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

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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 has 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.

Episode Selection

The selection of the period for the WRF-Chem simulation is based on the 2008-09 air quality measurements performed by the central pollution control board (CPCB) India. Observed air quality shows that maximum concentration of different criteria pollutants found during the winter season, which support the persistence of pollutants in the atmosphere.The simulations were conducted for four consecutive dasys (27th-30th Dec,2008) during winter season. The selection of simulation domain is mainly the national capital region (NCR) Delhi (28◦35′ N, 77◦12′ E), which is one of the most polluted city of the world (WHO, 2014).

WRF-Chem Model Configuration

Three nesting domain were defined using the Lambert projection, Fig 1. The Domain 1(D1) 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(D2) and Domain 3 (D3) covered Delhi and its surrounding areas. The domain settings and configuration options are shown in Table 1.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.

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 Parametrization	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)

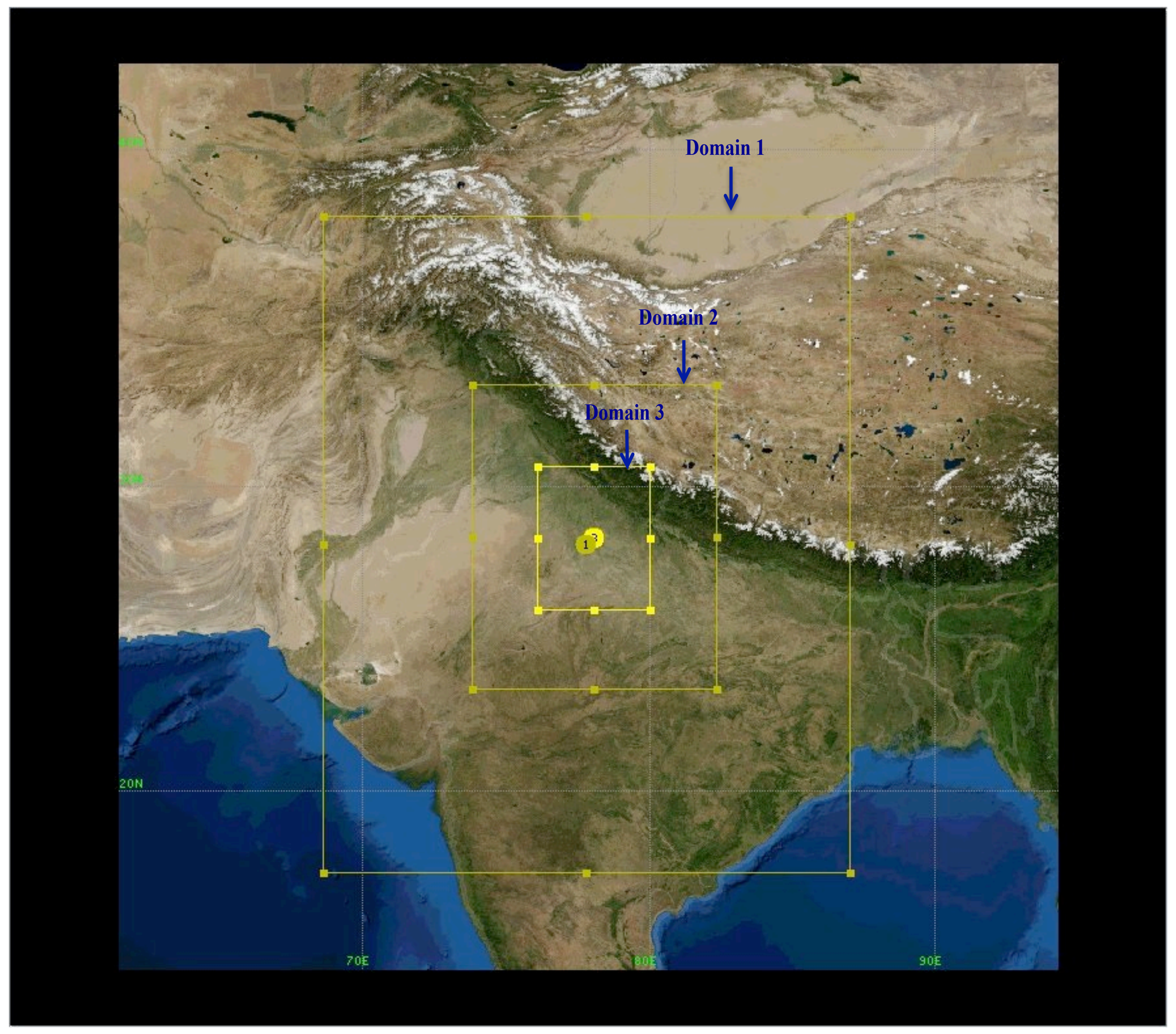

Fig.1 Three nested domain

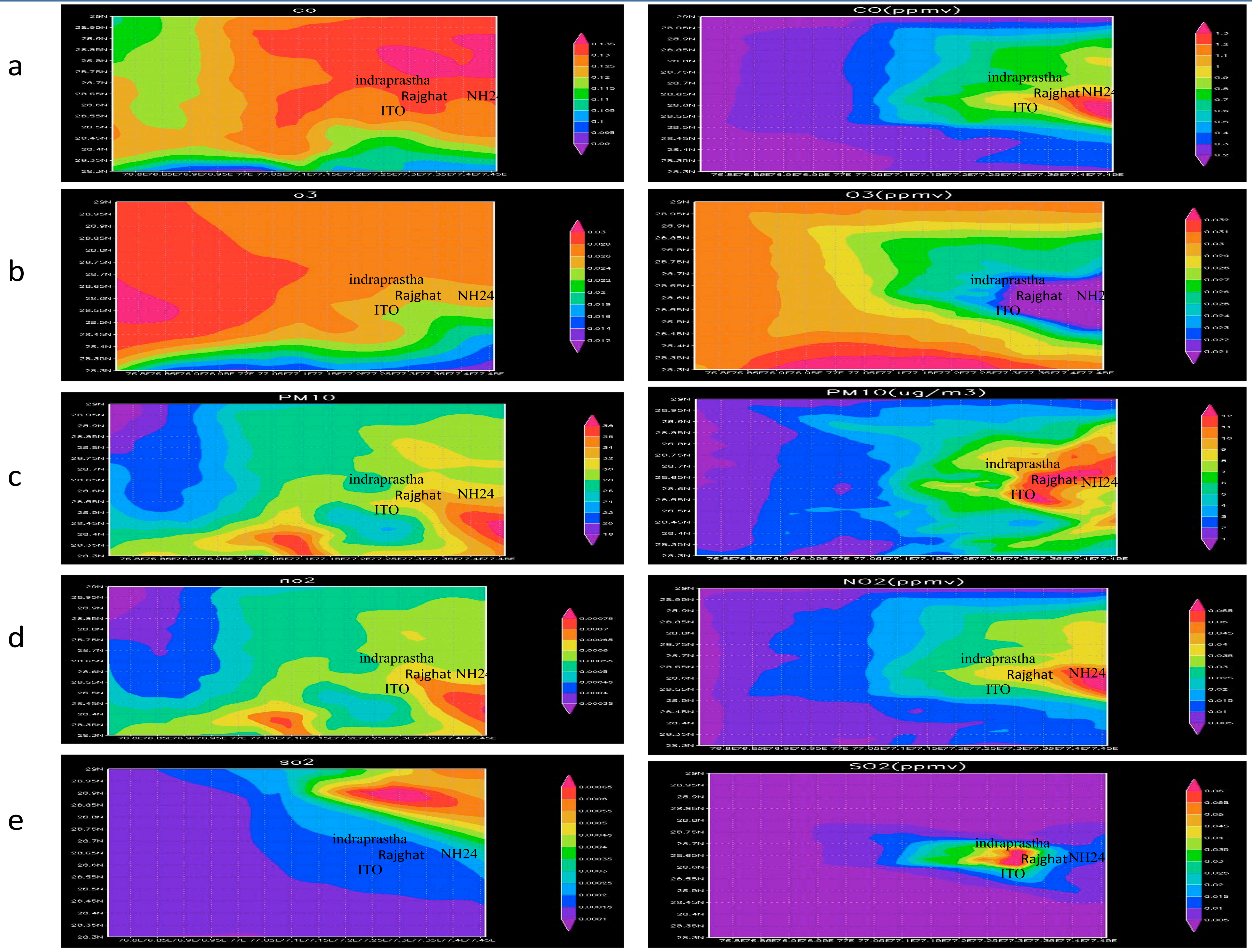

Fig.2

The Model Simulated concentration of (a) CO (b) O_3 (c) PM_{10} (d) NO_2 (e) SO_2 are shown spatially as in Figures 2 over Delhi (28◦35′ N, 77◦12′ E), India and it has been shown that CO, SO_2 and NO_2 is very well distributed spatially in over the study domain according to local scenario.

Emissions

The emissions of SO_2, NO_2 and CO were available for the model domain (D3) for a resolution of 0.02º x 0.02º for the base year 2008 for the National Capital Region (NCR), Delhi and 0.1ºx 0.1º EDGAR emissions are used for D1 and D2 in the present study. SO_2, NO_2 and CO emissions input to the model includes