Numerical modeling of Criteria Pollutants in Megacity Delhi: An Application of WRF-Chem Model

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1. INTRODUCTION

Rapid industrialization and urbanization over the past few decades have led to high levels of ambient air pollution throughout the world. Rapidly increasing urbanization have been a major environmental driving force in the 21st century, affecting air quality on all scales (e.g., local, regional, and global)(Molina and Molina, 2002). The main pollutants emitted into the atmosphere in urban areas are sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), metal oxides, and particulate matter (PM/aerosols), mostly consisting of black carbon, sulfates, nitrates, and organic matter. In this paper, concentrations of air pollutants CO, NOx, SO2 and PM10 are simulated over Delhi (28◦35′ N, 77◦12′ E), the capital and the largest city by area and second largest by population in India. It is the eighth largest megacity in the world with more than 18 million inhabitants. It is expected to reach 22.5 million in 2025 [UNHABITAT, 2008]. The National Capital Region (NCR) of Delhi has grown rapidly in the past two decades. It now covers an estimated area of 5000 km^2, which includes new townships and satellite centers such as Noida, Gurgaon, Ghaziabad, and Faridabad, all of which are a combination of information technology firms and industrial clusters. No single sector is responsible for all of Delhi's air pollution. Rather, it is a combination of factors including industries, power plants, domestic combustion of coal and biomass, and transport (direct vehicle exhaust and indirect road dust) that contribute to air pollution (Garg *et al.* 2006). Another external factor to air pollution in Delhi is agricultural clearing [Earth *Observatory,* 2008]. After harvesting crops, the land is cleared, a common practice in surrounding (largely agricultural) states. The smoke from clearing crops reaches Delhi and contributes to the smog formation and ozone pollution.

2. **Methodology**

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2.1 *Brief description of Model*

WRF-Chem (Grell et al. 2005) is the chemistry version of the Weather Research and Forecasting model, which simulates the turbulent mixing, transport, transformation, and fate of trace gases and aerosols. The version of the model (version 3.6) used in the present study includes simultaneous calculations of dynamical parameters (e.g., wind, temperature, boundary layer, and clouds), transport (advective, convective, and diffusive), dry deposition (Wesley,1989), gas phase chemistry, radiation and photolysis rates (Madronich and Flock 1999; Tie et al. 2003), and surface emissions, including online calculations of biogenic emissions. The parameterization schemes and the options used in this study are summarized in Table 1. The static geographical field such as the terrain height, land-use, vegetation fraction, soil properties, albedo etc. are obtained from the 10 min United States Geological Survey (USGS) data to the simulation domain by using the geogrid program of the WRF preprocessing system. The initial and lateral boundary conditions for meteorological parameters are obtained from NCEP Final analysis (FNL) fields available every six hours at the spatial resolution of $1^\circ \times 1^\circ$.The emissions of CO, NOx, and SO_2 were available for the model domain (D3) at a resolution of $0.02^\circ \times 0.02^\circ$ for the base year 2008, and are used in the present study (Personnel Communication). Criteria pollutant emissions input to the model includes residential, transport, industry and biomass burning emission. The remaining emissions were obtained from the global emission data set, which include the REanalysis of the TROpospheric (RETRO) chemical composition and Emission Database for Global Atmospheric Research (EDGAR). These datasets provide global emissions for several greenhouse gases, some precursor gases and particulate matter. As these emissions were based on past years compared to the simulation years, they were projected using various factors provided in (Ohara et al. 2007).

2.2 Model Settings and Initialization

Three nesting domain were defined using the Lambert projection, Fig 1. The Domain 1 covers the whole north-central India along with the surrounding areas of Delhi, with

the center point at latitude 27.2°N, longitude 76.60°E. Domain 2 and Domain 3 covered Delhi and its surrounding areas. The domain settings and configuration options are shown in Table 1.

