounts of respective provinces are divided with clipped ratio of province area size into each grid as area source, too. Adding to the pollutant sources investigated in this project, the grid SOx emissions for East Asia investigated by Iowa University are included as input data to the simulations.

The SOx emissions distributions in the whole of Thailand and the urban area for the years 2000, 2011 and 2011 with the control case are shown from Figure 6.1.2.1 to Figure 6.1.2.6. The most SOx emission grid in the whole of Thailand is located around the BMR with 119,000 tons for the year 2000, 131,000 tons for the year 2011 and 104,000 tons under

the control. In the urban area, the 36,600 tons per grid in the BMR is the most in year 2000, but it will decrease to 14,800 tons in the year 2011 and the other two grids with around 15,000 tons will appear in Chonburi province. These high emission amounts will decrease to 11,200, 13,100 and 14,400 tons by the control.

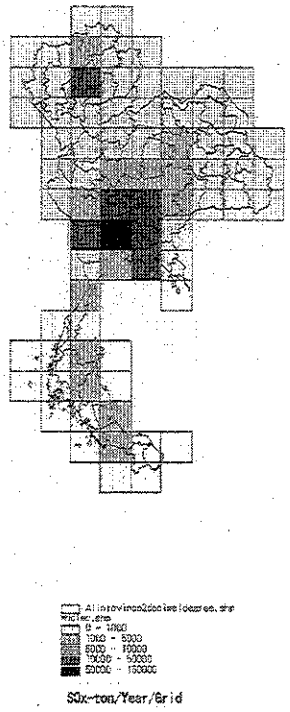


Figure 6.1.2.1 SOx Emission in the Whole of Thailand for the Year 2000

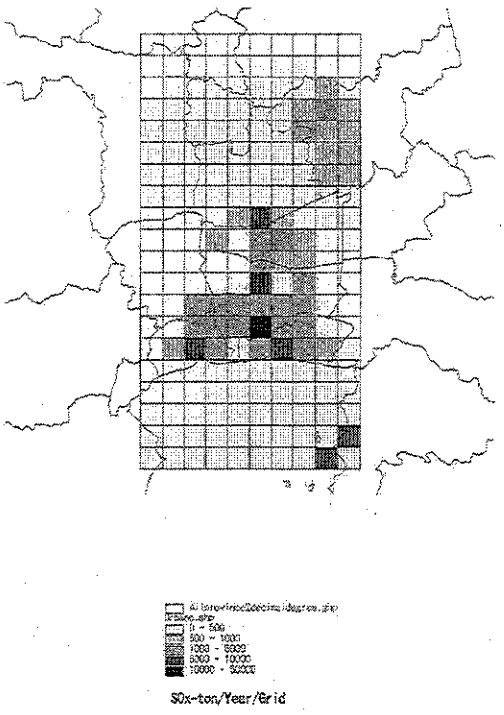


Figure 6.1.2.2 SOx Emission in the Urban Area for the Year 2000

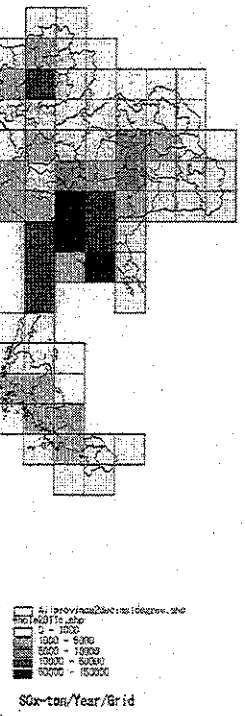


Figure 6.1.2.3 SOx Emission in the Whole of Thailand for the Year 2011

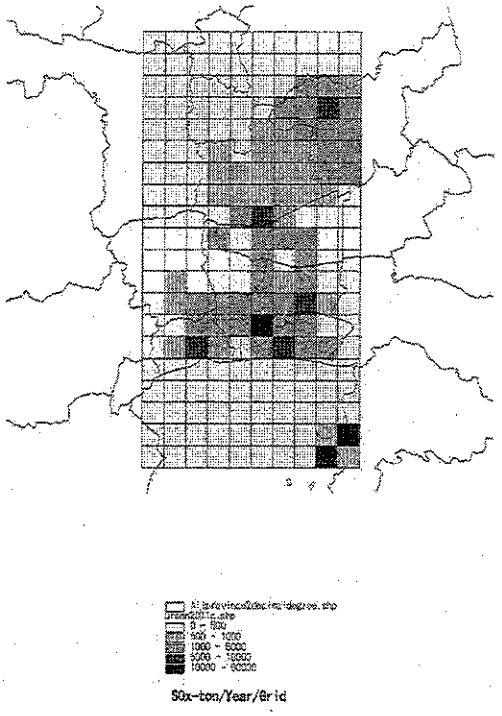


Figure 6.1.2.4 SOx Emission in the Urban Area for the Year 2011

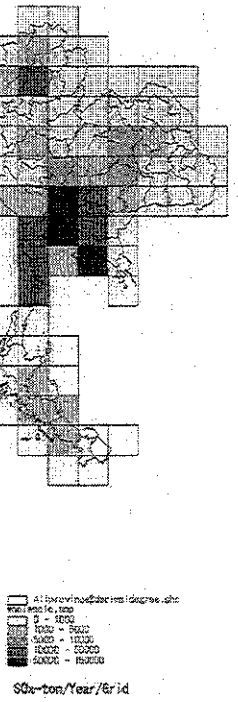


Figure 6.1.2.5 SOx Emission in the Whole of Thailand with the Control

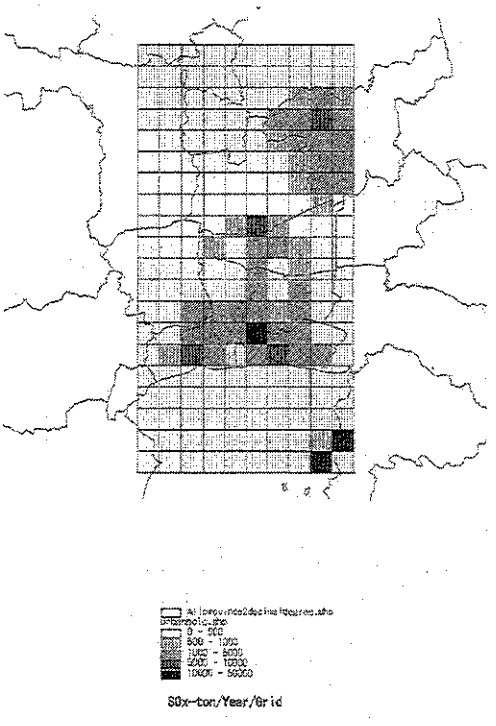


Figure 6.1.2.6 SOx Emission in the Urban Area with the Control

6.1.3 Simulation Model Description

6.1.3.1 Basic Structure of ATMOS2

1) Simulation Model Category

ATMOS2 is a multi-layer Lagrangian trajectory model and uses forward trajectory from each pollutant source. The trajectory model is adequate for long-range transport simulation since it can trace puff along the wind trajectory in the changing wind field. Compared with Eularian models, the trajectory model has the advantage of a reduced calculation amount because it just conducts the basic equation integration along trajectories.

2) Basic Equation

The trajectory model traces puffs emitted from pollutant sources by trajectories. The SO_2 and SO_4 concentration changes along the trajectories are obtained by integrating the following equations.

$$\frac{dC_{SO2}}{dt} = -\left(\frac{V_{DSO2}}{H} + K_{WSO2} + K_R\right)C_{SO2} + (1-\beta)\frac{Q}{H}$$

$$\frac{dC_{SO4}}{dt} = -\left(\frac{V_{DSO4}}{H} + K_{WSO4}\right)C_{SO4} + \frac{3}{2}K_R C_{SO2} + \beta\frac{Q}{H}$$

C_{SO2},C_{SO4}:	SO_2 and SO_4concentrations (μ g/m^3)
H:	Thickness of Bottom Layer (meter)
V_{DSO2}, V_{DSO4}:	Dry Deposition Velocity (ms^{-1})
K_{WSO2},K_{WSO4}:	Wet Deposition Coefficient (s^{-1})
K_R:	Transformation Rate from SO_2 to SO_4 (s^{-1})
3/2:	Molecular Weight Conversion Factor from SO_2 to SO_4
β :	SO_4 Fraction in Total Sulfur Emission (assumed as 0.05)
Q:	Emission Rate

The dry deposition process occurs only at the bottom layers (surface layer in the nighttime and boundary layer), and the layers where the pollutants are emitted change by pollutant sources types and the time of day (daytime or nighttime).

The ATMOS2 has multi-layers in a vertical direction (boundary and upper layers in the daytime, and surface, boundary and upper layers in the nighttime), and considers branching and mixing phenomena during the transition phases from the daytime to the nighttime and from the nighttime to the daytime. These features are explained later.

3) Basic Framework of Simulation

The basic frameworks of the simulation are as follows.

Meteorological Data:	East longitude 60.0 degrees to 160.0 degrees
	South latitude -20.0 to north latitude 55.0 degrees
	Resolution; 2.5 by 2.5 degrees (Figure 6.1.3.1)
Pollutant Emission Data:	Thailand and East Asia grids
	Regional Grid System; 1.0 by 1.0 degree resolutions (Figure 6.1.3.2)
	Urban Grid System; 0.1 by 0.1 degree resolutions (Figure 6.1.3.3)
Calculation Points:	Regional Grid System;
	Longitude 95.5 to 105.5 E degrees
	Latitude 5.5 to 20.5 N degrees
	1.0 by 1.0 degrees resolution (Figure 6.1.3.2)
	Urban Grid System;
	Longitude 100.0 to 101.0 E degrees
	Latitude 13.0 to 15.0 N degrees
	0.1 by 0.1 degrees resolution (Figure 6.1.3.3)
Calculation Period:	Year 2000
	Jan. 1 0:00 to Dec. 31 18:00 (8778hrs)

The target pollutants are fixed in the ATMOS2 model as follows.

