ADVANCED AIR QUALITY MODELING IN TAIWAN: LOCAL AND TRANSPORTED POLLUTANTS

Joshua S. Fu
University of Tennessee, Knoxville, TN, U.S.A.
email: jsfu@utk.edu
Horng-Guang Leu
Taiwan Environmental Protection Administration, Taipei, Taiwan
email: hgleu@sun.epa.gov.tw
Carey C. Jang
U.S. Environmental Protection Agency, Research Triangle Park, NC, U.S.A.
email: jang.carey@epamail.epa.gov
Hui-Chen Chien
Taiwan Environmental Protection Administration, Taipei, Taiwan
email: hcchien@sun.epa.gov.tw

1. INTRODUCTION

The rapid economic development in Taiwan drives the growth of air polluting activities such as fuel burning, manufacturing, vehicle driving, and constructing. Therefore, air quality improvement is a big challenge in Taiwan. An economic incentive scheme was adopted in the second amendment of the APCA of Taiwan in 1992. Taiwan Environmental Protection Administration (TEPA) started to collect Air Pollution Fee (APF) since 1995. Significant progress such as the monthly average concentrations of SO_2, NO_X, and PM_{10} has been decreased. However, cross-boundary transport of air pollutants is hindering the efforts to further improve Taiwan's air quality. A modeling effort through the first-year US-Taiwan bilateral air quality modeling technology transfer project has been undertaken to conduct a Taiwan air quality modeling assessment considered cross-boundary transport of air pollutants by applying an advanced modeling system, the Models-3/CMAQ, developed at United States Environmental Protection Agency (USEPA). The "one-atmosphere" Models-3/CMAQ system was designed to approach air quality as a whole by including state-of-the-science capabilities for modeling multiple air quality issues, including ozone, particulate matter, visibility degradation, acid deposition, and air toxics, at multiple scale. For this pilot study we use the Taiwan Emission Database System (TEDS) that is a comprehensive emission database in Taiwan. Meteorological input fields for the CMAQ model simulations are provided by the Mesoscale Model Version 5 (MM5). 36 km×36 km and 12 km×12 km grid resolutions set up by the MM5 meteorological processing model for episodes in 2001 used in USEPA's Regional Air Quality Modeling in East Asia funded by the USEPA OAQPS are used as the boundary conditions for this study (the Taiwan region domain is 4 km×4 km). The focus of this study is the Models-3/CMAQ application to establish feasibility of model simulations over the domain, i.e., covering the entire Taiwan and running the model for episodes. This Taiwan modeling application was aimed at studying the formation and regional transport of ozone, PM and acid deposition, for selected episodes in 2001 in the non-transport and transport scenarios. The boundary conditions of clean air concentrations and transported concentrations from outside of the Taiwan region are employed in the modeling runs separately. This study gives a description of the model configuration and setup and presents some preliminary model simulation results. This application provides an understanding on the formation of regional ozone and haze problems for the policy makers in Taiwan, but provides the experience for the TEPA to refine the model and adapt it more thoroughly to conduct air quality management in Taiwan.

2. USEPA'S MODELS-3/CMAQ MODELING SYSTEM

Over the past nine years, USEPA devoted major resources to developing an advanced modeling system with a "one-atmosphere" perspective, i.e., the U.S.EPA's Models-3/Community Multi-scale Air Quality (CMAQ) modeling system (Dennis, et. al., 1996; Byun, et. al., 1997; Byun and Ching, 1999; U.S.EPA, 1999). Models-3/ CMAQ is a numerical modeling system that can simultaneously simulate the transport, physical transformation, and chemical reactions of multiple pollutants across large geographic regions. The system is useful to states, other government and international agencies for making regulatory decisions on air quality management, as well as to research scientists for performing atmospheric research. It is a combination of Models-3, a flexible software framework, and the CMAQ modeling system for supporting air quality applications ranging from regulatory issues to scientific research on atmospheric processes. A modular science design of CMAQ allows the user to build different chemistry-transport models for various air quality problems. The "one-atmosphere" Models-3/CMAQ system was designed to approach air quality as a whole by including state-of-the-science capabilities for modeling multiple air quality issues, including ozone, particulate matter, visibility degradation, acid deposition, and air toxics, at multiple scales. The Models-3/CMAQ system was first released to the public in July 1998 and had a recent update release in May 2003 (U.S.EPA, 2003). Through the Taiwan-US bilateral collaboration, TEPA is engaged in uses of the advanced air quality modeling tool to assess the trans-boundary issue and its air pollution control strategies (Leu, et al., 2003).