transport, industry, waste and agricultural residue burning emission sectors of NCR region. The remaining emissions were obtained from the global emission data sets, which includes the Reanalysis of the TROpospheric (RETRO) chemical composition 0.5ºx0.5º and Emission Database for Global Atmospheric Research (EDGAR) (0.1ºx 0.1º). These datasets provide global emissions for several greenhouse gases, some precursor gases and particulate matter up to a resolution of grid. A grid mapping programme--prep_chem_sources was used to map the global emission data to a WRF domain using a lambert projection.

Results and Discussions

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, PM_{10}, NO_2 and O_3. In the left panel of fig.2, pollutant concentration is simulated using EDGAR emission inventory with its default values for all the three domains. 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 NO_2 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. As the coal based power plan are the major source for SO_2 emissions. 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.

Conclusions

In this study WRF-Chem model was applied to simulate meteorological and air pollutants parameters over Delhi (28◦35′ N, 77◦12′ E) for the selected period of winter season. The main findings are:

The model is capable of taking the account of local emission sources (using NCR emission Inventory) in a better way in comparison to the global emission inventory over study area. Model simulated spatial concentration plot of CO, NO_2 and SO_2 reveal that WRF-Chem has the able to identify location of SO_2 producing power plants and major trafic intersections which were constantly underestimated due to the use of Global EDGAR emission dataset. This shows the importance of local emission inventory for the estimation of air quality of the region.Therefore the use of regional or local emission inventory instead of EDGAR emissions over New Delhi, India may improve the results of simulated concentration of different criteria pollutants.

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