Pollutant Emissions:	SO_x as SO_2 and SO_4
	(Fraction of SO_4 assumed 0.05 in ATMOS2)
Simulation Outputs:	SO_2 and SO_4 concentration (ug/m^3)
	SO_2 and SO_4 dry deposition ($mg\text{-}S/m^2$)
	SO_2 and SO_4 wet deposition ($mg\text{-}S/m^2$)

Some other parameters set in the initialization file of ATMOS2 are as follows.

Trajectory Duration:	120 hours (Trajectories are traced for 120 hours as maximum)
Transport Time Step	3 hours (Each segment of trajectory calculated in every 3 hours)
Minimum Mass Fraction of S to Release:	
	0.1 % (If the S-mass included in puff becomes below this value, the tracing of trajectory finishes)

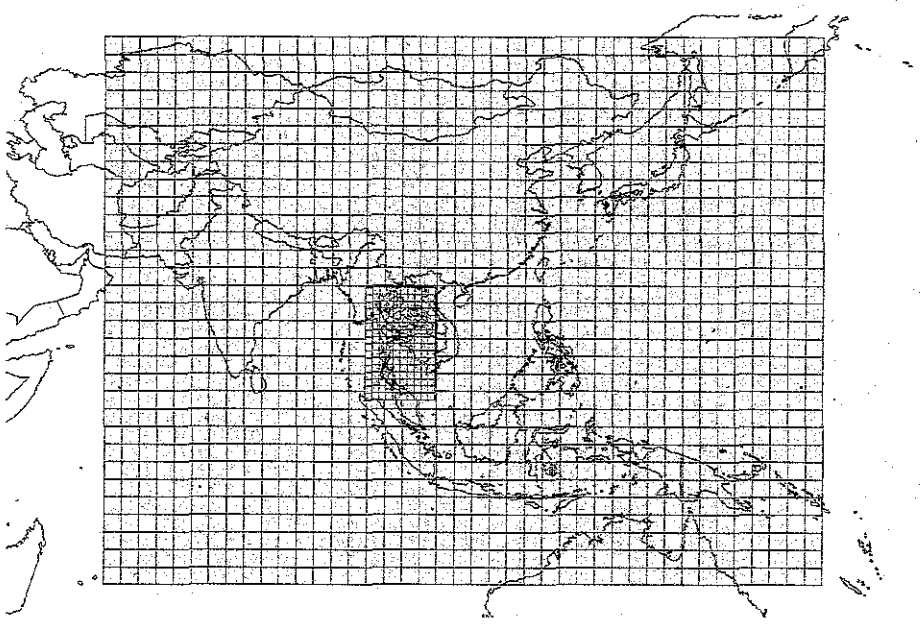


Figure 6.1.3.1 Meteorological Data Field

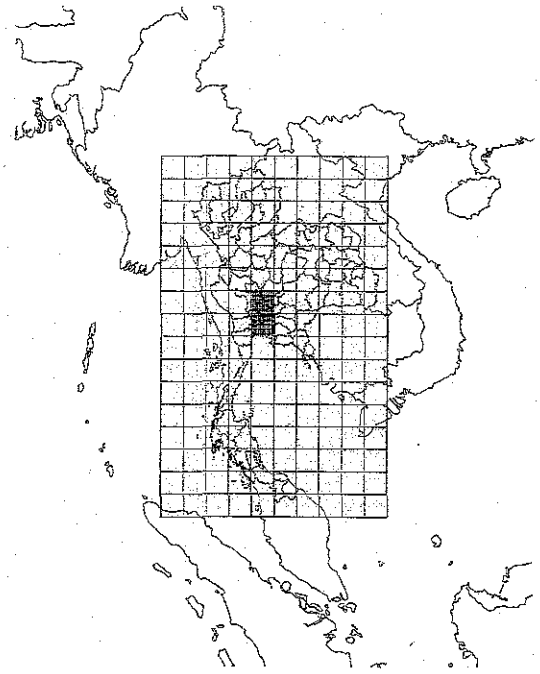


Figure 6.1.3.2 Regional Grid System

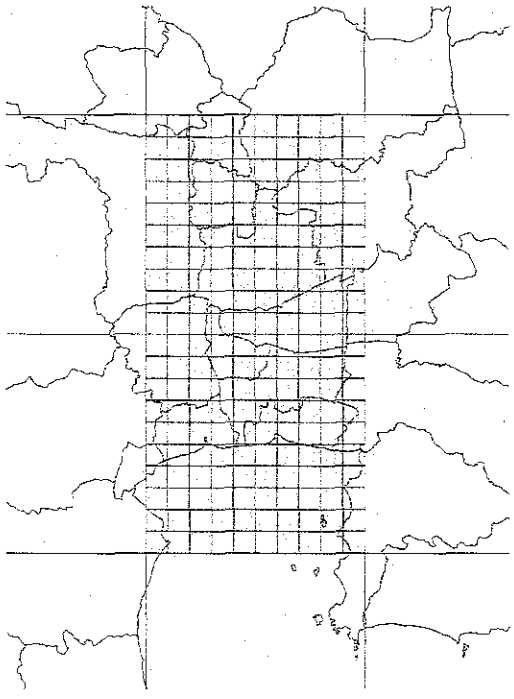


Figure 6.1.3.3 Urban Grid System

6.1.3.2 Meteorological Input Data

1) Necessary Meteorological Data for ATMOS2

The necessary meteorological data are as follows.

u (west - east direction) wind vector (meter / sec)

v (south - north direction) wind vector (meter / sec)

Precipitation rate (mm/hour)

Mixing layer height(meter) (boundary between boundary layer and upper layer)

The meteorological data are the grid point values in the 3-dimensional area;

41 dimensions with every 2.5 degrees in longitude

31 dimensions with every 2.5 degrees in latitude

3 layers in vertical direction

2) Meteorological Data Interpolation

The spatial and temporal resolutions of the original meteorological data differ from the ATMOS2 requirements. Namely, the spatial resolution of the original meteorological data

is every 2.5 degrees in longitude and latitude directions, but ATMOS2 needs meteorological data values at actual longitude and latitude of each trajectory segment. Meteorological data exist every 6 hours, but ATMOS2 starts and traces trajectories every 3 hours. Then, some types of interpolations are conducted in the ATMOS2 model.

Temporal interpolation of u and v wind vectors: linear interpolation

Precipitation rate and mixing layer height: Use every 6 hours value for the following 6 hours

Spatial interpolation of all meteorological data: 2-Dimensional linear interpolation

The 2-dimensional linear interpolation is described in Figure 6.1.3.4.

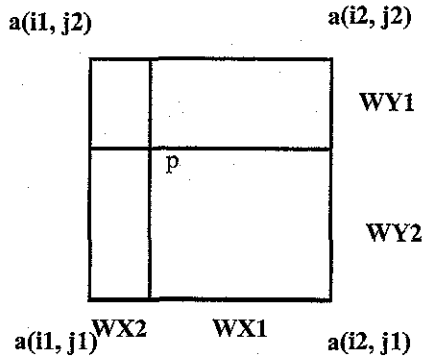


Figure 6.1.3.4 2-Dimensional Linear Interpolation

Meteorological value 'a' at point 'p' is obtained by the following equation.

a = a(i1,j1)*WX1*WY1+a(i1,j2)*WX1*WY2+a(i2,j1)*WX2*WY1+a(i2,j2)*WX2*WY2

3) Vertical Layers and Estimation of Critical Inversion Layer (Mixing Layer Height)

Vertical structures of the layers are shown in Figure 6.1.3.5. The top of the upper layer is constantly set at 6,000 meters and the top of the surface layer is set as 300 meters. The height at the critical inversion layer is defined as the mixing layer height.

The estimation method of the mixing layer height was described in section 6.1.1.23).

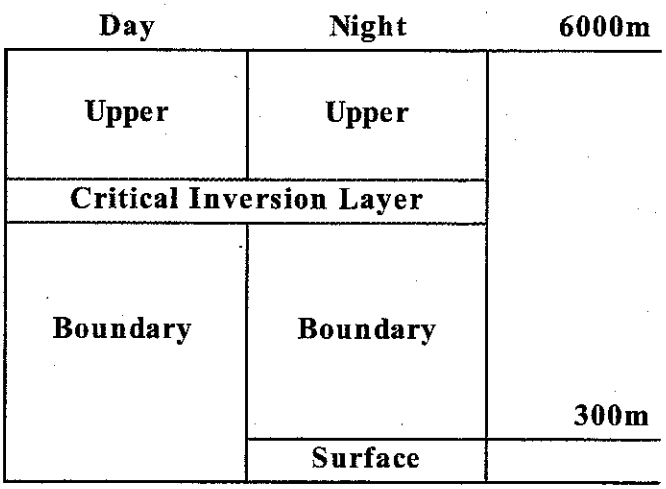


Figure 6.1.3.5 Vertical Layers Structures

6.1.3.3 Pollutant Emission Source

1) Pollutant Emission Source Type

ATMOS2 uses three types of pollutant emission sources as its input and sets their emission heights as in Table 6.1.3.1.

Table 6.1.3.1 Pollutant Emission Source Types

Emission Source Type	Layer of Emission	
	Daytime	Nighttime
Large Point Source	Upper Layer	Boundary Layer
Area Source	Boundary Layer	Surface Layer
Volcano	Upper Layer	Upper Layer

The necessary data of pollutant sources for ATMOS2 are;

Regional Code (If necessary)

Longitude (degree)

Latitude (degree)

Annual SO_x Emission Amount (ton-SO_2 / year)

Emission Release Height Flag (0: Area, 1: Point, 2: Volcano)

Puff Release Frequency (hours) (=3 hours)

6.1.3.4 Dispersion, Transformation and Deposition

1) Advection

In the ATMOS2 model, the advection is expressed by the trajectory and the modified Euler advection algorithm is used. The algorithm is shown in Figure 6.1.3.6.

