Long-range Transport Modeling System and its Application over the Northeast Asia

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ABSTRACT

A Comprehensive Acid Deposition Modeling (CADM) was developed at the National Institute of Environmental Research (NIER) and Yonsei University in South Korea in order to simulate the long-range transboundary air pollutants and regional acid deposition processes over the Northeast Asia. The modeling system CADM is composed of a real-time numerical weather forecasting model (RAMS) and an Eulerian air pollution transport/dispersion/deposition model including gas- and aqueous-phase atmospheric chemical processes for the real-time acquisition of model results and prediction of acidic pollutants. The main objective of CADM is to facilitate an efficient assessment tools by providing the explicit information on the acidic deposition processes.

This paper introduces the components of CADM, and describes the comprehensive atmospheric modeling system including atmospheric chemistry for the simulation of acidic processes over the Eastern Asia. The presently developed modeling system CADM has been used to simulate long-range transport over the Northeast Asian region during the spring season from March 5 to 15 2002. For the model validation, the simulated results are compared with both aircraft measurements and surface monitoring observations, and discussed for its operational consideration in Korea.

Key words: Long-range transboundary air pollutants, Comprehensive atmospheric modeling system.

1. INTRODUCTION

The acidic deposition processes across the neighborhood countries have been serious environmental problems in the Northeast Asia over the recent two decades. A vigorous industrialization of Korea and China during the last two decades resulted in significant deterioration of the air quality and eco-environment in the China including over the neighborhood countries.

In the light of these circumstances, Long-range Transboundary Air Pollutants Project (LTP) was launched as a real collaboration in promoting research activities in 1995 among China, Japan and Korea. The 1st expert meeting for LTP was held in July 1996 in Seoul, and since then the joint research project has been conducted to review the outcomes from the corporative researches on the long- range transboundary of air pollutants over the Northeast Asia. Through this LTP project, the Comprehensive Acid Deposition Modeling (CADM) was developed at the National Institute of Environmental Research (NIER) and Yonsei University in South Korea in order to simulate and assess the long-range transboundary air pollutants and regional acidic deposition processes in Korea.

This paper will introduce the comprehensive modeling system, CADM, which was developed from corporative research during LTP project, and discuss for its operational consideration of the real-time acid deposition assessment in Korea. In addition, the results of the case study of simulation of acidic deposition using CADM will be presented for the period from March 5 to 15 2002. The simulated air pollutant concentrations during the period over the Northeast Asian region will be compared with both aircraft measurements and surface monitoring observations.

2. MODELING SYSTEM

The components of comprehensive atmospheric Model, CADM

The CADM [5] has been developed during the LTP project for the simulation of acid deposition process. It is an on-line model directly coupled to meteorological model, CSU RAMS [8]. The emission fields are from those reported in the Annual Report for the year 2000 [4]. The CADM is composed of a real-time numerical weather forecasting model RAMS, air pollution dispersion model, and a heterogeneous chemical model RADM [3] including gas- and aqueous-phase atmospheric chemical processes (Figure 1).

The CADM employs the polar stereographic coordinate and sigma-z (terrain-following) coordinate. Here, the expression for the coordinate transformation is omitted to make the expression simple. Then the conservation equation for the multiphase atmospheric transport/chemistry/deposition process can be written in the following form:

$$\frac{\partial C_i}{\partial t} = -\nabla\cdot(C_i\vec{V}) + \nabla\cdot(K_c\cdot\nabla C_i) + R_i + E_i + \left(\frac{\partial C_i}{\partial t}\right)_{cloud} + \left(\frac{\partial C_i}{\partial t}\right)_{dry}$$

Where C_i is the concentration of i-th component, $\vec{V}$ the three-dimensional wind vector, K the eddy diffusion coefficient for atmospheric pollutants, R_i the chemical transformation rate, E_i the rate of concentration change due to emission, and $\left(\frac{\partial C_i}{\partial t}\right)_{\text{cloud}}$ and $\left(\frac{\partial C_i}{\partial t}\right)_{\text{dry}}$ are the rates of concentration change due to cloud effects and dry deposition, respectively. Vertical eddy diffusion coefficient, K_c is obtained from the profile functions of Brost et al. (1988) [1]. The present model employs the chemistry model of RADM to treat both the gas- and aqueous-phase chemistry. The RADM gas chemistry model considers 157 gaseous chemical reactions including 21 photochemical reactions involving 64 chemical species. Aqueous phase chemistry considers 17 reactions for 9 components. Dry deposition is treated using the RADM. The detail of the model can be found in Lee et al. (1998) [5].

