EFFECTS OF REGIONAL SO_2 EMISSION CHANGE ON THE DEPOSITION OF SULFUR IN NORTHEAST ASIA

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1. INTRODUCTION

It is widely accepted that, after the mid 1990s, the SO_2 emission in China has not increased thanks to the rigorous Chinese government policies against it. However, with the development of western China which is planned by the Chinese government till 2050, it is possible that the amount of SO_2 emission might increase again in regional scale. In this study, changes of emission and deposition patterns of sulfur species in east Asia caused by the development of western China are studied by using the RAINS-Asia (Regional Air pollution INformation and Simulation) model.

Various scenarios for SO_2 emissions in China are applied to estimate patterns of sulfur deposition amount and its effects in east Asia in 2010.

2. MODELING

RAINS-Asia model has been developed by International Institute for Applied System Analysis (IIASA) under the sponsorship of the World Bank and the Asian Development Bank since 1992. It estimates emission, transport, transformation, and deposition of sulfur species (mainly SO_2), and analyzes cost-effective strategies for reducing environmental impacts in Asia. The geographical model domain covers Asia from 60°E to 160°E and from 55°N to 10°S on the 1° x 1° grid. Base year is 1990 and results are calculated every five years till 2030. The model consists of three modules; EMCO (EMission COst module or the energy-emissions module), DEP (DEPosition and critical loads assessment module), and OPT (OPTimization module). In this study, RAINS Model version 7.52 has been used, and EMCO has been used for making emission scenarios and DEP for calculating deposition and source contribution. Details of the model are described elsewhere [1] [3].

The RAINS-Asia model provides three cases. In the NFC (No Further Control) case, emission of SO_2 increases with the economic growth and it is assumed that the emission control technologies similar to those in the 1990s will be used. Other cases are the maximum control and no control cases. But in the former case, the estimated emission amount is far less than the emission data from Chinese government [5] or other study [6]. In the latter case, the estimated emission amount is extremely high. Thus, the NFC scenario is adopted as the base case in this study.

The target regions of the development in western China are twelve provinces, autonomous districts, and cities under the direct control of the government including Nei Mongol autonomous district, Guangxi autonomous district, and Shaanxi province. The Chinese government has introduced the concept of eastern, middle, and western area, in the middle of 1980's during the 7th five-year plan. The regions in coastal area like Guangdong, Beijing, and Zhejiang are classified as eastern area, and other regions are classified as middle area (Figure 1).

Figure 1. Classification of western, middle, and eastern China [4].

Development of western China might be connected with the increase of the emissions of air pollutants, so in all scenarios it is assumed that the SO_2 emission of western China increases. On the other hand, there are several conflicting prospects on the future SO_2 emissions in eastern China. Thus, we accommodate this point and made four more scenarios as shown in Table 1. The emission amount for the cases of increase and decrease are 50% and 33% of those in the NFC scenario, respectively, in this study.

Scenarios	Scenario 1 (NFC)	Scenario 2 (I. China) [1]	Scenario 3 (E.I.W.I.) [2]	Scenario 4 (E.S.W.I.) [3]	Scenario 5 (E.D.W.I) [4]
Eastern China	NFC	Increase in China	Increase	No Change	Decrease
Western China			Increase	Increase	Increase

[1] I. China = Increase in all regions of in China

[2] E.I.W.I. = Increase in Western China and Increase in Eastern China

[3] E.S.W.I = Increase in Western China while Same in Eastern China

[4] E.D.W.I = Increase in Western China while Decrease in Eastern China

Table 1. Emission scenarios

3. RESULTS

The estimated SO_2 emission amounts for each scenario in whole, eastern, western, and middle China in 2010 are in given in Table 2.

Emission (Unit: Mt yr^{-1})	Scenario 1 (NFC)	Scenario 2 (I. China)	Scenario 3 (E.I.W.I.)	Scenario 4 (E.S.W.I.)	Scenario 5 (E.D.W.I)
Whole China	29.5	44.2	40.0	38.3	30.3
Eastern China	11.7	17.6	17.6	11.7	7.80
Western China	9.45	14.2	14.2	14.2	14.2
Middle China	8.30	12.4	8.30	8.30	8.30

Table 2. The emission of each scenario

It is found that the emission amount of SO_2 for scenario 5 is larger than that for scenario 1 for whole China. That is, in spite of the decrease of emission in east, the emission in whole China might increase because of the increase of emission in west. If the increase of emission in west is more than 2.2 times of NFC case, the total amount of emissions in China will increase regardless of the emission in east based on the numbers used in this study. Thus, in the future, the SO_2 emission in China might be rather influenced by the emissions in west than those in east.

