ENVIRONMENTAL SCIENCES 2000 Vol. 4, No. 2, 111~116
Bulletin of the Korean Environmental Sciences Society

Source-Receptor Relationships of Transboundary Air Pollutants in East Asia Region Simulated by On-Line Transport Model

Eun-Suk Jang and Itsushi Uno*

Dept. of Environmental Engineering, Kyungpook National University, Taegu 702-701, Korea
**Research Institute for Applied Mechanics, Kyushu University, Kasuga-Park 6-1, Kasuga, Fukuoka 816-8580, JAPAN*

(Manuscript received on May 25, 200)

Transboundary air pollution has recently become an area of increasing scientific interest and political concern as countries are receiving air pollutants from their neighbors. In order to gain a better understanding of the long-range transport processes of air pollutants and the source-receptor relationships among neighboring countries, an atmospheric transport model coupled with a RAMS(Regional Atmospheric Modeling System) model was applied to the East Asia region during the entire month of January 1993. The scalar transport option of the RAMS model was used to calculate special atmospheric constituents such as trace gases or aerosols. The sulfate production in clouds and rainwater and its removal processes by dry and wet deposition were considered.

The sulfate budget from source regions to receptor regions was estimated by analysing the source-receptor relationships. When a specific receptor site revealed a sulfate value higher than the sulfate concentration based on its own source origin, this was taken to indicate long-range transport from another source region.

The contribution ratio from various source regions was calculated. The contribution ratio of dry and wet deposition was higher on the main continent of the East Asia region. Furthermore, the high deposition amounts were identified on the west coast of Korea and the East China Sea.

Key words : transboundary air pollution, source-receptor relationship, sulfate, dry deposition, wet deposition

1. Introduction

The remarkable increase in energy consumption, resulting from the rapid economic growth in East Asian countries, is now leading to serious regional atmospheric pollution problem including both acid rain and acid deposition. In addition, transboundary air pollution has become a focus of public attention and has become an area of increasing scientific interest and political concern as countries are receiving pollutants from their neighbors. As a result, various countries have begun to expand their monitoring activities.

Furthermore, a number of numerical modeling studies have been performed on the long-range transport of air pollutants in East Asia(Kotamarthi and Carmichael[6]: Kitada and Lee[5]: Uno *et al.*[11]: Jang *et al.*[4]). The RAINS-ASIA project produced the first estimates of the regional impact of the expanding energy use in Asia. For the Indian subcontinent and Southeast Asia, biomass burning, industrial activities, and utilities are contributors to the total sulfur deposition throughout southeast Asia(Arndt *et al.*[1]). Recently, a model intercomparison study on long-range transport and the deposition of sulfur in Asia was performed as part of a collaborative project involving the CRIEPI (Central Research Institute of Electric Power Industry, Japan) and IIASA(International Institute for Applied System Analysis, Austria).

In this study, the long-range transport processes of air pollutants and the source-receptor relationships among neighboring countries in the East Asia region during the month of January 1993 were studied using an atmospheric transport model coupled with the RAMS model. The focus was to compare the source-receptor relationships including dry and wet deposition.

2. Outline of RAMS Application

The Regional Atmospheric Modeling system developed by scientists at Colorado State University was used to simulate the regional scale meteorological field. The model consists of non-hydrostatic compressible dynamic equations, thermodynamic equations, and microphysics equations for clouds and precipitation. The general characteristics of RAMS and its capabilities are summarized in Pilke *et al.*[8]. The RAMS model has a built-in Isentropic Analysis package(RAMS/ISAN). ISAN was used to model the field initialization and four-dimensional data assimilation (FDDA) based on ECMWF 2.5 global analysis data. ECMWF data was used for the continuous data assimilation of RAMS and strong nudging. Furthermore, the RAMS model contains a scalar transport option to calculate special atmospheric constituents such as trace gases or aerosols. This option was used to calculate the atmospheric sulfur concentration and sulfate production in clouds and rainwater together with its removal by dry and wet deposition. The present on-line transport model experiment was very simple and included SO_2 and the aerosol SO_4^{2-} For this application a linear chemical reaction was set as follows.

$$SO_2 \text{ ------> } SO_4^{2-} \text{ (reaction rate; } k_1\text{)}$$

It also included a below-cloud scavenging(wash out) of these species based on the cloud base and precipitation rate. A more detailed model inter-comparison parameter can be found at http://www.cgrer.uiowa.edu/people/gcalori/model_intercomp.htm. The on-line transport model is fully coupled with a regional meteorological model has many merits. For example, clouds, especially cumulus clouds have a significant influence on precipitation. They also play an important role in the exchange of species between the boundary layer and the cloud layer. These transport processes usually have a temporal and spatial variation and require detailed real-time information about the cloud distribution.

