



Sensitivity analysis of ground level ozone in India using WRF-CMAQ models



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HIGHLIGHTS

- Modelling of Ozone concentrations using high resolution inventories in India.
- NOx sensitive conditions prevail in India.
- Transport sector have the maximum potential for reducing Ozone in India.
- At urban scale, reduction of NOx results in increase in Ozone concentrations.
- In future NMVOC sensitivities towards Ozone increase marginally.

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ABSTRACT

Ground level ozone is emerging as a pollutant of concern in India. Limited surface monitoring data reveals that ozone concentrations are well above the prescribed national standards. This study aims to simulate the regional and urban scale ozone concentrations in India using WRF-CMAQ models. Sector-specific emission inventories are prepared for the ozone precursor species at a finer resolution ($36 \times 36 \text{ km}^2$) than used in previous studies. Meteorological fields developed using the WRF model are fed into the CMAQ model along with the precursor emissions to simulate ozone concentrations at a regional scale. The model is validated using observed ozone dataset. Sensitivity analysis is carried out to understand the effect of different precursor species and sources on prevailing ozone concentrations in India. The results show that NOx sensitive conditions prevail in India and control of NOx will result in more reduction in ozone than VOCs. However, further growth in the transport and power sector and decreasing VOC emissions from the residential sector may increase the sensitivity of VOCs towards ozone in the future. At the urban scale, presence of high NOx emissions form VOC limited conditions and reduction of NOx results in increase in ozone concentrations. However, this will help in improving regional scale ozone pollution in the downwind regions. A non-linear response has been observed while assessing the sectoral sensitivities of ozone formation. Transport sector is found to have the maximum potential for reducing ozone concentrations in India.

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1. Introduction

Ground level ozone has proven to be a difficult pollutant to control across the world. With growth in emissions of precursor species, the hemispheric concentrations of ozone are rising (TRS, 2008). Ozone not only has effects on productivities of different

crop varieties (Wilkinson et al., 2011), but also on human health (Gryparis, 2004). Moreover, it is also reportedly known to have a significant greenhouse potential and has been rated as a gas with considerable radiative forcing (IPCC, 2013).

In India, ozone is limitedly monitored at few locations and there is limited research on assessing the contribution of different sources responsible for emissions of its precursor species. Precursors emissions in India are not just exposing the receptors (humans and plants) in India to high ozone concentrations but also increasing the hemispherical ozone concentrations through transport (Cooper et al., 2010). Recently, a study conducted by Burney and

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Ramanathan (2014) has estimated that ozone accounts for up to 36% wheat loss in India.

Ozone is formed by photo-chemical reactions involving a number of precursor species (NO_x, VOCs, CO) emitted from a variety of sources (such as transport, residential, industrial, solvent use, etc.). In this context, it becomes important to assess the contribution of different sources and species towards formation of ground level ozone concentrations in India. Once apportioned, sector/species specific measures can be taken for effective control of the pollutant. The contribution of different sources towards ozone formation can be assessed through sensitivity analysis using the photochemical models. The effect of a particular source on ozone concentrations is quantified with and without its emissions included in the photo-chemical model to assess its sensitivity.

In the past, there are a few studies conducted in the Indian domain to simulate ozone concentrations. Some of them studied the spatio-temporal distribution of ozone over the Indian region in different urban and regional environments—urban (Singh et al., 1997; Londhe et al., 2008; Ganguly, 2009; Purkait et al., 2009); marine (Ali et al., 2009), regions like Indo-Gangetic plains (Beig and Ali, 2006; Lal et al., 2008) (Roy et al., 2008) assessed the seasonal distribution of ozone and its precursor in India. Recently, Kumar et al. (2012) simulated the tropospheric ozone concentrations using the WRF-Chem model over South Asia for 2008 and evaluated the model performances. In our previous work (Chatani et al., 2014), we modelled ozone concentrations for a domain over South and East Asia. That paper validates the model results with the observed ozone concentrations in India for the base year 2010. However, limited research has been conducted to assess the source sensitivities towards formation of ozone in India. This is extremely important for effective control of ozone. This study uses the same WRF-CMAQ models as used in Chatani et al., 2014 but with higher resolution emission and meteorological inputs to assess source and species sensitivities of ground level ozone concentrations in India and recommend key strategies for its control. Although, the family of models used is the same, this work uses CMAQ v4.7.1 while, our previous study (Chatani et al., 2014) applied CMAQ v5.0.1; higher resolution (36 × 36 km²) emission inventories and meteorological inputs than previous study (60 × 60 km²) and a different vertical layer setting (this work – 25 layers; previous study 28 layers). Considering differences in the two studies, fresh model evaluations are carried out to compare model predictions with actual observations.