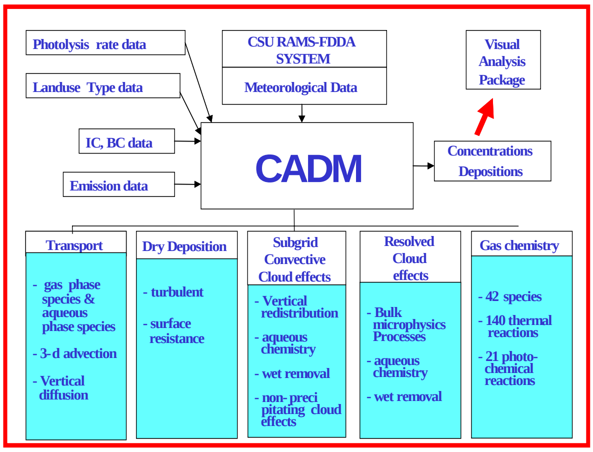

Figure 1. The Comprehensive Acid Deposition Model

Operational consideration of CADM

A comprehensive Eulerian air pollution model has been proven to be a useful tool in simulating transport and transformation of air pollutants. However, the available input data are not often accurate so the employed model simulation results contain non-negligible uncertainties. There was a great need to estimate the emissions of acidic pollutants. Recently there have been a lot of efforts in constructing source inventories (i.e., during the LTP project) as well as measuring air pollutant concentrations in Northeast Asia. As a result of these efforts, a good quality of input data can be prepared for detailed modeling studies such as the present work.

For the operational use of the CADM, initially we consider to routinely import the initial meteorological condition from GDAPS (Global Data Assimilation Prediction System) provided by the Korean Meteorological Administration (KMA), and applied FDDA for the prediction. The entire procedures such as receiving data for initial conditions, running the meteorological models, updating the meteorological fields, preparing the emission inventories, land-use type and photolysis data, and running the dispersion model, have been prepared by Shell script in Linux system [6].

3. RESULTS

Simulated concentration fields

Simulated surface concentrations of SO_2, NO_2, and O_3 on 06 UTC for 9 and 10 March 2002 are shown in Figure 2. Surface concentrations especially for SO_2 follow closely the pattern of emission over the eastern China on 9 March, but the significant transport of the pollutant from eastern China to the Korean peninsula was simulated on 10 March, yielding that the simulated maximum SO_2 concentration over China is more than 30 ppb at 06 UTC 10 March. The concentration over southern Korea is simulated in the range of between 3-7 ppb, for which transported pollutant may occupy significant portion. For NO_2, however, such transport is not appeared to be significant mainly due to relatively low concentration of NO_2. Maximum NO_2 concentration of more than 15 ppb at 06 UTC 10 March 2002 is simulated over eastern China. Surface concentration over the Korean peninsula is less than 3 ppb in general and it appears to be mainly due to locally emitted pollutants. However, O_3 shows a long range transported distribution pattern more clearly. For example, on 9 March 2002, a band of relatively higher concentration is found from southeastern China to the north of the Korean peninsula. The band of higher concentration extended from southeastern China to the north of the peninsula moves and slowly moved to the east-south direction. As a result, the simulated O_3 concentration around the peninsula is higher than 30 ppb with maximum concentration of more than 60 ppb over eastern coast of China and northern Japan (Figure 2), implying the importance of long range transport for the secondary air pollutant.