3. MODEL CONFIGURATION AND SETUP

Model Domain

In this Models-3/CMAQ application, the model domain covered the East Asia and in Figure 1. 36 km×36 km and 12 km×12 km grid resolutions set up by the MM5 meteorological processing model for episodes in 2001 used in USEPA's Regional Air Quality Modeling in East Asia are used as the boundary conditions for this study. The domains had 130 x 94 horizontal grid cells using a 36-km resolution, 135 x 198 horizontal grid cells using a 12-km resolution, and 56 x 108 horizontal grid cells using a 4-km (Figure 2.) resolution based on Lambert Conformal map projection centered at (34^0N, 102^0E). Twelve vertical layers were configured initially following the Sigma (σ) layer structure with denser grids at lower levels to better resolve the boundary layer. The σ -layer interfaces occurred at: 0.995 (38 m), 0.988 (92 m), 0.97 (230 m), 0.938 (482 m), 0.893 (846 m), 0.839 (1300 m), 0.777 (1850 m), 0.702 (2557 m), 0.582 (3806 m), 0.400 (6083 m), 0.20 (9511 m), and 0.00 (16,262 m).

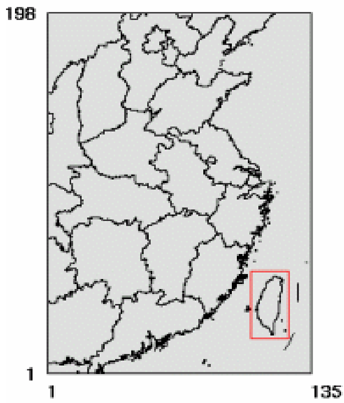

Figure 1. 12km Boundary Domain

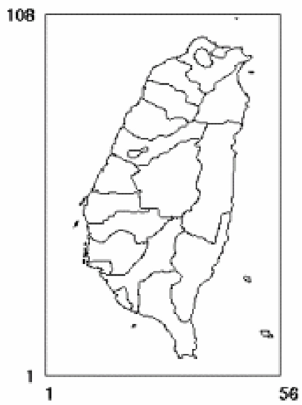

Figure 2. 4km Taiwan Domain

Model Configuration

The September 2003 release version of Models-3/CMAQ system was used in this modeling work. Further details of model configuration and science modules are given in Models-3/CMAQ science document (U.S.EPA 1999). The key science modules used in this modeling work are given below. Note that the selected science modules are the default options given in the September 2003 Models-3/CMAQ release version. The default initial conditions and boundary conditions are given in the CMAQ model.

Model Inputs and Setup

The Mesoscale Model Version 5 (MM5) was used to provide meteorological input fields for the model simulations. The 36-, 12- and 4-km domains and their meteorological outputs simulated by MM5 in the USEPA's East Asia modeling effort were used in this work. The newest Meteorology/chemistry Interface Processor (MCIP) 2.2 that corrected layers collapsing released in June 2003 was used to process the raw MM5 output data into the format and structure required by the Models-3/CMAQ modeling.

Emission Estimates

Figure 3 shows the contributions of the various source categories to the emissions of the individual contaminants for year 2001 in Taiwan. In 2001, total emissions were 321,000 Mt/year of PM_{10}; the majority of the PM_{10} emissions are from fugitive road dust and industry sources, which contribute 22% and 23% respectively. Total emissions were 235,000 Mt/y of SOx, industry sources account about 93%. Total emissions were 490,000 Mt/y of NOx, industry sources and mobile sources account for 52% and 48% separately. Total emissions were 889,000 Mt/y of NMHC, the majority of the NMHC emissions are from industry usage, mobile sources and a broad range of miscellaneous sources, including consumer products, architectural coating and pesticide application which contribute for 43%, 23% and 34% respectively. Total emissions were 1,104,000 Mt/y of CO; mobile sources are major contributors of CO (76%). Total emissions were 1,300 Mt/year of Pb, industry sources were major sources of Pb Total VOC emissions from biogenic sources were about 34% of VOC from anthropgenic emissions, isoprene emissions account for 46%. The Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System was used to prepare emission inputs based on the recently updated Taiwan Emission Data System (TEDS) (TEPA, 2001).