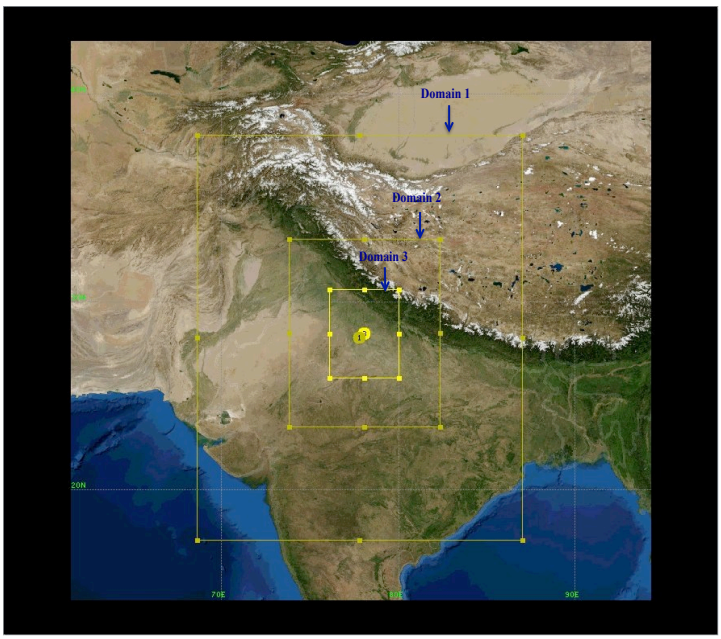

Figure 1. The nesting domain setting of the model.

The emissions that are input in the model were processed using a simple grid-mapping program called "prep-chem-sources" for global emission data (dust, sea salt, biomass burning), developed at CPTEC, Brazil (Frietas et al., 2011) and is available to WRF/Chem model users. The "prep-chem-sources" is an emission data generator package to provide gridded emission fluxes (kg/m^2), The emission data are interpolated to model grids using the same. The biogenic emissions are calculated using the scheme of Guenther *et al.* [Guenther et al. 1993, Guenther et al. 1994]. The Chemistry is represented in the model by a modified Regional Acid Deposition Model version 2 (RADM2) gas-phase chemical mechanisms (Chang et al. 1989), which includes 158 reactions among 36 species, in conjunction with the Secondary Organic Aerosol Model (MADE/SORGAM) of aqueous reactions (Schell et al. 2001). The chemistry was initialized with idealized profiles.

In the present study, the model was centered around Delhi, for the period from 00:00 UTC (Coordinated Universal Time) on 24 December 2008 to 00:00 on 30 December 2008; India Standard Time (IST) is the standard time zone of India and is 5:30 hours ahead of UTC.

Table 1. WRF/Chem model domain settings and configuration options.

Grid spacing	18 Km, 6 Km, 2Km
Microphysics	Lin et al. (1983)
Long wave radiation	RRTM
Shortwave radiation	GODDARD
Surface layer	Moni-Obukhov (Janjic Eta)
Land surface model	NOAH
Boundary layer	Mellor-Yamada-Janjic TKE
Cumulus parameterization	Kain-Fritsh Cumulus parameterization (Kain. 2004)
Chemistry option	RADM2
Biogenic emissions	Guenther scheme
Photolysis option	Madronich, 1987
Aerosol option	MADE/SORGAM (Schell et al. 2001)

