A Study on the Development and Application of Prognostic Meteorological and Photochemical Models to a Regional Atmospheric Environment

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Keywords mesoscale meteorological model, turbulent diffusion, photochemical reaction, simulation

1. Introduction

Because Japan has relatively complex topography and huge *industrial complexes are located* near coastal region, local wind circulations (such as land/sea and mountain/valley wind) play important roles to the transportation/diffusion/reaction process of pollutants (emitted from the urban area and coastal industrial complexes). The activities of fields measurements and its numerical modelings have been dedicated to have better understanding of regional atmospheric environment. Especially, prediction of a three-dimensional air flow and its turbulent motion is important to the atmospheric diffusion process. In this paper a numerical results from a prognostic meteorological (i.e., mesoscale meteorological model; MM) and photochemical grid model (GRID Model) developed for a vector computer will be presented.

2. Models

In this study, the mesoscale process which has a several hundred km horizontal scale will be studied by MM. The basic concepts of MM is a set of equations (that is, the momentum, energy, water vapor and turbulent kinetic energy transport). As a prognostic mesoscale meteorological model, the Colorado State University Mesoscale Model (CSUMM) is introduced (Pielke, 1974; Kessler, 1989). Then CSUMM is modified intensively for vector computer processing. A photochemical grid model (GRID Model) which can treat transport, diffusion and chemical reaction are also developed. This GRID model requires the meteorological field preprocessor based on the prognostic mesoscale meteorological model. The output of CSUMM is used as input to the GRID model. The Carbon-Bond Mechanism (CBM-4; Gery *et al.*, 1989) is used for chemical reaction process.

It have been pointed out that about 90 % of cpu time will be used in the chemical reaction module to simulate the transport, diffusion and reaction model. Thus, the improvement and efficiency of the chemical reaction calculation subroutine is very important to perform such a kind of simulation. In this study, G-prime method (Lamb, 1982) is used and modified to be a highly one-dimensional coding. The calculation of this modified G-prime subroutine recorded a calculation speed of 800 MFLOPS under the SX-3 supercomputer. In the following section, two dimensional version of MM and GRID are used to simulate the air flow and diffusion process (especially NO_2 *and* O_3) *under the typical winter time huge* coastal urban area.

3. Results and Discussion

Two-dimensional calculation domain (horizontally 450 km spread) was used. A relatively small mountainous area (height of 500m) is placed at the center of calculation domain. The urban area locates east side of mountain from x=300 km to x=330 km. The sea is placed both side of region (x=0 -120 km and 330 - 450 km). Roughness length z_0 was set *0.15 m over the land. Horizontal grid size of* $\Delta x = 3$ km and 23 vertical levels were used (fine resolution is adopted near the surface). Sea surface temperature was kept constant (T_{sea}=13 ℃). The initial condition for wind was set to calm and the gradient of potential temperature was 0.04 K/100m and relative humidity of 65% was used. Average diurnal emission patterns of NO, NO_2 and hydrocarbons(NMHC) concentrations were taken from the Tokyo Metropolitan Area (TMA) emission inventories. Initial concentration for all species except O_3 was set to 0 ppb. (O_3 = 35ppb). Dry deposition velocities were taken from Chang *et al.* (1990). The numerical calculation was started from December 1 for 3 days, and the third simulation day's data were used for analysis.

Figure 1 shows the calculated wind vectors and isopleth of potential temperature at 0600 JST (Dec. 3) and 1400 JST. The typical wind direction reversal of the sea/land breeze and the diurnal development of the stable and convective layers is well demonstrated. Penetration of sea breeze starts from 1200 JST. The surface inversion starts about 1700 JST. The thickness of nocturnal surface inversion layer over the urban area is about 100 m, and this is higher than the typically expected one in TMA. This discrepancy mainly comes from very high roughness element and huge anthropogenic heat release at the center of TMA. The simulation result indicates that the stable layer remains by 1000 JST and then the convective layer starts to develop. The maximum height of convective layer is about 1000 m. It should be also noted that the mixing layer developed over the sea even in night time because of cold air advection over the relatively warm sea surface.

Ohara *et al.*(1989) indicates that the sea/land breeze plays an important role to the high concentration of air pollution in the TMA. Simulated time development of convective layer qualitatively agrees with the observation results and the simulated flow fields show the very typical land/sea breeze circulation. Thereof we used this meteorological condition as an input of GRID model application.