4. RESULTS AND DISCUSSIONS

The objective of this study was to conduct model results on Taiwan's scenarios. Figure 4 shows the model nested down to 4-km domain over Taiwan. Wind fields of MM5 outputs are shown in Figure 5. The direction of wind is from Mainland to Taiwan during period of days in January. Figure 6 gives an example profile of several species (NO, PAR, and NH_3) prepared by SMOKE in January 2001. The boundary conditions (BC) are set to a set of background concentrations such as 35 ppb in the first layer for ozone. Results from the Models-3/CMAQ simulation are discussed below. The discussion first focused on the effects of transported pollutants such as Ozone, fine PM 2.5 and visibility and major PM 2.5 constituents such as

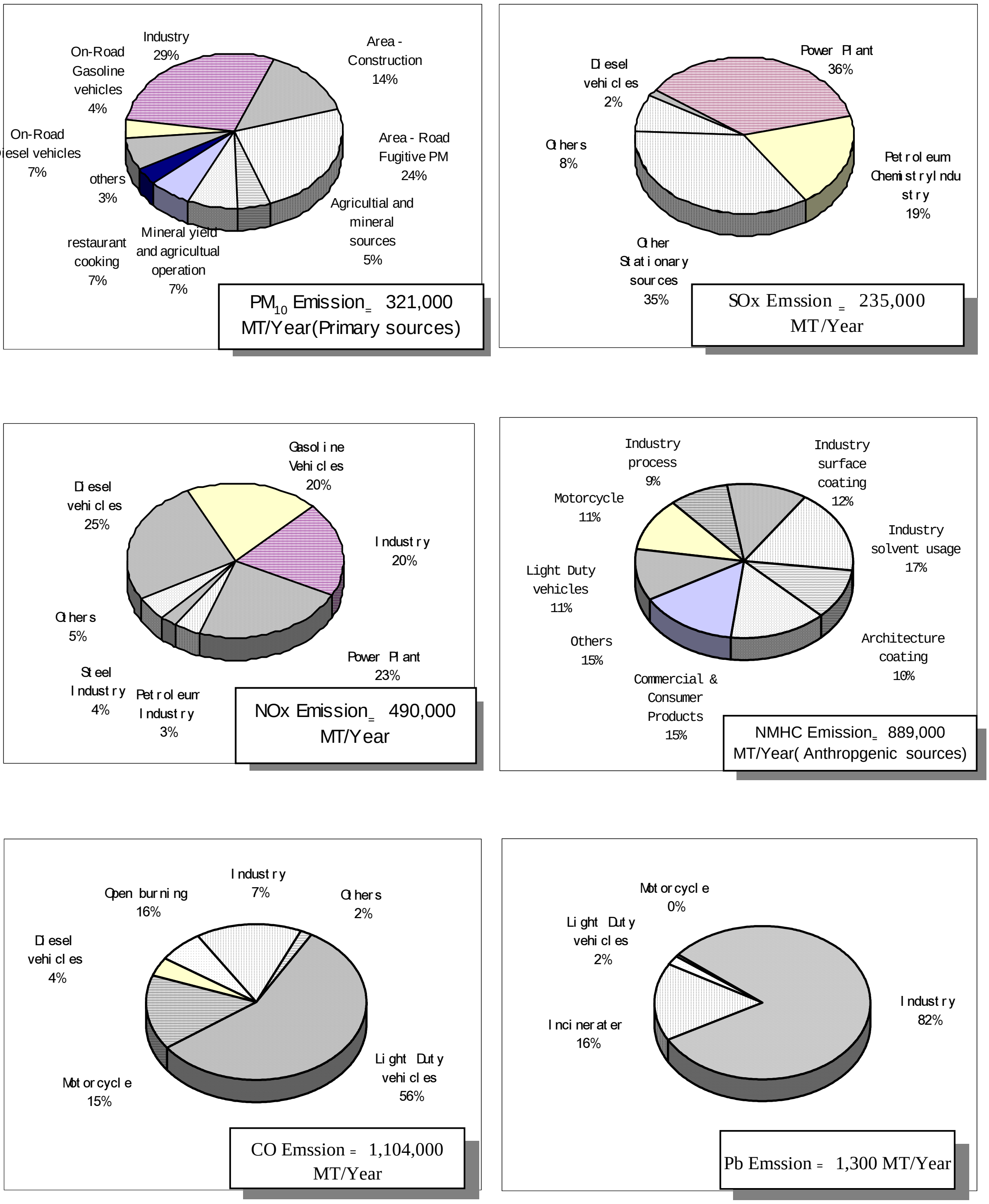

Figure 3 Taiwan Area Emission Inventory of year 2001

sulfate PM and nitrate PM. As part of a series of on-going modeling efforts, January 2001 episodes Models-3/CMAQ simulation over the Taiwan island was conducted. Results showed that the Models-3/CMAQ system was capable of simulating key criteria pollutants reasonably well over a typical day and within an acceptable run time. Concentrations Ozone, PM2.5 and its constituents from CMAQ simulations were shown the effects from outside of Taiwan region as Figures 7-13.