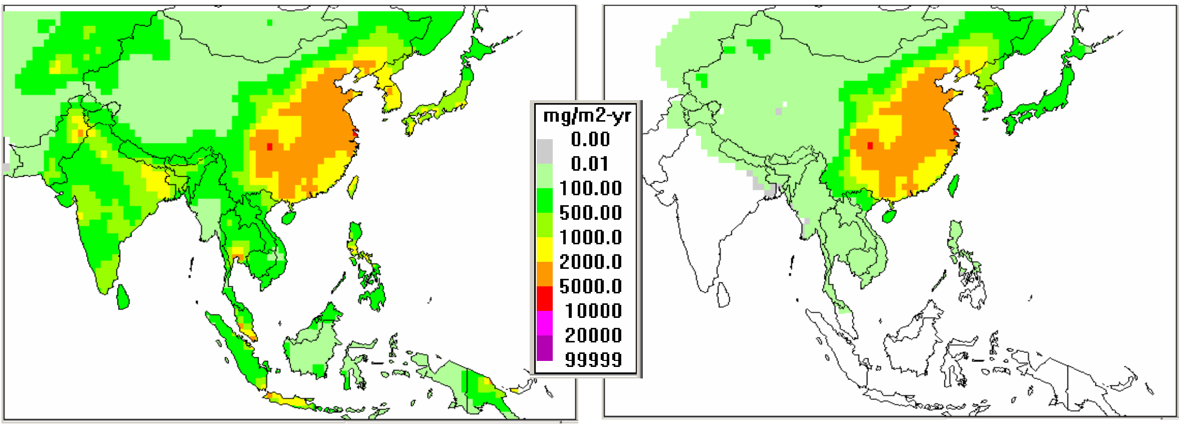
By using the DEP module, the regional deposition amounts in 2010 are calculated and the result of source contribution is shown in Table 3. The SO_2 emission in Asia is influenced most by China and in all scenarios, and the SO_2 emission in western China influence more than eastern China with regard to the deposition on whole Asia.

Figure 2 shows the deposition pattern of sulfur species in 2010 for scenario 1 (NFC), from different source areas. It shows that the deposition on Asia from the SO_2 emission in

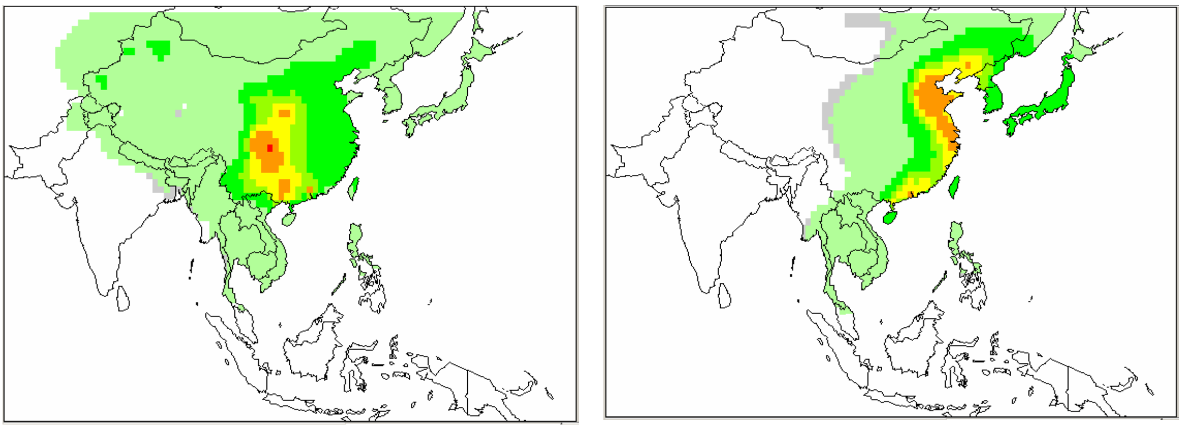
Asia is similar to from the emission in China. And Korean peninsula and Japanese islands are affected more by the emission of eastern China than western China.