3. Model Domain and Input Data

The East Asia model domain is shown in Fig. 1. It was divided into 8 region sets for all countries (see Table 1) and volcano sources.

The center points of the model in polar stereographic were E120° and N30°. The horizontal grid number was a 60 x 56 polar stereographic grid.

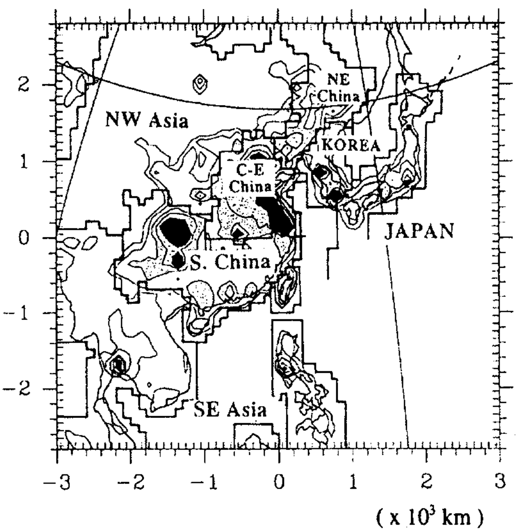

Fig. 1. Model domain and 8 region sets for East Asia region.

The grid resolution was 100km. The vertical model domain consisted of 30 layers from ground level to 23km. The model used a terrain-following z* coordinate system. The sea surface temperature (SST) was taken from NCAR SST monthly data for January 1993. The vegetation-type index was converted from Matthews's vegetation data. ECMWF 2.5 global analysis data was used for a continuous data assimilation of the RAMS model. Base emission data from 1993 was used for the study domain based on a RAINS-Asia analysis. The data consisted of area and large point source emissions(including emissions from ships), as well as volcanic emissions. And the total emission was considered as 95% SO_2 and 5% SO_4.

Table 1. Region sets for source-receptor analysis

Japan	Japan
Korea	North Korea, South Korea
North Eastern-China	Heilongjiang, Jilin, Liaoning, Shenyang
Central Eastern-China	Hebei, Anhui, Henah, Beijing, Tianjin, Shandong, Shanxi, Taiyuan, Hubei, Wuhan, Jiangsu, Shanghai
Southern-China	Hunan, Jiangxi, Zhejiang, Fujian, Guangdong-Hainan, Guangzhou, Guangxi, Sichuan, Chongqing, Guizhou, Guiyang, Yunnan, Hong Kong
Taiwan	Taiwan
South Eastern-Asia	Bangladesh, Bhutan, Myanmar, Cambodia, India, Indonesia, Laos, Malaysia, Philippines, Thailand, Vietnam
North Western-Asia	NW China (Shaanxi-Gansu), Inner Mongolia SE Asia Ningxia, Tibet, Qinghai, Xinjiang, Mongolia

4. Results

4.1. Time Variations of Surface Sulfate Concentrations

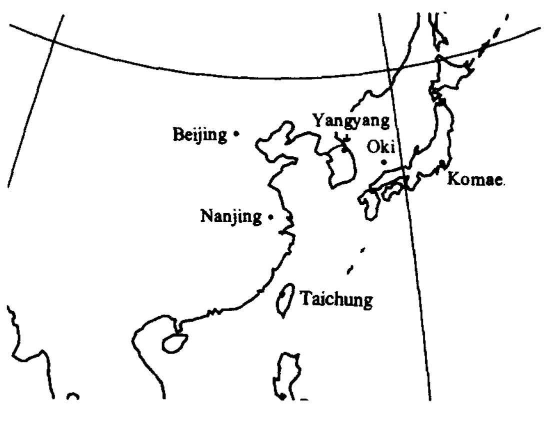

Fig. 2. Location of representative sites(Beijing, Nanjing, Taichung, Yangyang, Oki, Komae) in model domain.

In order to make a quantative analysis of the long-range transport of air pollutants from the main continent of the East Asia region to the region on the west side, 6 representative sites(Beijing, Nanjing, Taichung, Yangyang, Oki, Komae) within the 8 region sets were chosen. These sites are shown in Fig. 2.