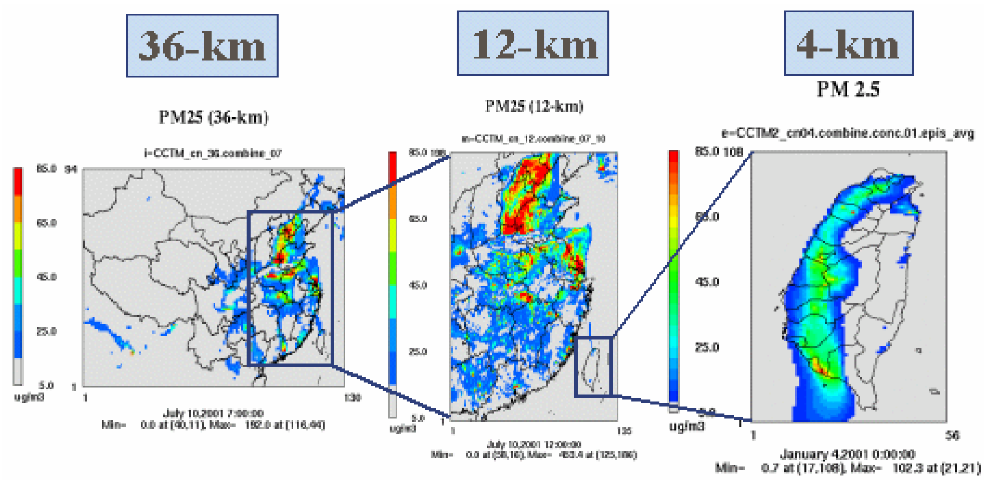

Figure 4. Model nesting

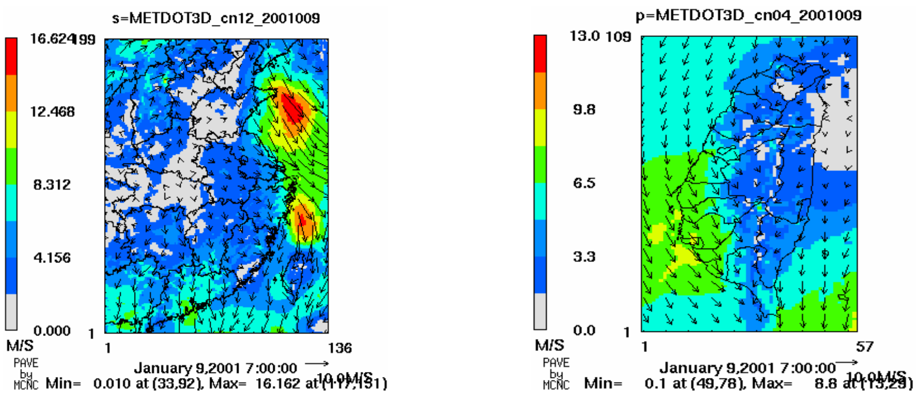

Figure 5. Wind Fields

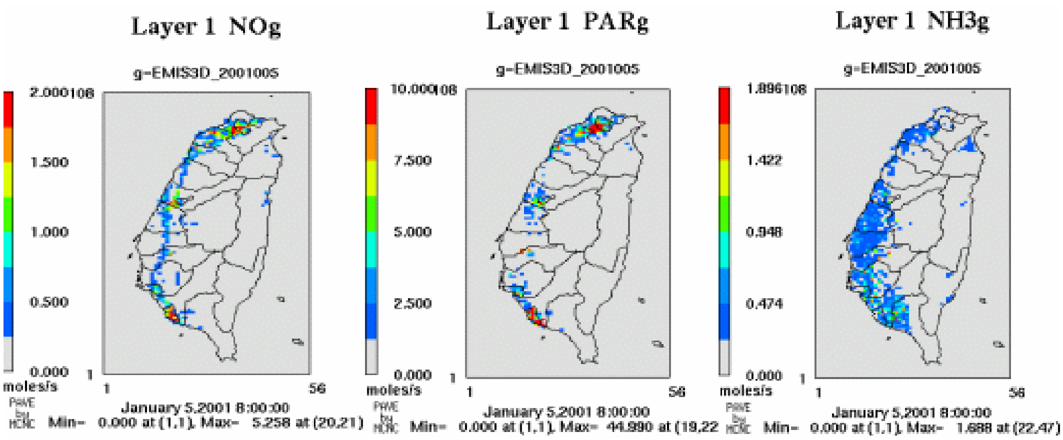

Figure 6. NO, PAR and NH_3 Emissions

The ozone concentrations are different the background of ozone concentration from the nesting boundary which is transported from outside of the region based on the wind field of the MM5 output. The impact of the ozone concentrations is up to 20 ppb on the northwest direction and 15 ppb in the north and central of Taiwan. The PM2.5 concentrations contributed from outside of Taiwan are up to 20 ug/m^3 on the northwest direction and 15-20 ppb in