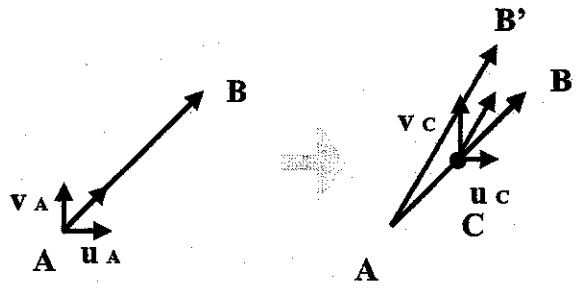


Figure 6.1.3.6 Modified Euler Algorithm for Trajectory

The calculation of trajectory is conducted by the following steps.

1. Wind at A point has u_A and v_A vector components.
2. Point B is calculated with u_A and v_A from the point A.
3. C is the middle point between A and B.
4. Wind vector components, u_C and v_C, at point C is calculated.
5. Point B' is re-calculated with u_C and v_C.

Wind vector components can be calculated with the 2-dimensional linear interpolation from the wind filed data. The calculation intervals for each trajectory are 3 hours and each trajectory is traced in the domain for 120 hours as maximum, and if trajectory go out from the domain, trace for the trajectory finishes.

2) Diffusion

For lateral diffusion, Gaussian distribution is assumed and the diffusion widths (σ_h) is used. The calculations of σ_h are different for the regional option and the urban option.

(a) Regional option

$$\sigma_h = \sigma_{h0} + 0.5 \times \delta_t$$

σ_{h0} : Initial diffusion width (meter)

40,000 m for area source and volcano

10,000 m for large point source

δ_t : traveling time (second)

(b) Urban option

The initial diffusion width for area sources is set as 8,000 m.

The estimation is divided into the short-range below 30.0 kilometers from a pollutant source, and the long-range beyond that.

In the short-range, Pasquill-Gifford-Turner sigma-y values are used for the rural area and Briggs urban sigma-y values for urban area. The urban area definition is based on the definition for the Airviro model, and only 2 grids among 231 grids in the urban grid system are defined as urban condition.

For the long-range, the same method used for the regional option is adopted.

For the vertical direction, pollutant concentrations are uniform in each vertical layer, and the setting multi-layer and adoption of branching and mixing mechanism improve the vertical resolutions of the model.

3) Branching and Mixing

Branching and mixing occur at the transition phase from the daytime to nighttime and vice versa as in Figure 6.1.3.7.

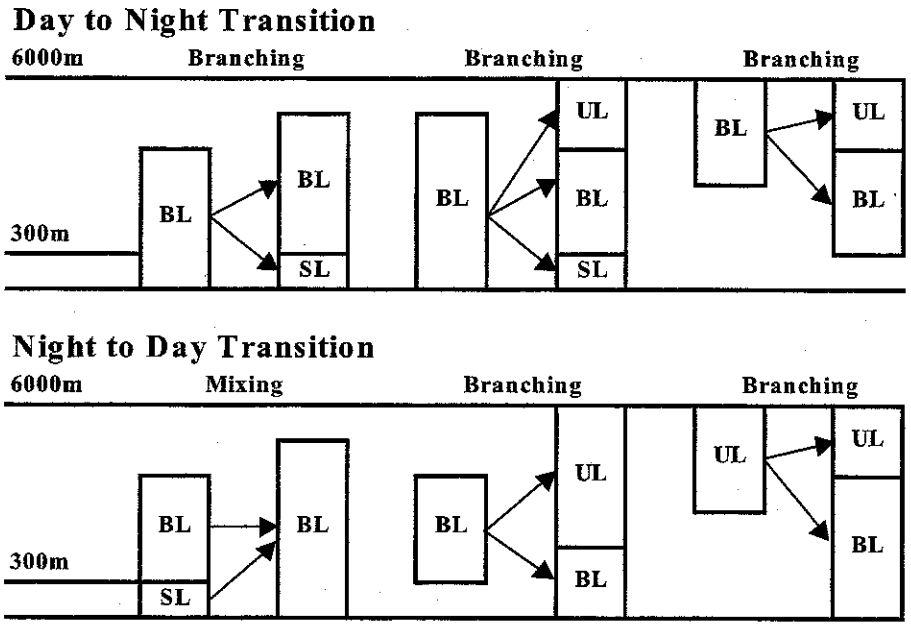


Figure 6.1.3.7 Branching and Mixing during The Transitions

For an example of the upper left figure, the pollutant included in the boundary layer during the daytime branches into the surface layer and the changed boundary layer during the nighttime.

For another example of the lower left figure, the pollutant in the surface layer and the boundary layer during the nighttime mixes into the boundary layer during the daytime.

4) Transformation

Transformation in ATMOS2 means conversion or oxidization from SO_2 to SO_4. The transformation process as well as the dry and wet deposition processes are all modeled as quasi-first order process in ATMOS2.

$$dC/dt = K \cdot C \qquad \text{C: Pollutant Concentration}$$

Here, K is a constant for each process and the functions to obtain K are different for transformation, dry deposition, and wet deposition, respectively.

The transformation rate K_R is a function of latitude and Julian day of the year, and the K_R ranges from 0.16 to 3.6 % per hour below 55 degrees latitude.

5) Dry Deposition

Dry deposition only occurs at the lowest layer both in the daytime and the nighttime, and the dry deposition coefficient is calculated from the dry deposition velocity.

$Kd = Vd/H$

Kd: Dry Deposition Coefficient (s^{-1})

Vd: Dry Deposition Velocity (ms^{-1})

H: Thickness of the Lowest Layer (m)

The dry deposition velocity Vd is defined for SO_2 and SO_4 depending on the season and the land/sea surface as in Table 6.1.3.2.

Table 6.1.3.2 Dry Deposition Velocity

Dry Deposition Velocity (10^{-3}m/s)		SO_2	SO_4
Land	Winter (Oct. to Mar.)	1.25	2.00
	Summer (Apr. to Sep.)	2.50	2.00
Sea		3.20	1.00

6) Wet Deposition

Wet deposition occurs in the all layers with the precipitation and wet deposition coefficient Kw is a function of the precipitation rate.

$$Kw_{SO2} = 2.00 \times 10^{-5} \times P$$

$$Kw_{SO4} = 5.00 \times 10^{-5} \times P^{0.83}$$

P: Precipitation Rate (mm/h)

6.1.4 Model Simulation for the Year 2000

6.1.4.1 Simulation for Comparison with Monitoring Data

The wet deposition amount of nss-Sulfur for all collected precipitations at OEPP, TMD, ERTC and Khao Laem Dam stations are targeted. For the simulations in order to compare their results with monitoring data, the precipitations collected at respective acid deposition monitoring stations (circle symbols in Figure 5.1.1.1) are used as the precipitation rate of 4 grid points around the stations because the monitored deposition amounts correspond to collected precipitations. For the remaining other grids, the CDC/NCEP data are used.

The comparisons of the calculation results in the Progress Report (2) showed underestimations and improvement of the simulation model was necessary.

The improvement of the simulation was conducted as the following two steps.

Step 1: Adoption of Urban Option for Urban Grids

Step 2: Calibration of Wet Scavenging Coefficient

The pollutant emission sources for the BMR were investigated in more details for the Airviro simulation and the pollutant sources concentrated in the most around the BMR. Then, the pollutant sources around the BMR are compiled into the detailed grids with 0.1 degrees sizes. On the other hand, ATMOS2 has the urban options for urban grid simulation.

For the simulation for the stations in the urban grid system, OEPP, TMD and ERTC, the urban option simulation and the regional option simulation without the urban grid emissions were conducted respectively. Finally, the contributions from the urban grid emissions and the regional grid emissions without the urban grids were summed up. For the simulation for the Khao Laem Dam station, only the regional simulation was conducted with all pollutant emissions to obtain deposition amount.

Based on the comparisons of the results of step-1 with the monitoring values, the calculation showed little underestimation, and the original wet scavenging coefficients for SO_2 and SO_4 were calibrated by multiplying 1.5 times for the improvement.

The original coefficients were calibrated as follows (See Supporting Report 5.2).

Original; $Kw_{SO2} = 2.00 \times 10^{-5} \times P$

$Kw_{SO4} = 5.00 \times 10^{-5} \times P^{0.83}$

Step-2; $Kw_{SO2} = \underline{\boldsymbol{3.00}} \times 10^{-5} \times P$

$Kw_{SO4} = \underline{\boldsymbol{7.50}} \times 10^{-5} \times P^{0.83}$

These calibrated values are within the range of affordable values compared with the coefficients used in the other similar models. The improved results are shown in Figure 6.1.4.1 and Table 6.1.4.1.

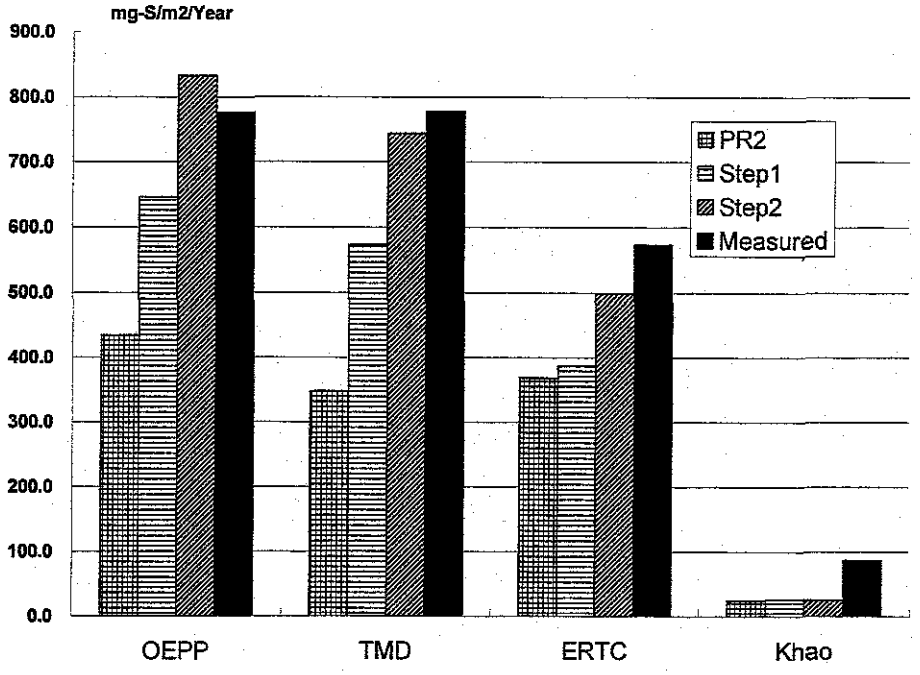


Figure 6.1.4.1 Improvement of Simulation Model

Table 6.1.4.1 Comparison of Simulation Results with Measurements

	OEPP	TMD	ERTC	Khao Laem Dam
Precipitation (mm/year)	1144.3	975.0	941.3	881.3
Calculated (mg-S/m^2/year)	833.0	744.2	498.8	25.7
Measured (mg-S/m^2/year)	776.9	777.8	573.6	87.0

6.1.4.2 Acid Deposition for the Year 2000

For the simulation of year 2000, the combined precipitation data explained in section 6.1.1.3 2) were used.