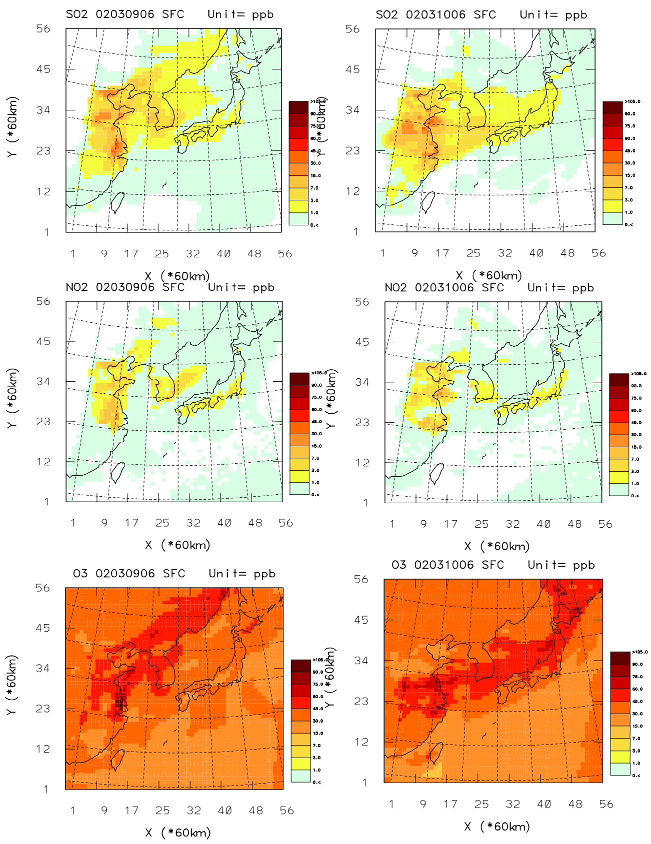

Figure 2. Surface SO_2, NO_2 and O_3 concentration at 06 UTC 9, 10 March 2002

Verification of modeling against observation

The surface-observations in Korea (Kanghwa and Geoje) are comparable to the simulated concentrations with a general agreement. Furthermore, the simulations have captured some of the significant temporal variations at Geoje (Figure 3). Concentrations at Japanese stations such as Rishiri and Oki are also comparable to the observations, although model does not capture the observed occasional high concentrations. In China, the simulated magnitudes at Xiamen are comparable to observations, but the temporal variation shows significant discrepancies. For Dalian, the simulation does not show significant temporal variations, while the observation shows very large temporal variations with large peak concentrations over 50 ppb.

In general, simulated NO_2 and O_3 concentrations show more inconsistencies and discrepancies of temporal variations from observation than SO_2 concentration. These inconsistencies between simulated and observed values are most likely due to the uncertainty in emissions and driving meteorology rather than the uncertainty in transport and diffusion processes as revealed by Carmichael et al (2002) [2].

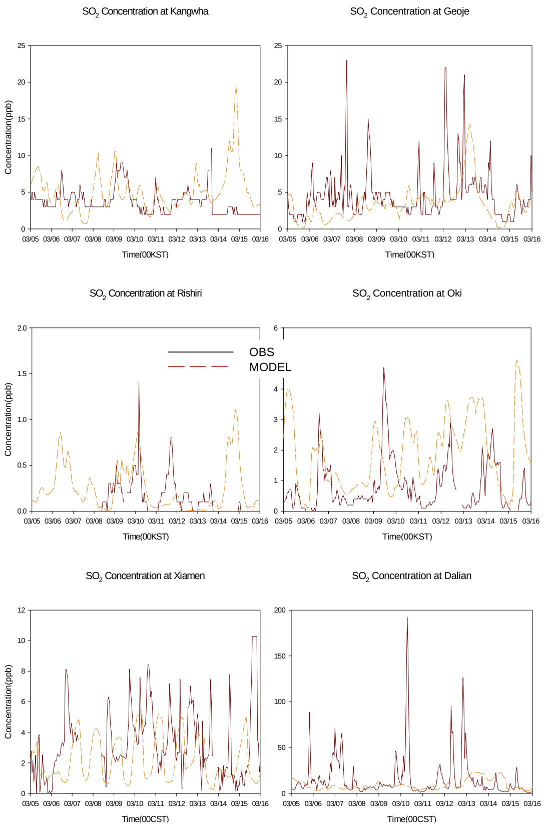

Figure 3. Diurnal variation of SO_2 from 00KST 5 Mar. 2002 through 00KST 16 at each observation site

SO_2 concentrations at levels below 700 m in aircraft observation [7] show good agreement with observations. On the other hands, the observations at levels above 700 m reveal higher values than those of background concentrations. This indicates that the SO_2 concentrations can be transported from the outer domain to the western boundary of LTP domain along the higher levels.

4. CONCLUSIONS

This paper introduced the components of CADM, and described the comprehensive atmospheric modeling system for the simulation of acidic processes over the Eastern Asia. In addition, CADM-based case study on long-range transport during the spring season from March 5 to 15 2002 was presented, and the simulated transboundary air pollution concentrations were compared with those from both aircraft measurement and surface observation.

The comparison with observations has shown some encouraging agreements, but disagreements are more significant. Generally, underestimations by model are found, and there were large inconsistencies of the vertical concentrations of NO_x and SO_2 at higher levels, suggesting further researches for the improvement of present modeling system such as extension of the target domain, subsequent source inventories over the larger domain, and improvement of inputs data including meteorological fields.

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