3. Results and Discussion

To keep the presentation of paper in manageable size only hourly averaged concentration plots of criteria pollutants at 16th hour have been discussed. Fig.2 shows the spatial distribution of different pollutants CO, SO_2, PM10, NO_2 and O3. In the left panel of fig.1 pollutant concentration is simulated using EDGAR emission inventory with its default values. In right panel, pollutant concentrations are modeled using emissions of Delhi and EDGAR inventory. Right panel plots are showing remarkable improvement over the left panels plots. Maximum & minimum concentration of CO (ppmv) is increased by almost 10 times. The maximum concentration of CO became 0.135 ppmv to 1.3 ppmv. SO_2 range changed from (0.0001-0.00065 ppmv) to (0.005-0.06 ppmv). PM_{10} from (1-12 ug/m^3) to (18-38 ug/m^3). Ozone precursor NO2 showed a remarkable improvement from (0.00035-0.00075 ppmv) to (0.005-0.065 ppmv). Vehicular pollution being the major source of CO pollution is simulated in a better way using local emission values of Delhi. Moreover in the similar way, spatial distribution of SO_2 is able to identify the emission hotspot in Delhi identified as the major traffic intersection ITO and coal based power plant Rajghat and Indraprastha located in its vicinity. Thus, the accountability of the local emission sources becomes more visible in the latter simulation.

Further study is necessary to fully understand the impacts of

local emission inputs, meteorological variables, nesting option, horizontal grid spacing on the formation and transport of chemical species. Also, different chemistry options are needed to be analyzed.

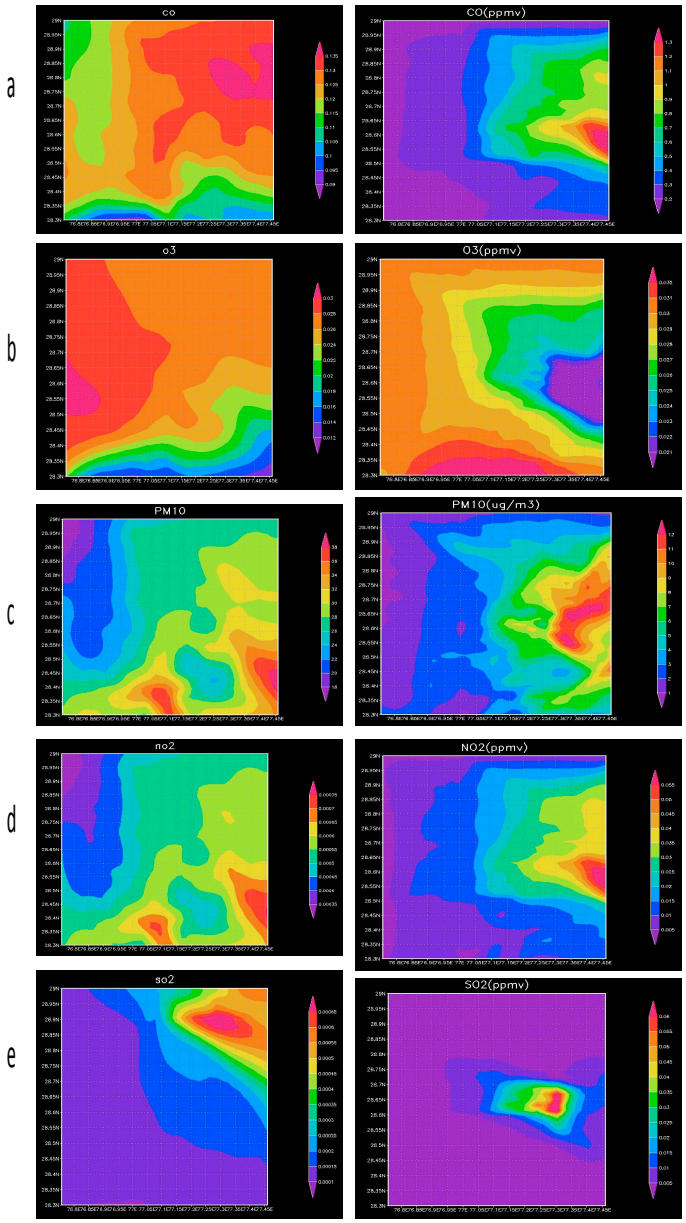

Fig 2. Spatial distribution of (a) CO (b) O3 (c) PM_{10} (d) NO_2 (e) SO_2

4. *References*

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