1) Sulfur Deposition in the Whole of Thailand

The wet and total depositions (wet and dry depositions) of sulfur are shown in Figure 6.1.4.2 and Figure 6.1.4.3. The depositions of the urban grids are shown separately in later figures. The most wet deposition of 642 mg-S/m^2 and total deposition of 959 mg-S/m^2 appear in the grid over Chaochoensao and Chonburi provinces.

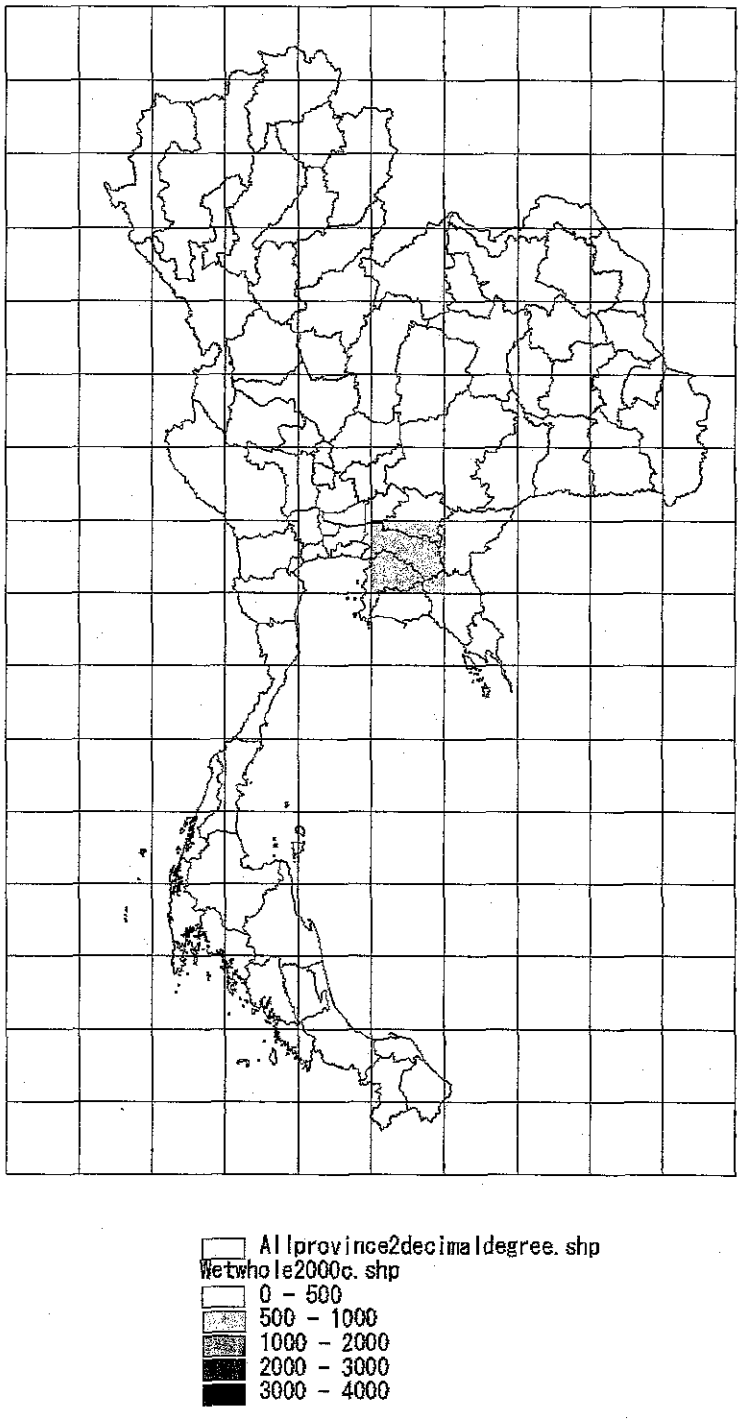


Figure 6.1.4.2 Wet Deposition in the Whole of Thailand for the Year 2000

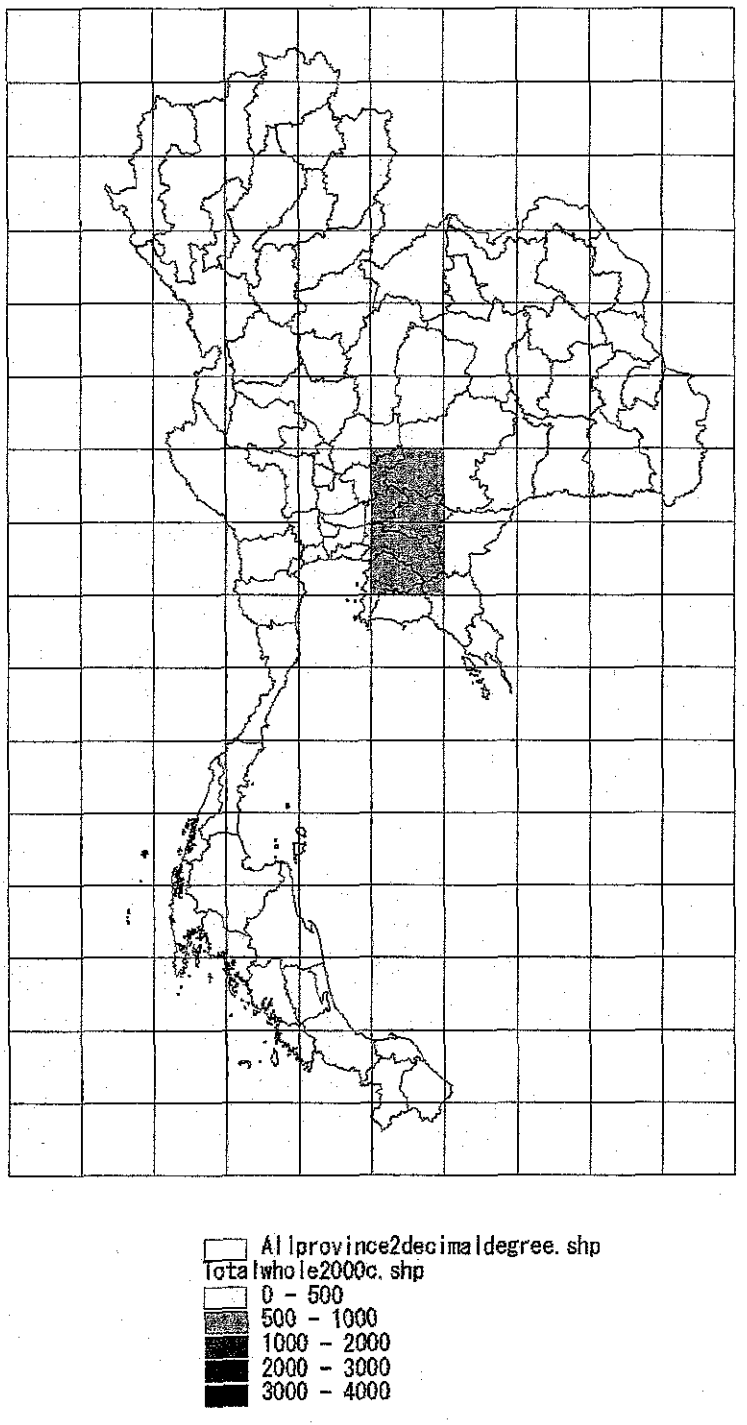


Figure 6.1.4.3 Total Deposition in the Whole of Thailand for the Year 2000

2) Sulfur Deposition in Urban Area

Wet and total depositions in the urban area are shown in Figure 6.1.4.4 and Figure 6.1.4.5. The most wet deposition of 1756 mg-S/m^2 and total deposition of 3329 mg-S/m^2 appear in the grid over Bangkok and Samutprakan provinces.

The urban area shows the most depositions, with more than 2000 mg-S/m^2 of the area covered for almost all the area of Bangkok province.

3) SO_2 Concentration in the Whole of Thailand

The SO_2 concentrations estimated are also shown in Figure 6.1.4.6, and the highest concentration of 3.89 ppb appears in the BMR grid. According to the screening by ATMOS2 simulation, the BMR seems to be the most polluted area for SO_2 in the viewpoint of wide area average at year 2000.

4) Trans-boundary Effects

To estimate the trans-boundary effects on sulfur depositions, the contributions from outside of Thailand on total sulfur deposition is shown in Figure 6.1.4.7. Certain amounts of deposition appears in the southern boundary with Malaysia and the northeastern boundary with Laos. As a result, around 111,700 tons of sulfur emitted from Thailand deposit within it, and foreign contributions are counted as around 35,100 tons and reach 24 % of the whole of Thailand's sulfur depositions. However, the foreign emissions are less accurate than the ones for Thailand, so multilateral investigations are necessary for the trans-boundary issues.