Taipei, Taitung and Kaohsiung metropolitan areas. The nitrate PM concentrations are affected by the pollutants from outside of Taiwan shown the significant impacts in north of Taiwan. Visibility shown in Figure 13 is reduced in north of Taiwan to the distance of 10 km. The visibility impairment is caused by the secondary PM2.5 such as nitrate PM, sulfate PM, organic PM, etc. The nitrate PM impacted the visibility impairment in the these episodes in January and caused by transported pollutants from outside of Taiwan.

(a) **(b)** **(c)**

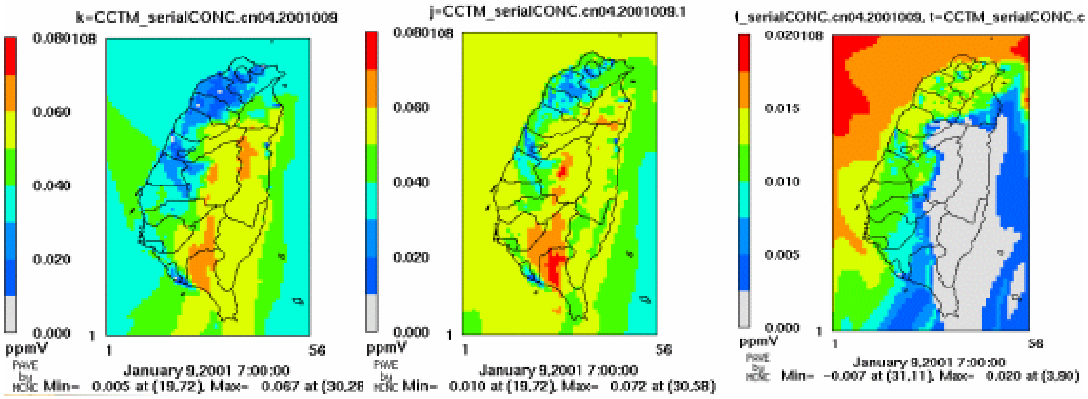

Figure 7. O_3 concentrations: (a) background BC, (b) nested BC, (c) effects of O_3

