Using Models3/CMAQ to Simulate Regional Air Quality in China

Xiaoping Wang[1*], Yongtao Hu[2], Armistead Russell[2],
Denise Mauzerall[1], Yuanhang Zhang[3]
[1]Woodrow Wilson School, Princeton University
[2]School of Civil and Environmental Engineering, Georgia Institute of Technology
[3]School of Environment, Peking University
e-mail: **xwang@princeton.edu**
Telephone (609) 2582837 Fax (609) 258-6082

1. INTRODUCTION

We are interested in examining the impact of air pollution on public health in the greater region of Shandong Province in China (Figure 1). Due to lack of observational air quality data, we will use Models3/CMAQ to simulate the ambient concentrations of various pollutants which we will use in our subsequent health impact analysis. In this paper, we will discuss the approach we are taking to compile a regional emission inventory for the Shandong region. We will also report on our progress using MM5/SMOKE/CMAQ to make a regional emission inventory in China ready for use in CMAQ. The data collection for the Shandong region is under the way. We will use the Pearl River Delta Region (part of Guangdong Province) in south China (Figure 1) as a case study for SMOKE because there is a relatively complete anthropogenic emission database available for this region (Hu 2000). We will focus on anthropogenic emissions. Finally we will discuss the problems we have encountered and future work.

Fig. 1 Geographic location of Shandong and Guangzhou Provinces in China

* *Corresponding author address:* Xiaoping Wang, Woodrow Wilson School, Princeton University, Princeton, NJ08540

2. APPROACH AND INITIAL RESULTS

2.1 General Framework

Shandong Province is one of the major coal producing regions in China. The objective of the impact assessment project is to examine the potential environmental impacts of undertaking drastic changes in energy technologies, i.e. migrating from conventional coal combustion to coal gasification technologies. The health impact assessment involves the following steps: energy technology scenarios->emissions -> model simulation of ambient pollutant concentrations ->physical outcomes->economic damages. The results of physical and economic impacts will, in turn, be used for recommending scientifically well founded energy technology choices. Below we report on the approach to compiling the regional emission inventory in China and application of MM5/SMOKE/CMAQ for the case study of the Pearl River Delta Region.

2.2 Preparing the Regional Emission Inventory in China

The approach delineated below to developing a regional emission inventory in SMOKE input format is being applied for the Shandong region. A similar method has been successfully applied in developing a regional inventory in EPS2 input format for the Pearl Region.

The annual emissions are estimated based on emission related activities and their respective emission factors. They are divided into point, area, mobile and biogenic sources.

2.2.1 Point Sources

Each point source is defined by a county code, a source classification code (SCC), a source industry code (SIC), a plant/stack ID, and latitude and longititude. We use the list of large point sources in different provinces originally identified in the RAINS-ASIA Model Version 7.52 (released in 2001, see www.iiasa.ac.at/~rains). All other stationery sources are included in the area source category.

2.2.2 Area Sources

Area source emissions are estimated on a county basis. Each source is defined by a county code and an SCC. However, most statistics are available only at the city or more aggregate level. We use various proxies to derive the level of county-level activities and resulting emissions. For area source combustion emissions, city level energy consumption by fuel and sector is directly collected from city statistics or other sources, and is prorated to each county under the city jurisdiction based on the fraction of GDP or population. For industrial process emissions, outputs of various industrial products for cities are obtained, and are then allocated to counties based on the fraction of secondary (industrial) GDP. For those cities where relevant statistics are not available, we disaggregate the provincial energy consumption or output of industrial products data to cities based on the fraction of city GDP in the province. For residential emissions, the provincial per capita domestic energy consumption is applied to all counties in the province. In recent years, field burning of crop residues in China has become a large source, particularly during the harvest seasons. We estimate the amount of crop residues burnt in the open field based on the total amount of crop residues generated and the fraction openly burnt. The total amount of crop residues generated is derived as a product of the output of different grain crops and the residue to crop ratio. Solvent evaporation from industrial and domestic utilization is difficult to estimate. We are considering the possibility of basing the estimates on population or number of production operations.

2.2.3 Mobile sources

For mobile sources, we obtain the number of different types of passenger and freight vehicles in each city and the total passenger and freight mileage (measured by person kilometer and ton kilometer) for each city or county from the literature. The number of vehicles in a city is disaggregated into counties based on the number of passengers and freight transported yearly in a county. Based on the seating or loading capacity of different types of vehicle, we derive total mileages traveled by vehicle type and county. That is, mileage traveled (km) = passenger or freight turnover (person km or ton km)/number of the vehicle/seating or carrying capacity (person or ton)/loading efficiency.

For all anthropogenic emissions, we rely on the Chinese literature to obtain emission factors, if available. Otherwise, we draw emission factors for similar activities from AP42 in the US (USEPA 1995), and adjustment is made when deemed necessary.