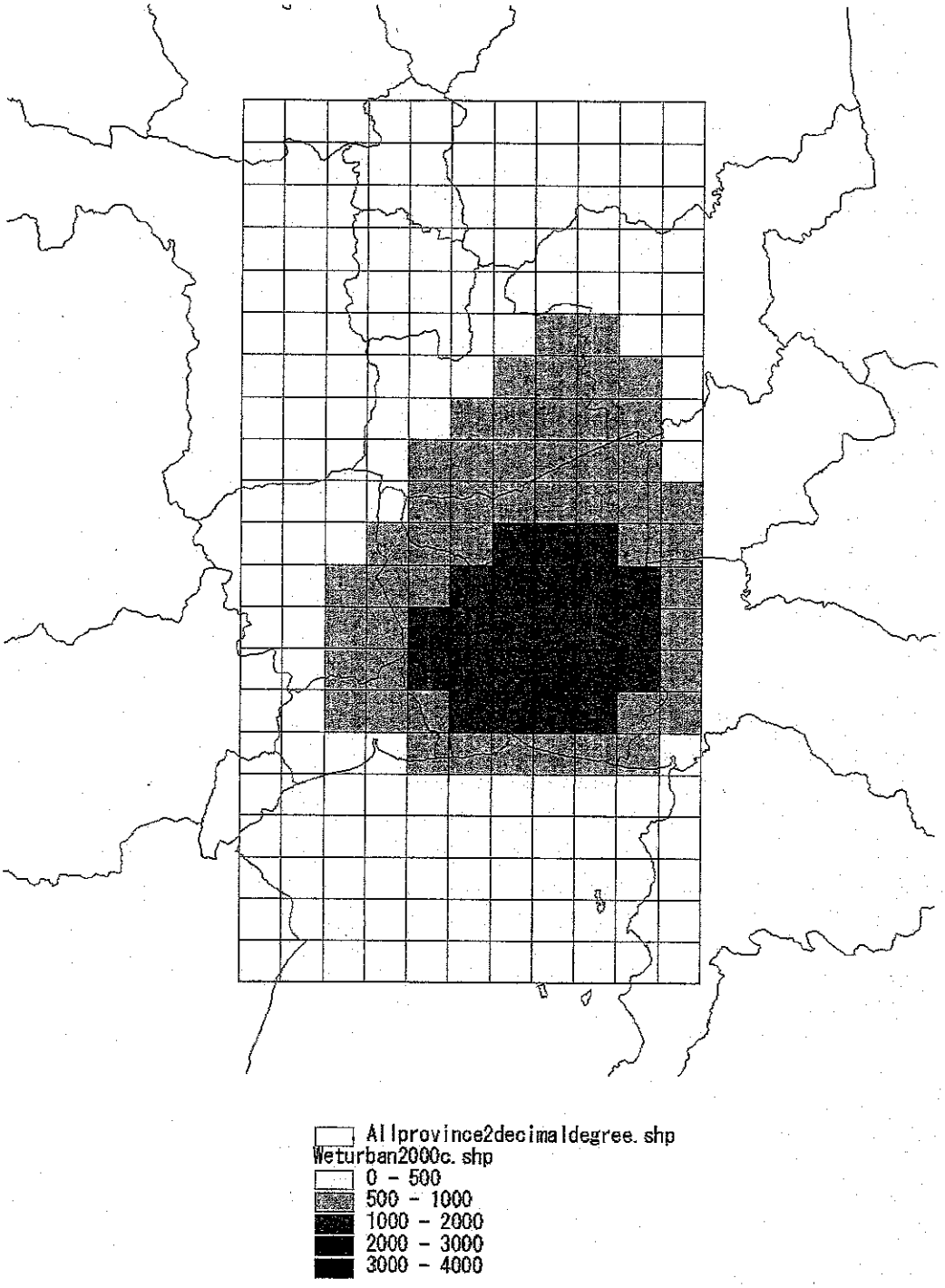


Figure 6.1.4.4 Wet Deposition in the Urban Area for the Year 2000

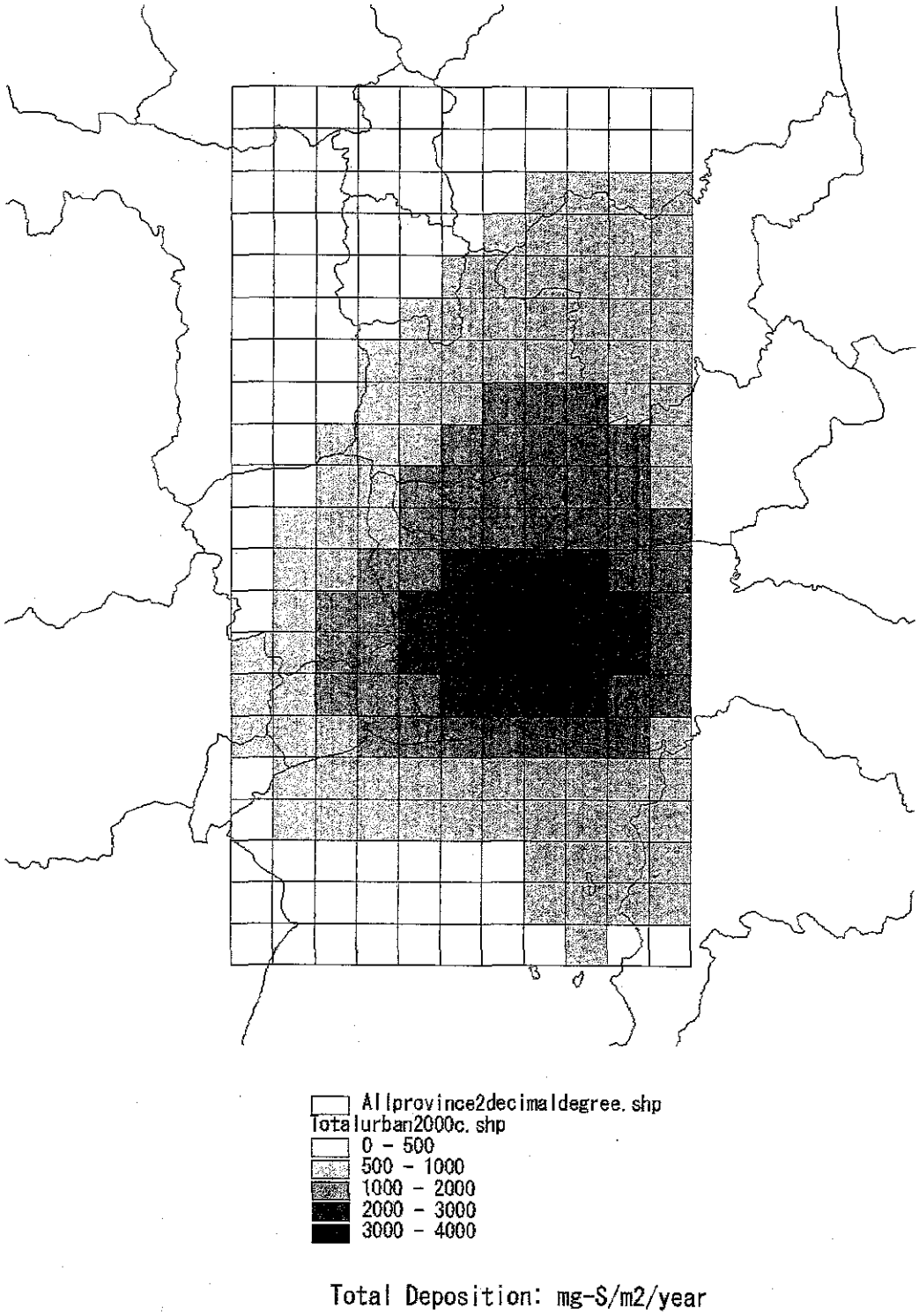


Figure 6.1.4.5 Total Deposition in the Urban Area for the Year 2000

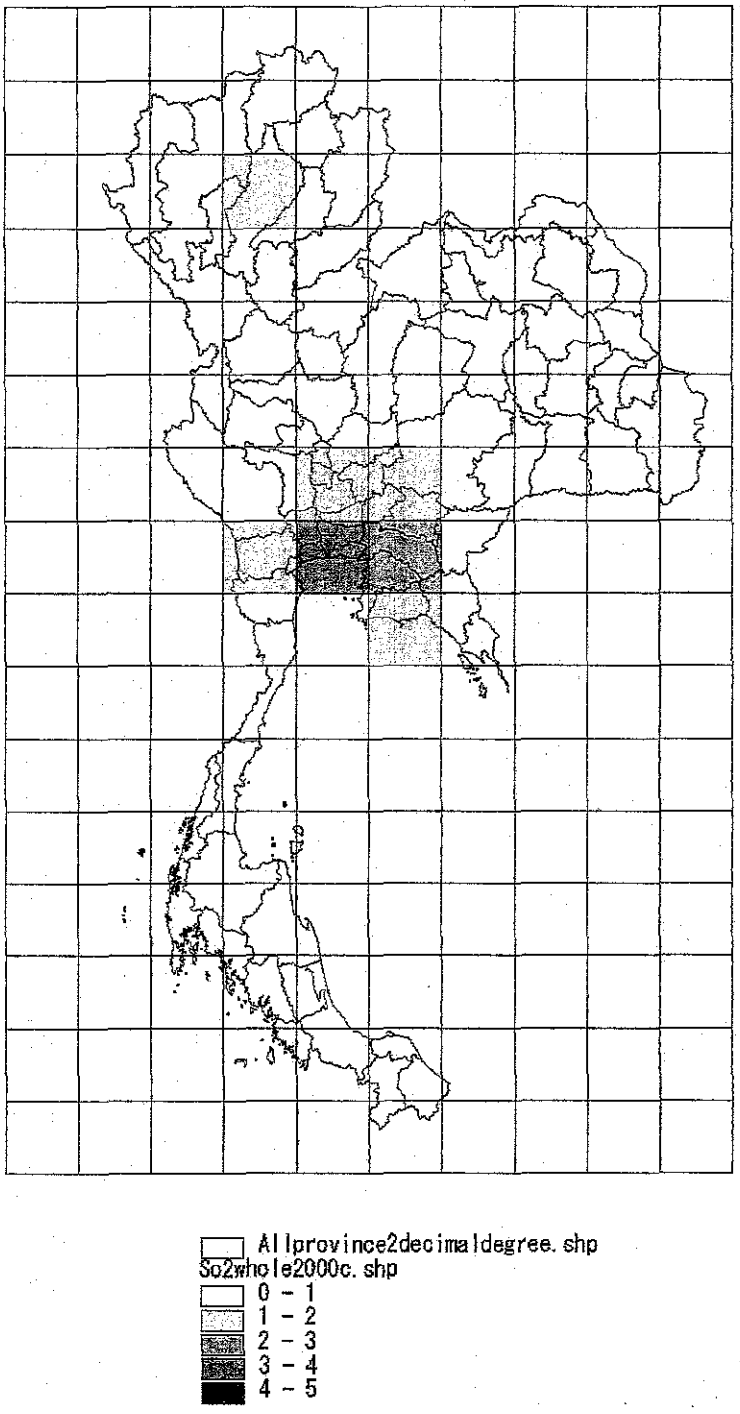


Figure 6.1.4.6 SO_2 Concentration in the Whole of Thailand for the Year 2000

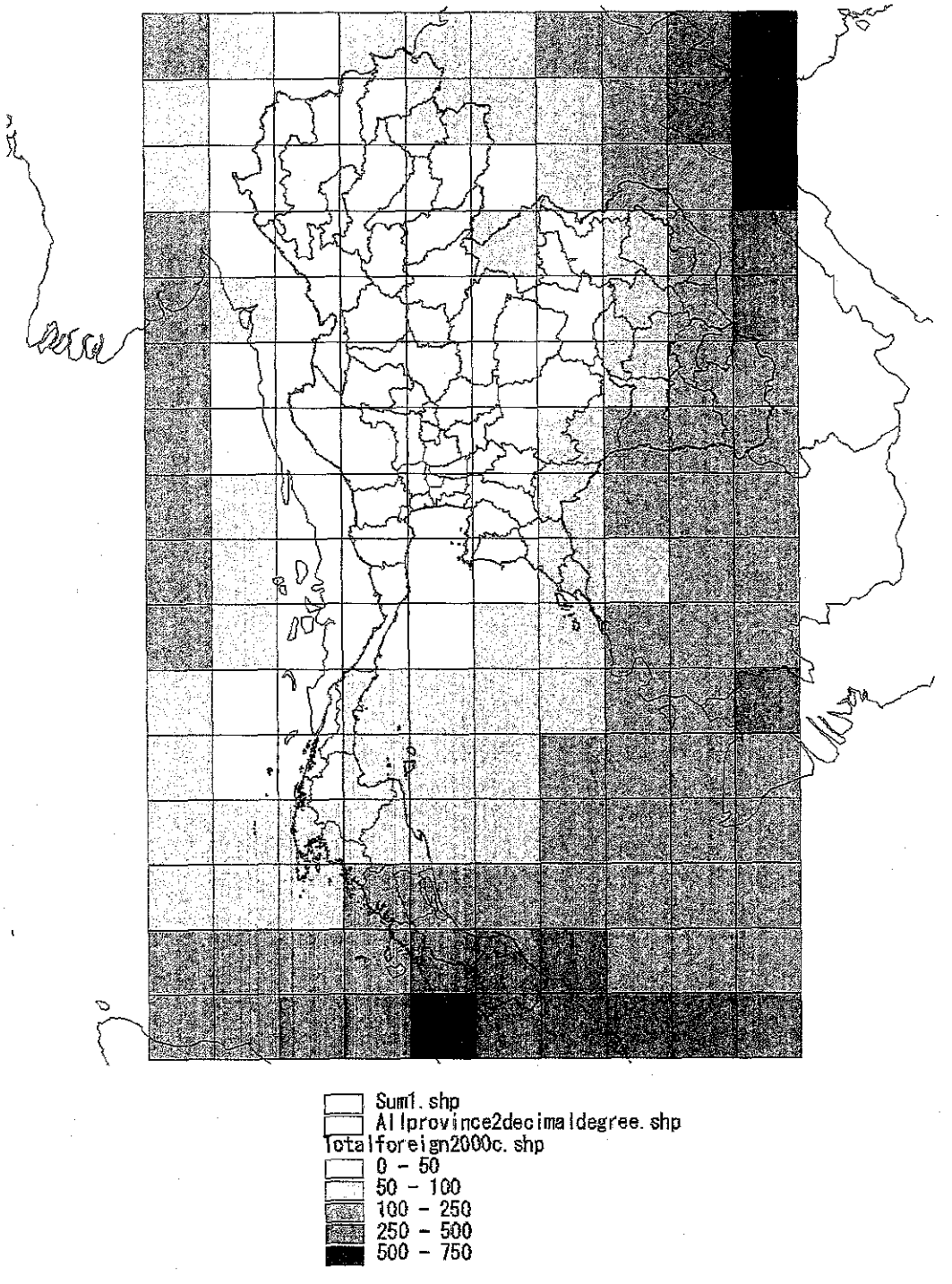


Figure 6.1.4.7 Trans-Boundary Contributions on the Total Deposition

6.1.5 Model Simulation for the Year 2011

6.1.5.1 Simulation Conditions for the Year 2011

The meteorological conditions are the same as to the ones for the year 2000, and the pollutant emission of mobile and stationary sources in Thailand are estimated as in chapter 3 and 4. The pollutant emissions outside of Thailand are assumed as the same as the one for the year 2000 for the backgrounds.

6.1.5.2 Acid Deposition for the Year 2011

1) Sulfur Deposition in the Whole of Thailand

The total deposition of sulfur is shown in Figure 6.1.5.1. The most deposition in the grid across Chaochoensao and Chonburi provinces will increase to 1185 mg-S/m^2 from 959 mg-S/m^2 for the year 2000.

2) Sulfur Deposition in the Urban Area

Total depositions in the urban area are shown in Figure 6.1.5.2. The most total deposition in the grid of Bangkok province will slightly decrease to 3062 mg-S/m^2 from 3329 mg-S/m^2 for the year 2000 according to the pollutant source change in the future. However, more than 2000 mg-S/m^2 area will remain in most parts of Bangkok.

3) SO_2 Concentration in the Whole of Thailand

The SO_2 concentrations estimated are also shown in Figure 6.1.5.3, and the highest concentration of 4.54 ppb will also appear in the same BMR grid as in the year 2000. The BMR is predicted as the most polluted area even in the year 2011.