Fig. 3 shows the time variation with the calculated surface sulfate concentrations. This was calculated using the scalar transport option, as described above in section 2. The "All amount" in Fig. 3 represents the calculated surface sulfate concentration at each site. However the other lines represent the fraction from each of the source regions.

In Nanjing in CE-China, the highest sulfate concentration reached a value that was about twice that of the other sites. Yangyang located on the East Sea side of South Korea was found to be more affected by the western continental sources than by Korean. sources. Also, Oki located in the Japan Sea, was affected by the Korean Peninsula and western continental origin sources. Accordingly, the contribution of the Peoples Republic of China was found to be quite substantial at each site. These figures are a fair representation of the sulfate budget from other countries to each site. When a special receptor site revealed a higher sulfate value than that of its own origin source, this indicated long-range transport from another source region.

Furthermore, sulfate concentration peaks were intermittently observed with a short time delay at each site. Therefore, heavily polluted air masses in the western continent was transported intermittently according to wind pattern variations associated with the winter synoptic weather system. Hence it was found that a time lag occurred from Yangyang to Oki and Komae.

4.2. Distribution of Total Deposition Amount and Contribution Ratio of Deposition

The contribution ratio of the deposition from the Peoples Republic of China source to the total deposition amount in East Asia region, January, 1993, is presented in Fig 4. The dotted line contour represents the contribution ratio of the deposition and the contour interval was 0.2(contribution ratio). The black tone represents the distribution of the

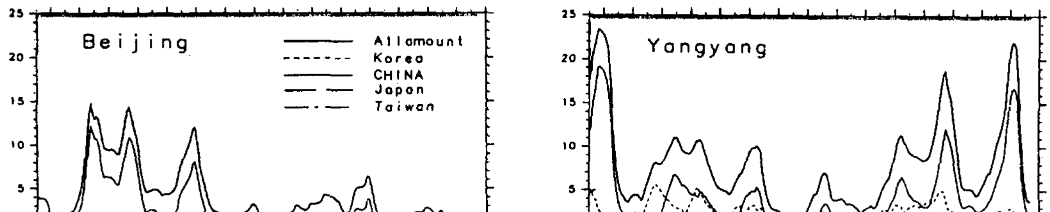

Fig. 3. Time variations of calculated surface sulfate concentrations using scalar transport option of RAMS model(upper thick solid line represents total amount of sulfate at each site, thin solid line represents level of sulfate in NE-China, CE-China and S-China, and other line is seen in table 1, sulfate concentration unit; ug/m^3).

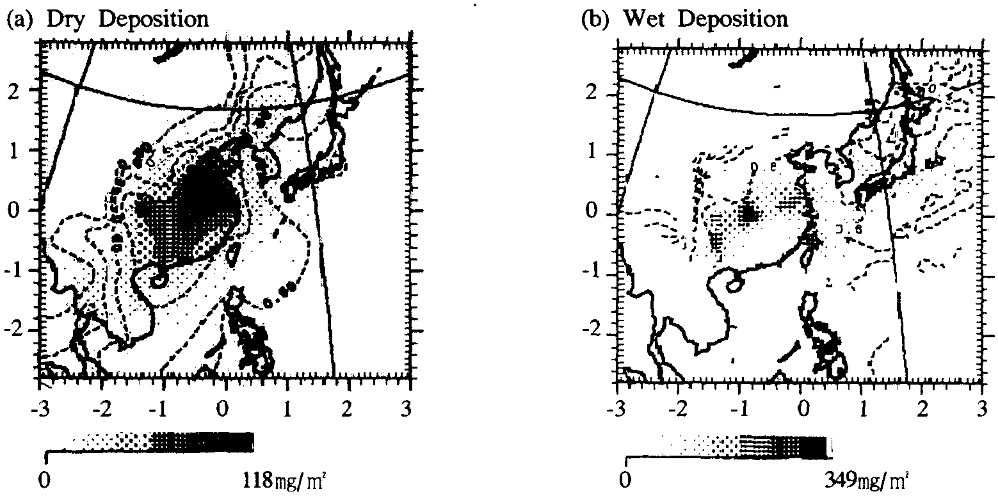

Fig. 4. Contribution ratio of deposition from Peoples Republic of China(NE-China + CE-China + S-China) and distribution of total sulfate deposition amount, January 1993(dotted contour interval: 0.2, dry and wet deposition unit : mg/m^2, (a). Dry, (b). Wet).