2.2.4 Biogenic Sources

The model BEIS Version 2.5 is being used to estimate biogenic emissions, provided with the Chinese vegetation database and the emission factors for 109 types of vegetation available in the Chinese literature (Hu and Zhang 2002).

2.3 Running MM5/SMOKE/CMAQ for the Pearl River Region

We chose the Pearl River Delta Region as a case study to explore the feasibility of applying MM5/SMOKE/CMAQ for regional air quality modeling in China. The Pearl Region is situated in Guangdong Province on the south coast of China. Guangdong has a population of 73 million, and is a relatively economically developed area. Guangzhou and Hong Kong are two large cities in the region each with multiple millions of people.

2.3.1 Defining CMAQ Model Domains

We first define the CMAQ model domains of interest as shown in Figure 2. Using Lambert conformal projection, the true latitudes are set at 25N and 47N, and the origin at 112 35 50E and 22 00 33 N. We include one mother domain and two nested domains. The first domain is x1=-243km, x2=486km, y1=-243km, y2=486km, and a 27km*27km resolution. It covers a large area of 729*729km^2 including Guangdong Province, Hong Kong, Macao and part of the neighboring provinces. The second domain is x1=0km, x2=243km, y1=0km, y2=243km, and a 9km*9km resolution. It covers an area of 243*243 km^2 with Guangzhou and Hong Kong included. The third domain is x1=54km, x2=108km, y1=108km, y2=162km, and a 3km*3km resolution. It covers an area of 54*54 km^2 with Guangzhou alone included.

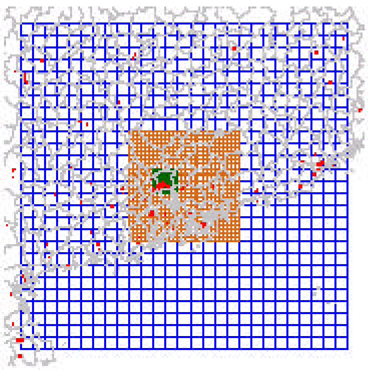

Fig. 2 27, 9, and 3 km CMAQ domains superimposed over the county boundary map (grey). Red dots denote urban centers as of the year 1990.

2.3.2 Running MM5

To create the MM5 domains, in general we add three more grid cells to each horizontal side of the three CMAQ domains. Because the MM5 mother domain must be symmetric in both X and Y directions with a given central latitude and longitude but the CMAQ mother domain is not across the origin, we add more than three cells to the left and bottom sides of the CMAQ mother domain. As a result, the first MM5 domain has 42*42 grid cells, the second 33*33 grid cells, and the third 24*24 grid cells.

We include 21 vertical layers in MM5. The NCEP global reanalysis data is used for the first guess fields in INTERPF and for objective analysis in little-r. The simulation period is from 0 hour 15 October 1998 to 0 hour 22 October 1998. As seen in Fig 4.1, northeastern wind was dominant at 4pm 17 October 1998 (local time) with a wind speed of 2-7 m/s over land, and 5-7m/s over sea. There was a high wind area in the north of the model domain.

2.3.3 Running SMOKE

For SMOKE, we first convert the 1998 inventory for point, area and mobile sources developed by Hu (Hu 2000) in the EPS2 input format to the SMOKE-acceptable IDA format. The SMOKE domains are set the same as those in CMAQ. The temporal and VOC speciation profiles are taken from (Hu 2000) who adapted the VOC speciation profile from those recommended by US EPA. Speciation is done based on the requirements of the CB-IV chemical mechanism which will be used in CMAQ. The spatial profile is obtained by using ARC/INFO to allocate area and mobile emissions in each county to the involved grid cells based on the ratio of county area and road length in a particular grid cell to the total area and road length of the county. We include only anthropogenic emissions and no biogenic emissions in this test case.

As shown in Figure 4.2, the spatial distribution of NOx (=NO+NO_2) and VOC (=sum of ALD2,ETH, HCHO, ISOP, OLE, PAR, TOL, and XYL) emissions correlate well with urbanization as indicated with red spots. Extraordinarily high NOx and VOC emissions occur in metropolitan areas of Guangzhou and Hong Kong. We also find that both NOx and VOC emissions have a strong diurnal cycle, higher during the day and lower at night. In addition, mobile sources in Guangzhou and Hong Kong metropolitan areas contribute most to the anthropogenic NOx emissions.

2.3.4 Running CMAQ

Before biogenic emissions are made available, we have used the SMOKE results with only anthropogenic emissions into CMAQ, and test run the model for the period from 15 October 1998 to 20 October 1998. We use the CB-IV (cb4_ae2_aq) chemical mechanism, and take photolysis rates, the boundary and initial conditions as predefined in CMAQ.