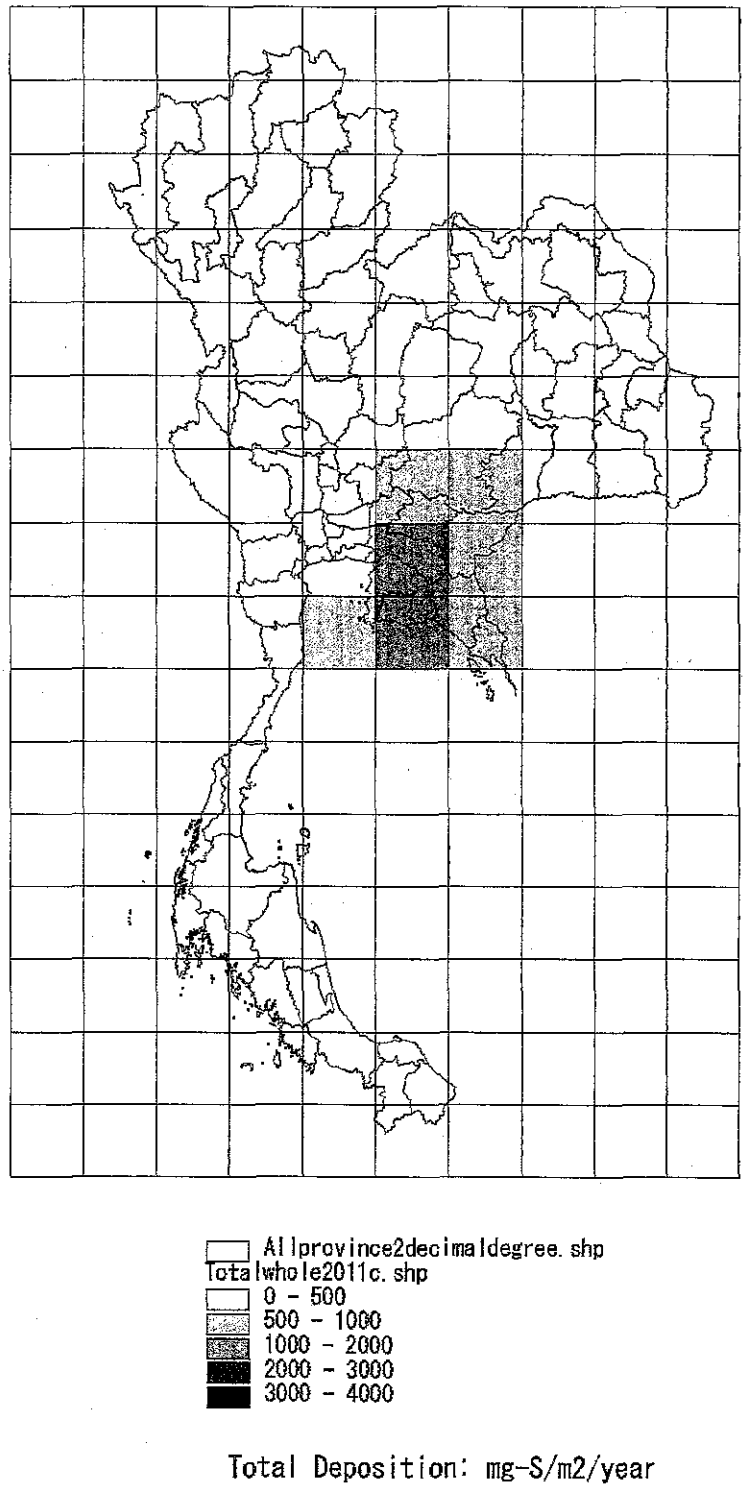


Figure 6.1.5.1 Total Deposition in the Whole of Thailand for the Year 2011

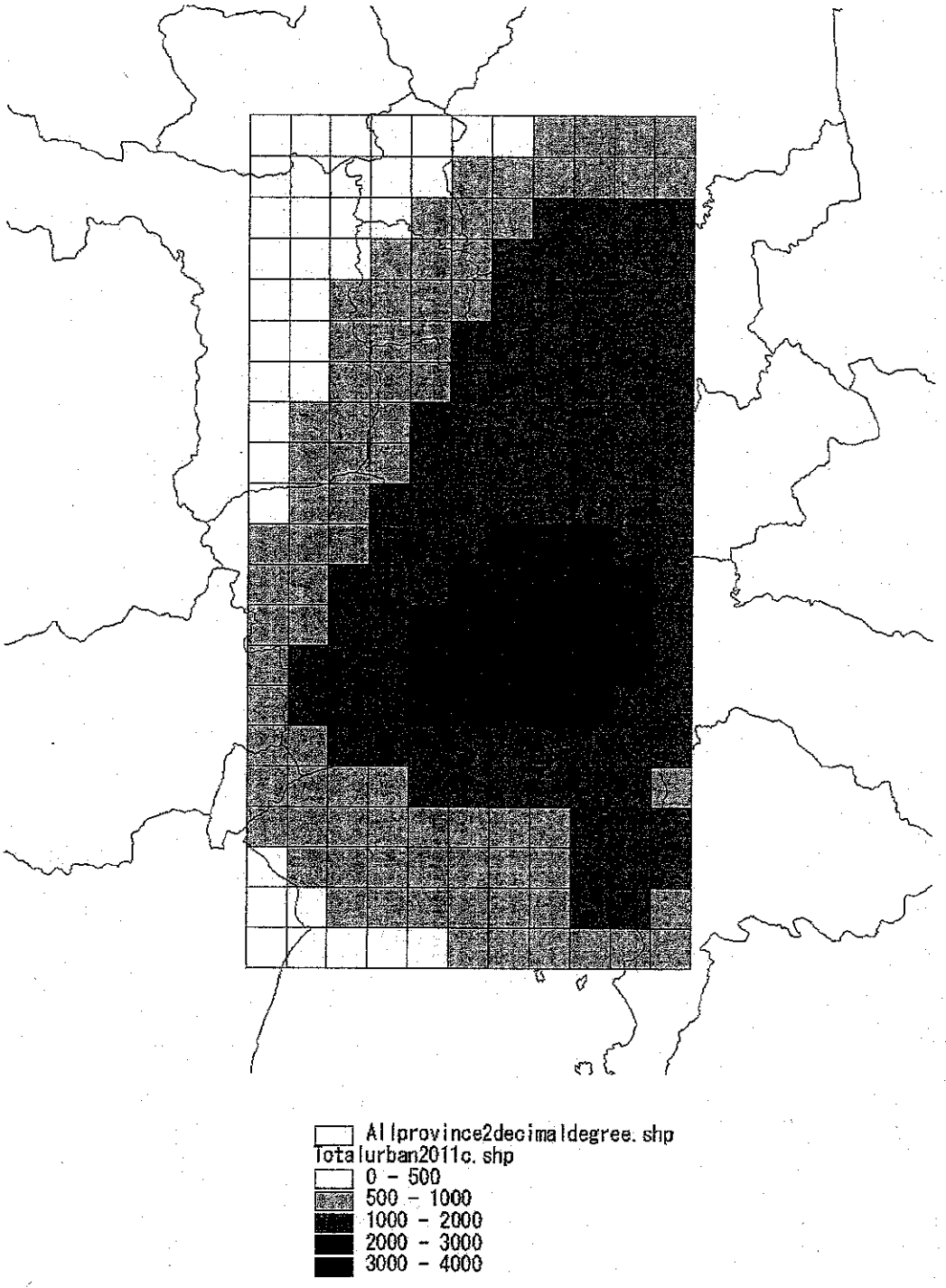


Figure 6.1.5.2 Total Deposition in the Urban Area for the Year 2011

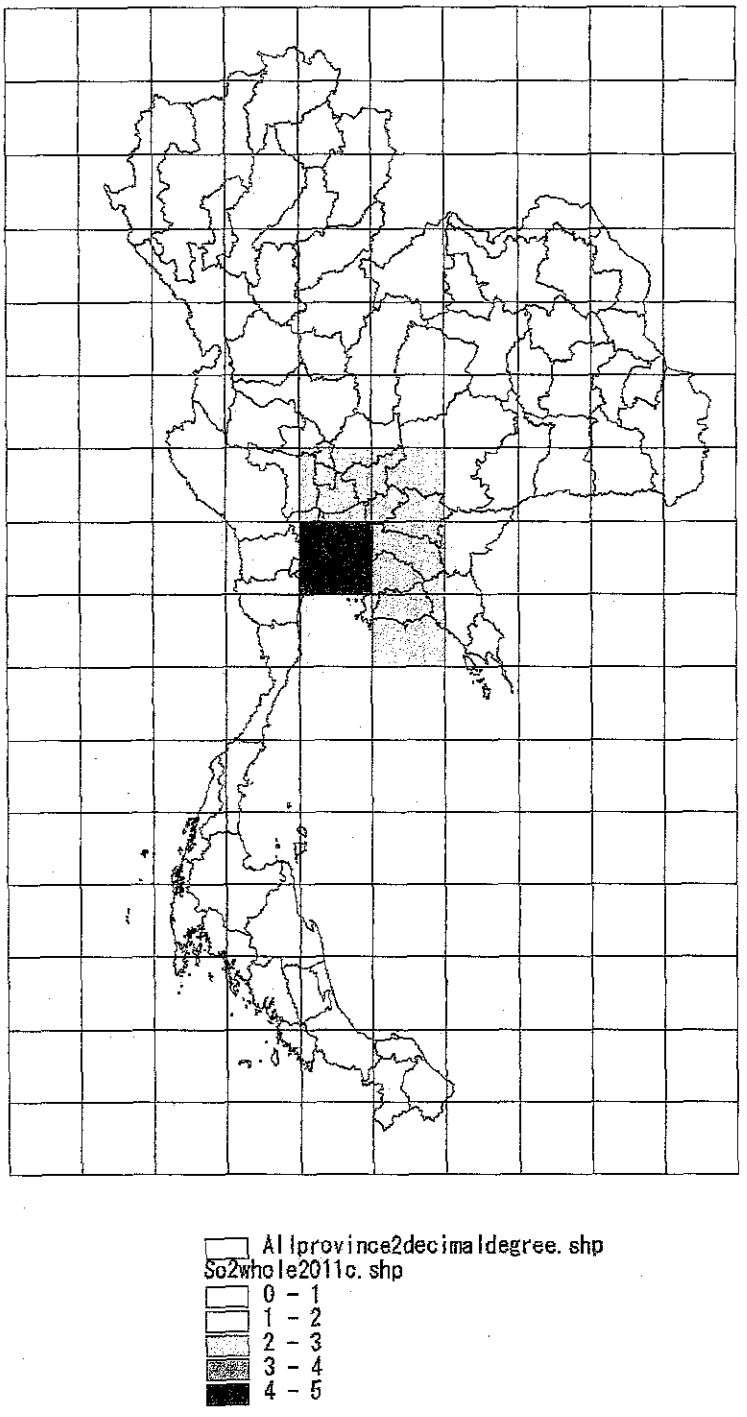


Figure 6.1.5.3 SO_2 Concentration in the Whole of Thailand for the Year 2011

6.1.6 Model Simulation for the Year 2011 with the Control

6.1.6.1 Simulation Conditions for the Year 2011 with the Control

The control case was investigated and the details of the control measures are described in chapter 7. Other conditions except pollutant emission are the same as to the ones for Year 2011 BaU simulation.

6.1.6.2 Acid Deposition of Year 2011 with Control

1) Sulfur Deposition in the Whole of Thailand

The total deposition of sulfur is shown in Figure 6.1.6.1. The most deposition of 1185 mg-S/m^2 in the grid across Chaochoensao and Chonburi provinces under the BaU case will decrease to 1030 mg-S/m^2 and the most deposition under the control case is 1126 mg-S/m^2 around Rayong province.

2) Sulfur Deposition in the Urban Area

Total depositions in the urban area are shown in Figure 6.1.6.2. The most deposition in the grid of Bangkok province will relatively decrease to 2380 mg-S/m^2 from 3062 mg-S/m^2 for the year 2011 BaU case by the control. The areas with more than 2000 mg-S/m^2 total depositions will also shrink.

3) SO_2 Concentration in the Whole of Thailand

SO_2 concentrations estimated are also shown in Figure 6.1.6.3, and the highest concentration of 4.54 ppb under the BaU case will decrease to 3.73 ppb by the control.

6.1.7 Comparisons with Critical Load

"Critical Load" is one of the indices of damages by acid depositions to eco-systems, but there are various criticisms on its adoption to Asia regions. So, the critical load is not used as target values for emission controls, but used as reference values for comparisons with simulated depositions (Supporting Report, Chap.5.1, Chap.9.1). Comparing the simulated sulfur depositions over Chachoengsao and Chonburi provinces in the years 2000, 2011, and 2011 under the control with 25% critical values, 58%, 66%, and 61% of reductions are necessary. In urban areas, the maximum depositions in year 2000, year 2011, and year 2011 under the control correspond to the 82%, 80%, and 74% of the necessary reductions.