Figure 2 shows the time-height cross-section of NO_2 and O_3 over the cities. The NO_2 isopleth of 30-40 ppb agrees with the development of convective layer from 1000 JST to 1600 JST. NO_2 concentration displays almost uniform concentration profile within the daytime convective layer which validates the photochemical box model (PBM) assumption (Uno *et al.*, 1992). This uniform vertical distribution comes from the result of non-linear interaction among vertical diffusion, emission intensity, deposition and complex chemical reaction. This high concentration region aloft is maintained until the next morning. Concentration levels near the surface decrease because deposition becomes important after 1900 JST. The surface level maximum concentration of O_3 was 25 ppb at 1400 JST and almost zero at night. The simulated concentration showed and validated the characteristic variation of the pollutants in winter.

4. Concluding remarks

The mesoscale meteorological model and the photochemical grid model were used and modified to study the air flow and atmospheric diffusion and reaction process within a horizontally several hundred km scale regional atmospheric environment.

The developed models are used to validate and understand the basic behavior of air pollutant concentration in a typical winter time huge coastal urban area. The calculation results showed a qualitatively good agreement with the observations (Ohara *et al.*, 1989; Uno *et al.*, 1992). The model results suggested that the atmospheric oxidation process plays an important role to understand the concentration levels of NO_2 even in winter.

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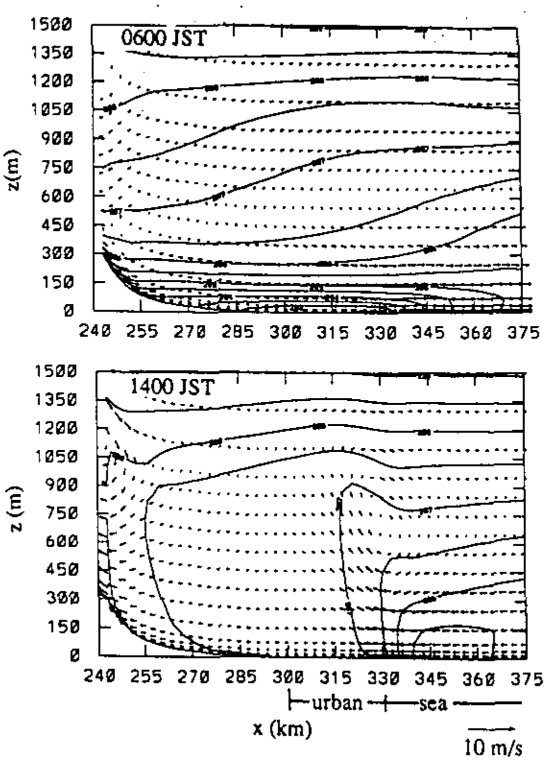

Figure 1 Numerical results for wind and potential temperature at 0600 JST (Dec. 3) and 1400 JST Arrows in Figure are wind vectors (horizontal and vertical direction; note that the vertical wind scaling is multiplied by a factor of 30).

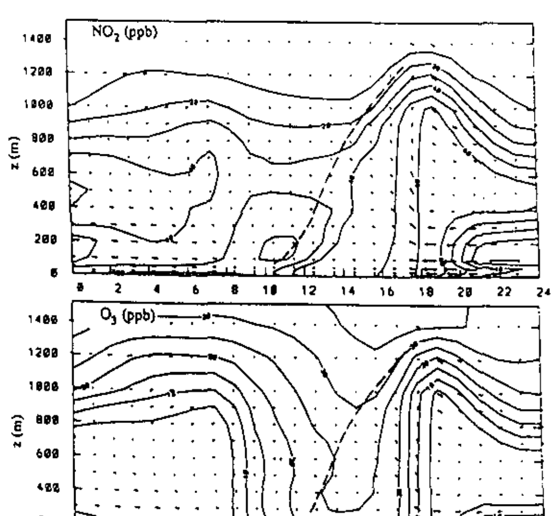

Figure 2 Time-height cross-section at x=306 km of NO_2 and O_3 The data starts at 0000 JST on 3rd simulation day (December 3). Arrows in Figure are wind vectors (horizontal and vertical direction; note that the vertical wind scaling is multiplied by a factor of 30). Dashed line indicates mixing layer height Z_i.