This paper will be useful for not only the academic community for advancement of science but also for policy makers to take informed decisions for its control. The results of sensitivity analysis at a fine resolution of 36 × 36 km² would prove to be extremely useful in control of ozone and also in improving estimates of ozone at Asian, hemispheric or global scales, by suggesting the improvements required in emission inventories.

2. Materials and methods

2.1. Study domain

This study covers the entire India as a study domain (Fig. 1). It includes some neighbouring countries and the Indian Ocean. The horizontal grid resolution is 36 km × 36 km and 25 vertical layers are set from the ground level to about 19.5 km (5639 hPa above). India is further divided in states and districts for spatial allocation of emissions of different sectors and pollutants.

2.2. Methodology

The overall framework used in this study is shown Fig. 2.

Emission inventories of different ozone precursor species are prepared for combustion and non-combustion sources. The sectors considered for energy use and emission estimation are residential, transport, industries, power, and non-energy, under the fuel categories of coal, natural gas, diesel, gasoline, LPG (liquefied petroleum gas), other petroleum products such (fuel oil, kerosene, etc.), and biomass. The data on energy use, in different sectors, is collected from various reliable government and published sources. This includes sectoral energy use data (MoPNG (2010)), industrial production statistics (CSO, 2011), power generation (CEA, 2011), population (RGCC, 2011), household fuel combustion (NSSO, 2011), vehicle registration data (MoRTH (2011)), and others. Other than energy use sectors, data is also estimated for emission contributing sectors like open burning of agricultural residues, using cropping patterns in agricultural sector and crop to waste ratios. The details of activity data collection is presented in the study conducted by Sharma et al., 2015.

Activity data for different sectors is fed into the GAINS Asia model (Greenhouse Gas and Air Pollution Interactions and Synergies, Amann et al., 2011) to estimate emissions of ozone precursors. For emission inventories we followed the same approach as Klimont et al., 2002 (Eq. (1)), which is consistent with the methodology applied in several other regional inventories (e.g., Streets et al., 2003; Wei et al., 2008; Zhang et al., 2009) and the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model framework used for Europe and Asia.

$$E_k = \sum_l \sum_m \sum_n A_{k,l,m} \cdot ef_{k,l,m} \cdot (1 - \eta_{l,m,n}) \cdot X_{k,l,m,n}$$

where: k, l, m, n are region, sector, fuel or activity type, abatement technology; E denotes emissions of ozone precursor (kt); A the activity rate; ef the unabated emission factor (kt per unit of activity); η the removal efficiency (in fraction); and X the actual application rate of control technology n (in fraction) where $\sum X = 1$ (Klimont et al., 2002).

Some of the sources have offered control of pollutants like NO_x. For an example, Euro-III/IV equivalent norms have gradually been introduced in India for control of pollutant emissions from transport sector, and the same have been accounted during development of emission inventories.

The emission factors used for inventories of NMVOC are presented in Sharma et al., 2015. The emission factors used for NO_x and CO emissions inventories are present in GAINS Asia database (<http://gains.iiasa.ac.at>). Inventories prepared in this study are compared with other previous studies for validation. The inventory is spatially allocated at 36 × 36 km² resolution using district/unit level information of vehicles, industries, and the human population in India.

The emissions are spatially, temporally, and vertically distributed based on the available information and thereafter further analysed. Sector-specific spatial allocations are made using GIS software based on district-wise information on registered vehicles, population, and state-wise information on industrial production. For large industries like cement, refineries, oil and gas explorations, iron and steel, thermal power plants allocations are made at the exact grid location. Emissions for some of the sectors like transport and residential have also been distributed temporally mainly based on information on traffic flows and time of cooking. Vertical distributions of emissions are made based on information on stack heights. Emissions of transport and residential sectors are allocated in the lowest layer (30–43 m), while emissions from industries and power plants are allocated in second (75–100 m) and third layers (170–225 m) of WRF simulated meteorological fields. Emissions from other neighbouring countries, falling in the study domain, are

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