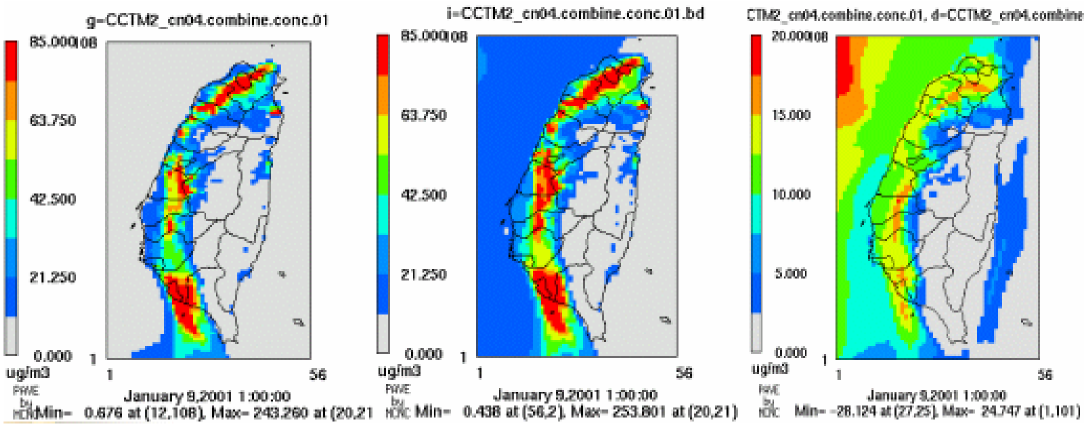

Figure 8. PM2.5 concentrations: (a) background BC, (b) nested BC, (c) effects of PM2.5

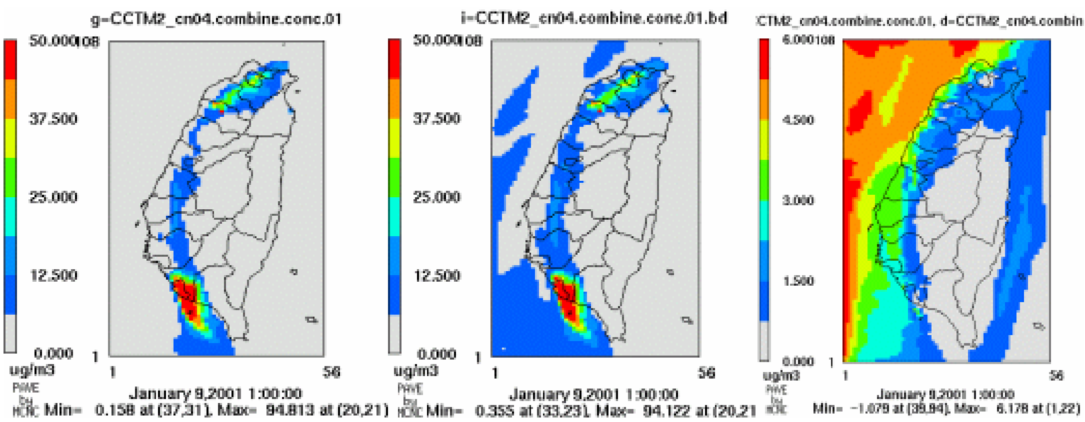

Figure 9. Sulfate PM2.5 concentrations: (a) background BC, (b) nested BC, (c) effects of PM2.5