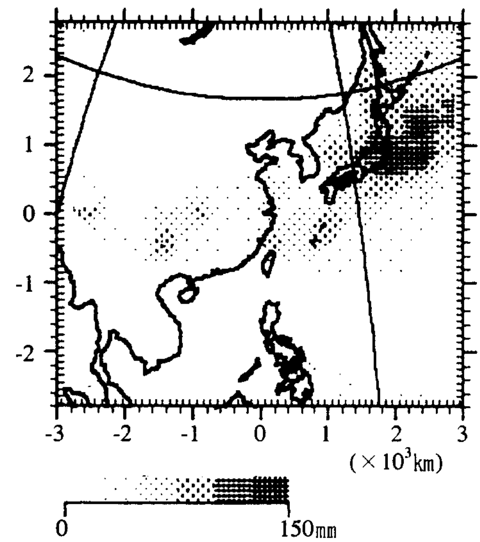

Fig. 5. Simulated total precipitation during January 1993.

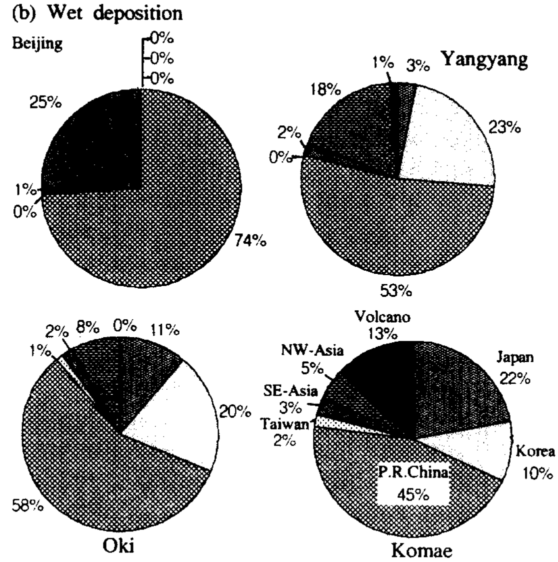

Fig. 6. Contribution percentage ratio of dry and wet deposition from 7 source regions at Beijing, Yangyang, Oki, and Komae((a). Dry deposition, (b). Wet deposition).

total dry and wet sulfate deposition amount in January 1993. The contribution ratio of dry and wet deposition was higher over the main continent of the East Asia region. Also, the deposition amount indicated high values on the west coast of Korea and the East China Sea. Wet deposition depends on the precipitation processes in the atmosphere (see Fig. 5). The contribution ratio of wet deposition was about 0.5 in Tokyo, Japan.

4.3. Analysis of Source-receptor Relationships

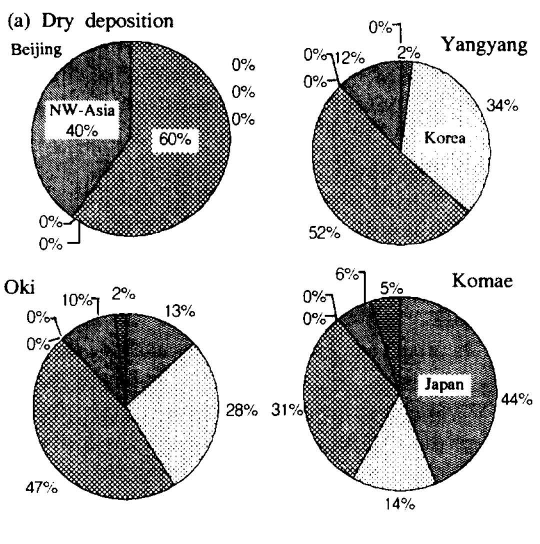

Fig. 6 shows the contribution percentage ratio of dry and wet deposition from 7 source regions in each receptor region(Beijing, Yangyang, Oki, and Komae). The 7 sources included NW-Asia, SE-Asia, Taiwan, Peoples Republic of China, Japan, Korea, and volcano sources. Beijing exhibited the highest dry and wet deposition amount from an NW-Asia source predominantly from their own origin sources.

The Peoples Republic of China's sources accounted for 47% of the total dry deposition and 58% of the total wet deposition at Oki, Japan. Also Komae of Japan accounted for 31% of the total dry deposition and 45% of the total wet deposition from a Chinese source. Oki, which is located on the coast of Japan was more affected by the continental sources than Komae, even though Oki does not have any strong emission sources of its own. This fact can be clearly explained by the long-range transport of air pollutants.