The simulated ozone concentrations are shown in Figure 4.3. The maximum hourly mean ozone concentration is only about 50 ppb, which is not surprising given that biogenic emissions are not included yet. As Hu (2000) pointed out,

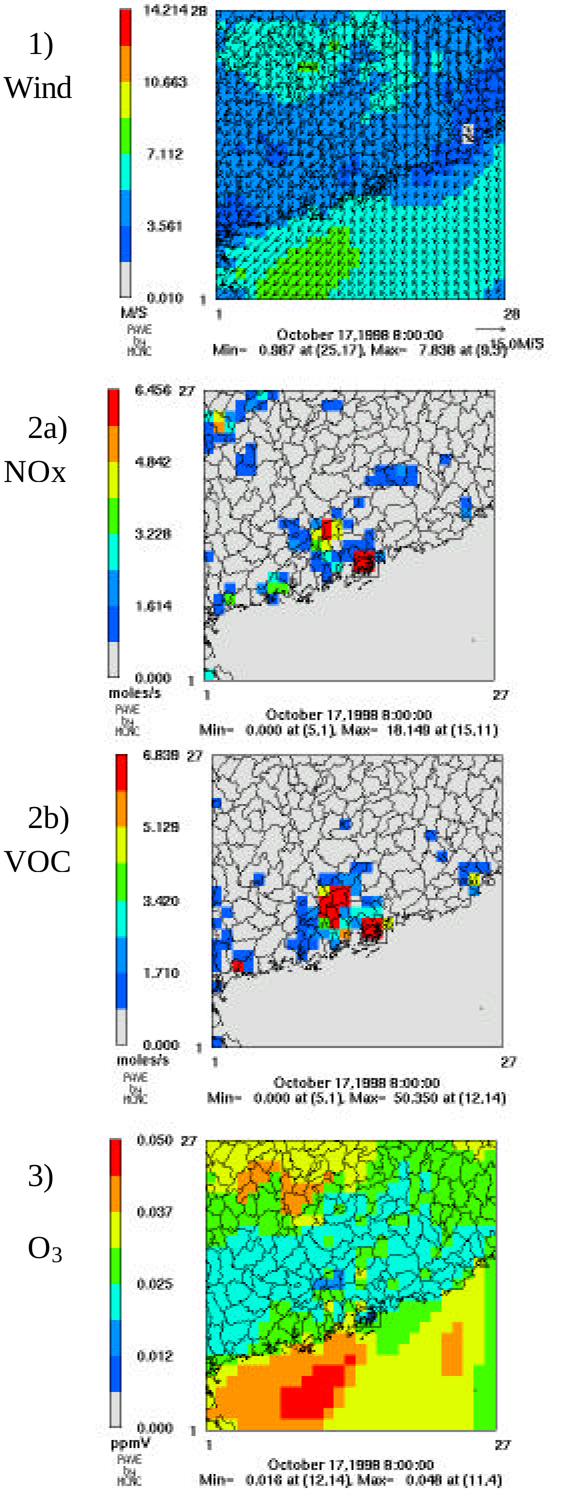

Fig. 4 MM5/SMOKE/CMAQ results showing: 1) surface wind speed and direction, 2) total anthropogenic NOx and VOC emissions, and 3) surface hourly ozone concentrations at 4pm (Beijing Time) 17 October 1998 for the 27km CMAQ domain.

biogenic sources contributed to more than 50% of the total VOCs in the Pearl River Region. With omission of this significant portion of VOCs, ozone production in this region is very likely VOC limited with ozone titrated by the relatively abundant NOx.

3. DISCUSSIONS AND CONCLUSION

We have demonstrated the feasibility of compiling a regional emission inventory for anthropogenic emissions, and of using MM5/SMOKE/CMAQ to simulate regional air quality in the Pearl River Delta Region of China. We are developing a regional emission inventory for the Shandong Region and a biogenic emission inventory for all of China. However, there remains a great deal of uncertainty involved in different stages of the process. First, our information on energy consumption and industrial activities is limited to various statistics, and thus suffers from the inherent weakness of those statistics and inconsistency of the sources. Second, we have limited information on emission factors, temporal and speciation profiles that are developed for local conditions. Whereas local emission factors are not available we resort to those developed in the US, but lack ability to verify their accuracy under Chinese conditions. Third, we face a great challenge in setting boundary and initial conditions and in evaluating the modeling results due to the dearth of air quality data for China. We are optimistic, however, that this type of analysis will provide an initial valuable quantification of the physical and economic impacts of air pollution in a region of China.

4. REFERENCE

Hu, Y. T. (2000). Study on regional air quality and its influence factors (in Chinese). Peking University, Beijing. 126 p.

Hu, Y. T. and Y. H. Zhang (2002). "Development of biogenic VOC emissions inventory with high temporal and spatial resolution." Environmental Science (in Chinese with English abstract) Under preparation.

USEPA (1995). Compilation of air pollution emission factors AP-42. United States Environmental Protection Agency, Research Triangle Park. p.