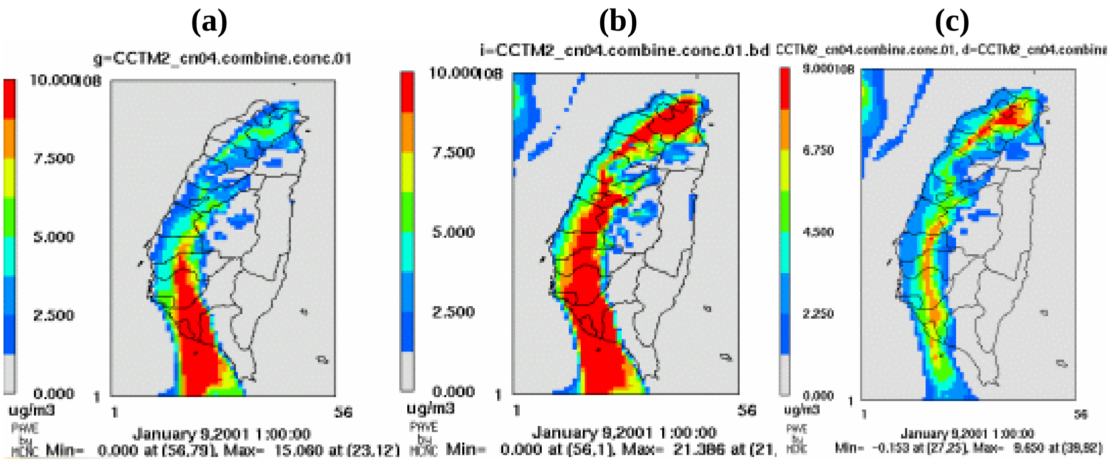

Figure 10. Nitrate PM2.5 concentrations: (a) background BC, (b) nested BC, (c) effects of PM2.5

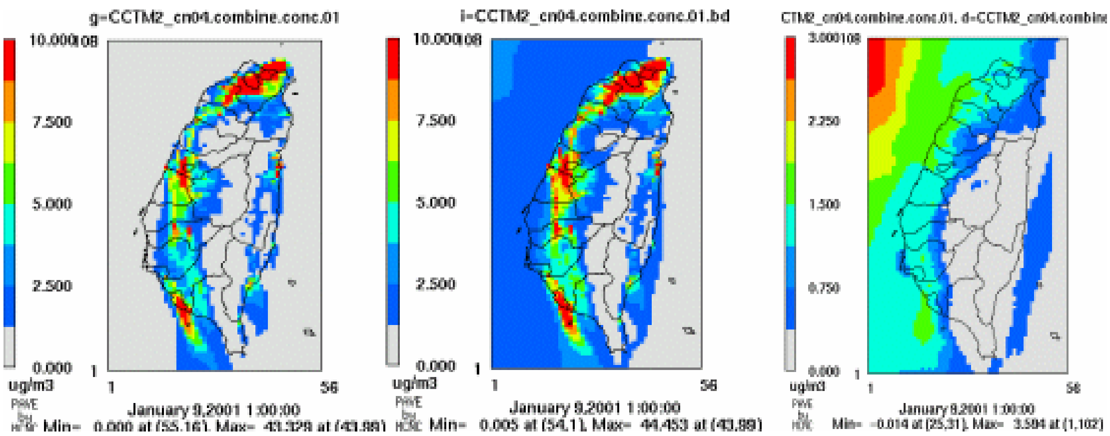

Figure 11. Organic PM2.5 concentrations: (a) background BC, (b) nested BC, (c) effects of PM2.5