For wet deposition, every site had deposition amounts from variable source regions and, in particular, Yangyang, Oki, and Komae exhibited a higher wet deposition amount, compared with the dry deposition amount. This implies that sulfate becomes associated with aerosol while sulfur is being transported away from its source. Savoie and Prospero[9] proposed that elevated sulfate and nitrate levels could be found in aerosol as far away as in the central Pacific Ocean. Sulfate is also produced on the surface of wet dust particles through reactions with peroxide and other available oxidants(Carmichael *et al.*[2)3)]). Sulfate is a major component of the acidity of precipitation. Therefore, more complicated aerosol and gas-phase chemical processes must be considered to explain the wet deposition mechanism.

5. Conclusions

In order to analysis the long-range transport processes of air pollutants and the source-receptor relationships among neighboring countries, an atmospheric transport model coupled with the RAMS model was carried out over the East Asia region during entire month of January 1993. The numerical results were able to elucidate the long-range transport phenomena in this region.

The sulfate budget from source regions to receptor regions by long-range transportation was estimated. Sulfate concentration peaks were observed intermittently. This fact along with the observed time lag between Yangyang, Oki, and Komae correlated with the winter synoptic weather system. In addition, the distribution of the dry and wet deposition amount in the East Asia region showed that sulfate becomes associated with aerosol while sulfur is being transported away from its source due to the atmospheric processes of cloud physics.

During the analysis of the source-receptor relationships, when an individual receptor site revealed a higher sulfate value than that of its own source, this was taken to indicate long-range transport from another source.

References

[1] Arndnt R.L. and G. R. Carmichael(1997): Sulfur dioxide emissions and sectorial Sulfur dioxide emissions and sectorial contributions to sulfur deposition in Asia, *Atmos. Environ.*, 31, 1553~1572.

[2] Carmichael, G. R., L. K. Peters and T. Kitada(1986): A second generation model for regional scale transport/chemistry/deposition, *Atmos. Environ.*, 20, 173~188.

[3] Carmichael, G. R., Yang Zhang, Li-ling Chen, Min-Sung Hong and Hiromasa Ueda(1996): Seasonal variation of aerosol composition at Cheju Island, Korea, *Atmos. Environ.*, *30*, 2407~2416.

[4] Jang E.-S., I. Uno, K. Murano, T. Shimohara, O. Oishi and A. Utsunomiya(1999): The behavior of acid rain precursors in east asia simulated by a long-range transport model, Proceeding of the Workshop on the Transport of Air Pollutants in Asia, July, Austria, 5-1/9.

[5] Kitada, T. and P. C. S. Lee(1993): Numerical modeling of long-range transport of acidic species in association with meso *B*-convective cloud across the Japan sea resulting in acid snow over coastal Japan-II. Results and discussion, *Atmos. Environ.*, 24A(7),1077~1090.

[6] Kotamarthi, V. R. and G. R. Carmichael (1990): The long-range transport of pollutants in the Pacific rim region, *Atmos. Environ.*, 24A, 1521~1534.

[7] Murano, K., H. Mukai, E.-S. Jang and I. Uno(1999): Ground-based observations of air pollutants at some remote areas in Japan, Proceeding of International Joint Seminar on Regional Deposition Processes in the Atmosphere, 15-21, October, Korea.

[8] Pilke, R. A., W. R. Cotton, R. L. Walko, C. J. Tremback, M. E. Nicholls, M. D. Moran, D. A. Wesely, T. J. Lee and J. H. Copeland (1992): A comprehensive meteorological modeling system-RAMS, *Meteor. Atmos. Phys.*, 49, 69~91.

[9] Savoie D. and Prospero J.(1989): Comparison of oceanic and continental sources of non-sea-salt sulfate over the Pacific Ocean, *Nature,* 339, 685~687.

[10] Sharma M., E. A. McBean and U. Ghosh (1995): Prediction of atmospheric sulfate eposition at sensitive receptors in Northern India. *Atmos. Environ.*, 29, 2157~2162.

[11] Uno I., E.-S. Jang, S. Sugata and S. Emori (1999): Development of meteorology-chemistry coupled on-line tracer model for long-range transport analysis over Asia-Pacific region, Proceeding of the Workshop on the Transport of Air Pollutants in Asia, July, Austria, 10-1/7.