Deposition amount	Emissions from whole Asia	Emissions from China only	Emissions from western China only	Emissions from eastern China only
Scenario 1 (NFC)	12.6 (100 %)	8.4 (67 %)	3.2 (25 %)	2.6 (21 %)
Scenario 2 (I.China)	16.8 (100 %)	12.5 (74 %)	4.8 (29 %)	3.9 (23 %)
Scenario 3 (E.I.W.I.)	15.5 (100 %)	11.2 (72 %)	4.7 (30 %)	3.9 (25 %)
Scenario 4 (E.S.W.I.)	14.2 (100 %)	9.9 (70 %)	4.7 (33 %)	2.7 (19 %)
Scenario 5 (E.D.W.I.)	13.0 (100 %)	8.8 (68 %)	4.5 (35 %)	1.8 (14 %)

Table 3. Deposition amount of sulfur species in Asia from different source areas (unit: Mt yr^{-1})



(a) Emissions from whole Asia (b) Emissions from China only



(c) Emissions from western China only (d) Emissions from eastern China only

Figure 2. Deposition patterns of sulfur species in 2010 for scenario 1 from different source areas

The ratios of the areas of unprotected ecosystems to the total area of the ecosystem in China, Japan, and Korea fore each scenario are shown in Table 4. In RAINS-Asia model, the ecosystem areas considered are; 9160000 km^2 in China, 380000 km^2 in Japan, and 97000 km^2 in Korea and the ecosystem areas considered are 67% (China), 50% (Japan), and 65% (Korea) of the whole areas, respectively.

The ratios of unprotected ecosystem are changed by the changes of SO_2 emission in China. In scenario 2 (emissions of SO_2 in all Chinese areas increase), the ratio increases most, 2% in China, 2% in Japan, and 8% in Korea. In areawise, 120000 km^2 are unprotected in China while 4500 km^2 in Japan and 5000 km^2 in Korea are unprotected, respectively. The changes of ratio are small, but the changes of unprotected areas are not small. It means the increase of the emission of SO_2 in China would make the large area of ecosystem unprotected. In other scenarios, the ratios of unprotected ecosystem increase by about 0.5 – 6%.

	Scenario 1 (NFC)	Scenario 2 (I. China)	Scenario 3 (E.I.W.I.)	Scenario 4 (E.S.W.I.)	Scenario 5 (E.D.W.I)
China	8.3	10	10	9.4	8.3
Japan	5.6	7.7	7.0	6.0	5.0
Republic of Korea	50	58	56	52	50

Table 4. Ratio of unprotected ecosystem in China, Japan, and Korea (in %).

Table 4 shows that the unprotected ecosystem for scenario 5 (emissions of SO_2 in west increase while those in east decrease) is lower than scenario 1 (NFC case) in Japan. It means Japan is affected more by the emission in eastern China. It is found again that Japan and Korea are more affected by the emission in eastern China by source contribution than western China.

In Korea, generally, more than 50% of ecosystem is unprotected. The major reason of the high unprotected ratio in Korea is low critical load. The critical load of Korea is generally lower than Japan or China [2]. Another reason is the higher emission intensity of SO_2 in Korea (about 10 t/ km^2) than China (about 3 t/ km^2) or Japan (about 2 t/ km^2). Third, transport from outside Korea is important. Although the SO_2 emission in Korea becomes zero, the ratio of unprotected ecosystem in Korea is 15%, still higher than China or Japan. Therefore, the long-range transport of sulfur species from other countries is not negligible. According to the source contribution calculations using this model, 59% of sulfur species deposition in Korea is from Korea, 35% from China, and 6% from other countries except China.

4. CONCLUSIONS

In this study, the effects of the change of the emission pattern of SO_2 in China on east Asia are studied by using the RAINS-Asia model. Five scenarios have been postulated to reflect possible future SO_2 emission changes in China. In all cases, it is assumed that the SO_2 emission in western China increase, while that in eastern China might increase, not change, or decrease. In scenario 5 (emissions of sulfur in west increase while those in east decrease), the amount of SO_2 emission in whole China can increase, in spite of the emission reduction in eastern China.

It is found that the changes of SO_2 emission in China also affect the ecosystem in Korean peninsula and Japanese islands. It is found that Korea and Japan are affected more by the emission in eastern China than emissions in west. The range of changes of unprotected ecosystem ratio is just 0.5 – 8%, but the absolute areas are not small.

It is expected that the amount of fuel usage in China would increase. Therefore scenario 3 (emissions of sulfur in west increase while those in east are not change) or scenario 4 (emissions of sulfur in both west and east increase) is more likely than scenario 5 (emissions of sulfur in west increase while those in east decrease). Consequently increase of the emission of SO_2 in western China would make increase of the deposition of sulfur species on Asia, and the unprotected ecosystem.

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