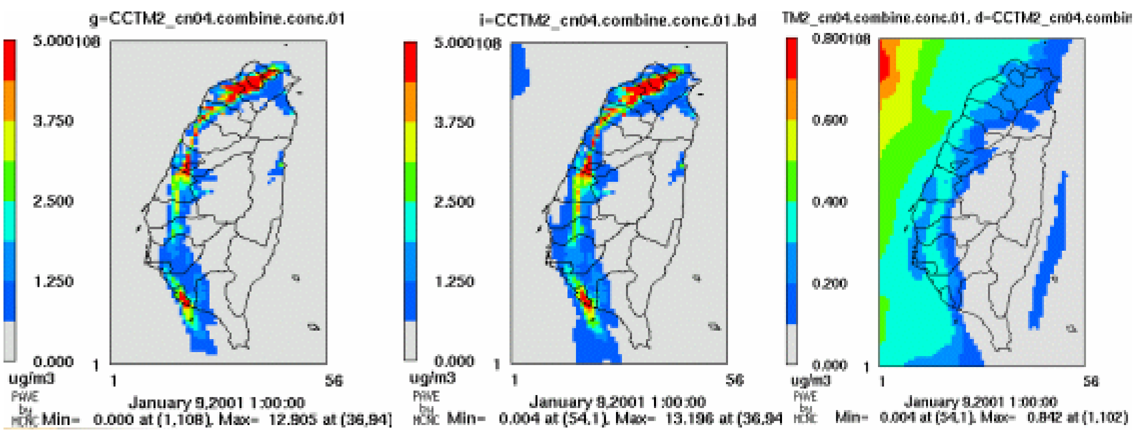

Figure 12. Elemental Carbon concentrations: (a) background BC, (b) nested BC, (c) effects of PM2.5

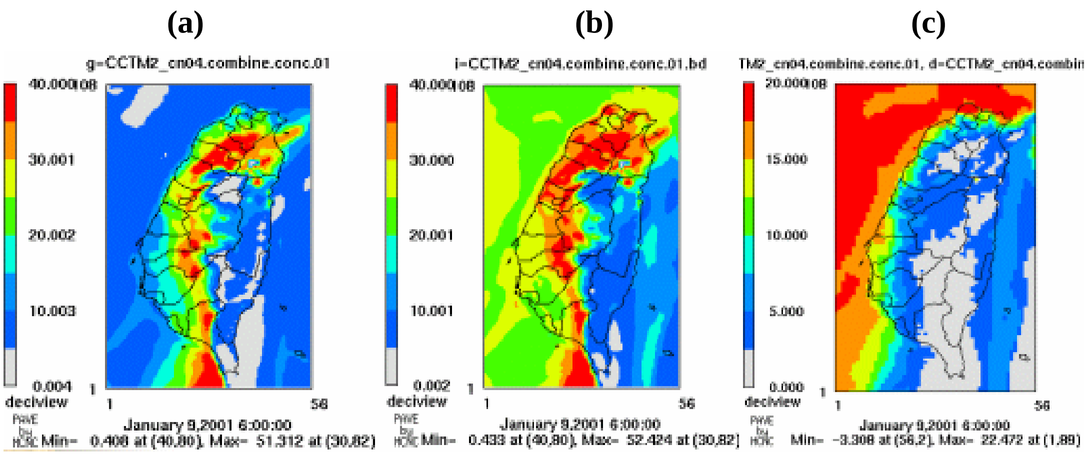

Figure 13. Visibility: (a) background BC, (b) nested BC, (c) effects of PM2.5

5. SUMMARY

The air pollution fees (APF) fund finances TEPA in various air quality improving projects. These projects include: motor vehicles inspection and maintenance, promotion of low-polluting vehicles, compensating new cars to replace old cars, subsidizing public transportation, providing free consulting to major emission sources, subsidizing landfill gas power generation, and etc. These projects provide even more incentives for air quality improvement (Chen and Chiang, 2000). However, cross-boundary transportation of air pollutants is hindering our efforts to further improve our air quality. For example, the dust storm from Mongolia caused the high PM_{10} levels in January, February, and April of 1999. Using an advanced air quality modeling system such as USEPA's Models3/CMAQ, the "One Atmosphere" model, we are able to assess multi-pollutants at once such as ozone, particulate matter, acid deposition, and visibility. The Models3/CMAQ is conducted with the air quality assessment applications in Asia countries (Fu, et al., 2003). A pilot study using Models-3/CMAQ has been conducted over Asia (36-km), Regional (12-km) and Taiwan (4-km) to simulate multi-pollutants, including primary and secondary pollutants such as ozone, PM, acid deposition, visibility, SO2, NOx, etc. The preliminary results (January case) seemed to show lower O3 than expected. High PM2.5 were simulated over metropolitan areas with significant secondary constituents. When TEPA considers the cap quantity control, the local pollutants transport and regional pollutants transport are needed to assess, even seasonality contribution in different areas such as Taipei, Taitung and Kaohsiung metropolitan areas. The Models-3/CMAQ system can be a useful research & management tool for regional/urban AQ assessment over China and Taiwan regions. It provides the additional profiles to the decision and policy maker in Taiwan that assist the TEPA on the development of control strategies to improve air quality in Taiwan.

6. REFERENCE

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