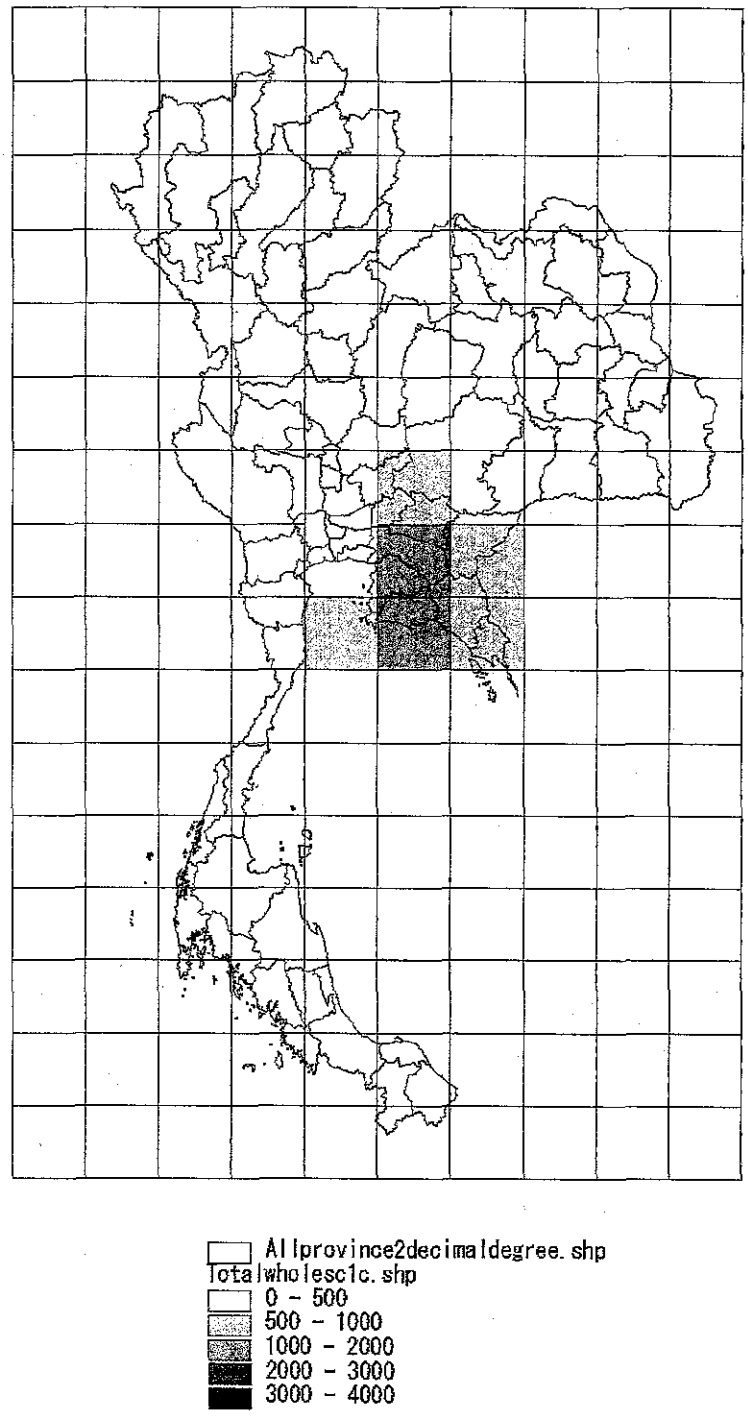


Figure 6.1.6.1 Total Deposition in the Whole of Thailand for the Year 2011 with the Control

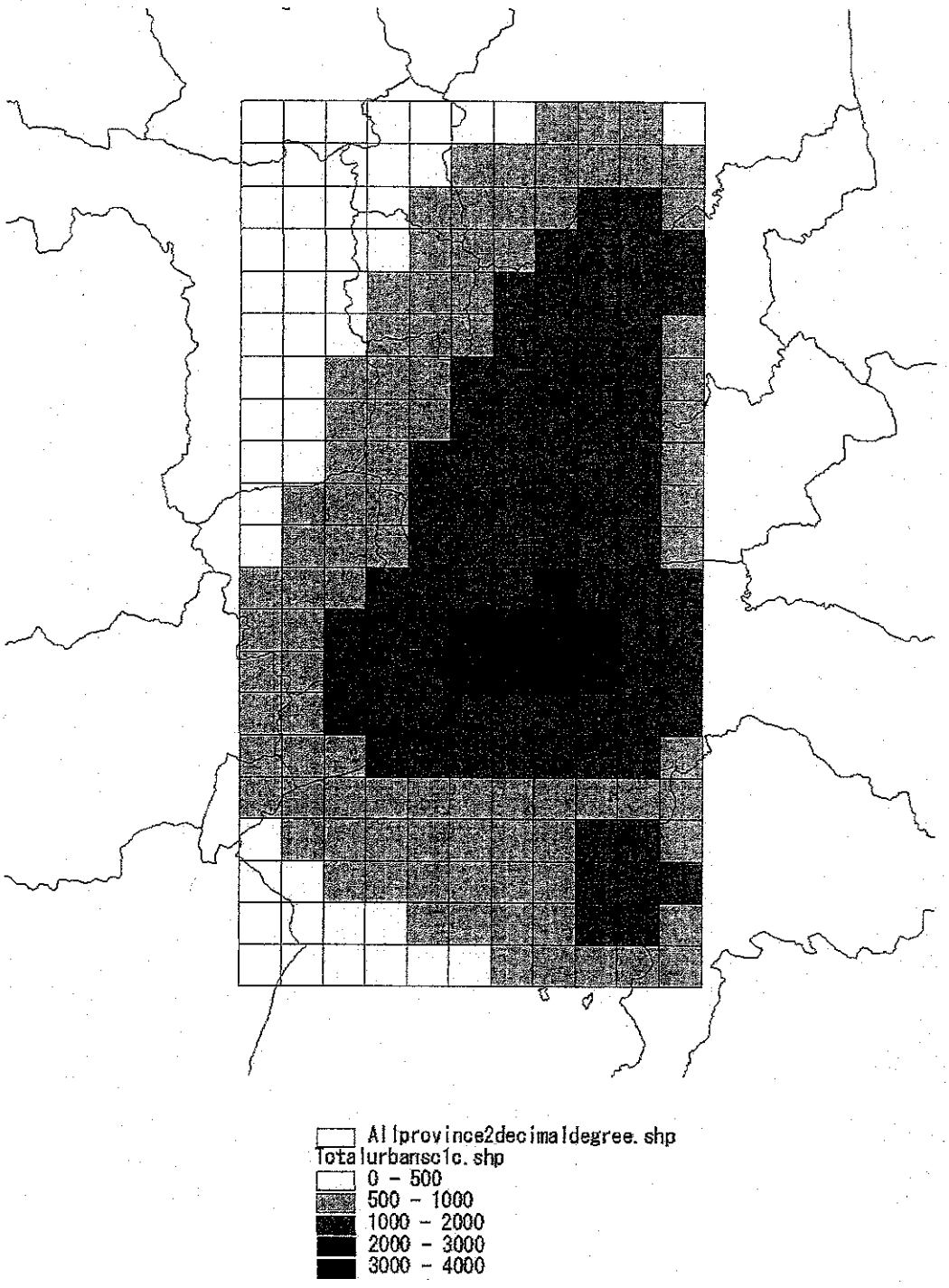


Figure 6.1.6.2 Total Deposition in the Urban Area for the Year 2011 with the Control

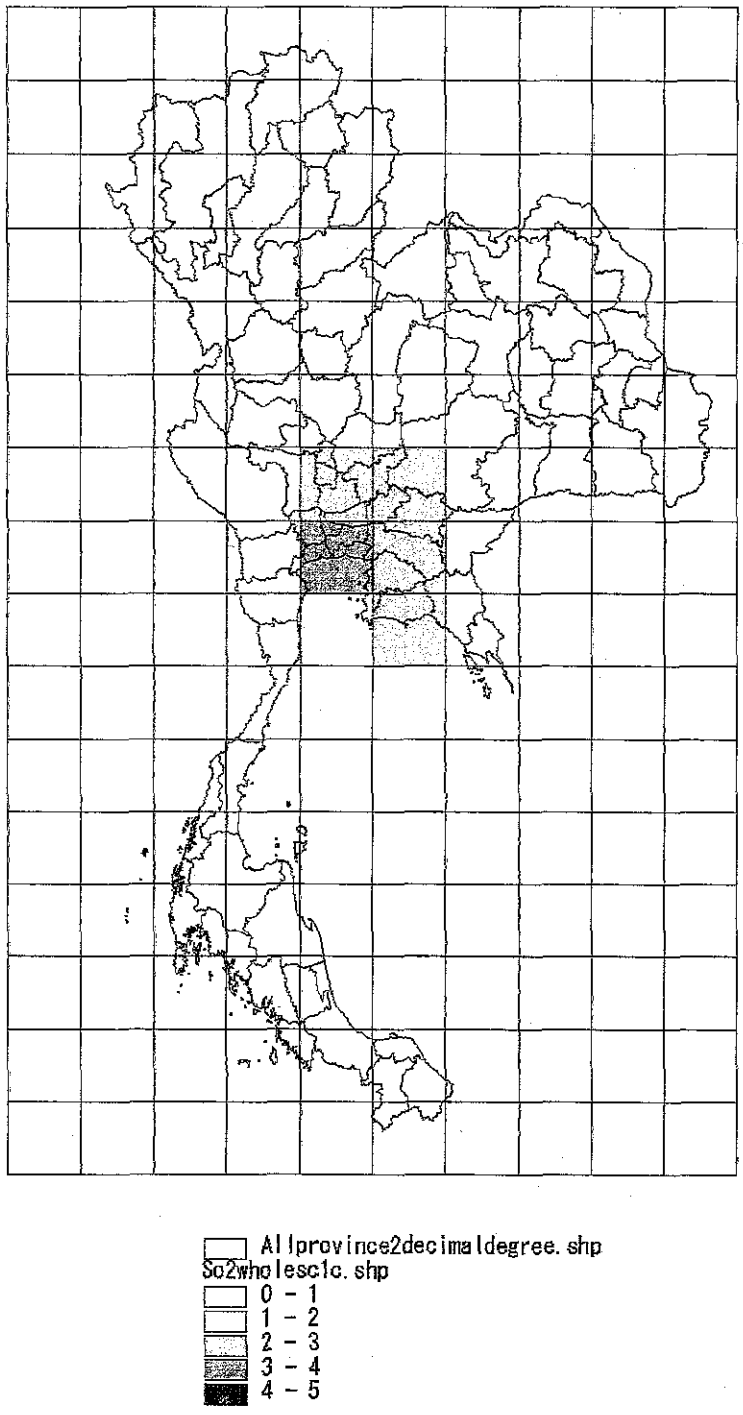


Figure 6.1.6.3 SO_2 Concentration in the Whole of Thailand for the Year 2011 with the Control