Atmospheric Environment 125 (2016) 486–504

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Inter-comparison and performance evaluation of chemistry transport models over Indian region

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HIGHLIGHTS

- WRF-Chem, SPRINTARS models are evaluated against ground-based, satellite observations.
- Inspite of underlying differences, the models underestimate BC by similar margins.
- Underestimations in BC emissions from global inventories are quantified.
- Dust and Sea-salt are found to be sensitive to meteorological inputs.
- Potential causes of models underestimating BC and optical depth are investigated.

ARTICLE INFO

Article history:
Received 6 March 2015
Received in revised form 20 October 2015
Accepted 23 October 2015
Available online 28 October 2015

Keywords:
WRF-Chem
SPRINTARS
BC
AOD
Dust

ABSTRACT

Aerosol loading over the South Asian region has the potential to affect the monsoon rainfall, Himalayan glaciers and regional air-quality, with implications for the billions in this region. While field campaigns and network observations provide primary data, they tend to be location/season specific. Numerical models are useful to regionalize such location-specific data. Studies have shown that numerical models underestimate the aerosol scenario over the Indian region, mainly due to shortcomings related to meteorology and the emission inventories used. In this context, we have evaluated the performance of two such chemistry-transport models: WRF-Chem and SPRINTARS over an India-centric domain. The models differ in many aspects including physical domain, horizontal resolution, meteorological forcing and so on etc. Despite these differences, both the models simulated similar spatial patterns of Black Carbon (BC) mass concentration, (with a spatial correlation of 0.9 with each other), and a reasonable estimates of its concentration, though both of them under-estimated vis-a-vis the observations. While the emissions are lower (higher) in SPRINTARS (WRF-Chem), overestimation of wind parameters in WRF-Chem caused the concentration to be similar in both models. Additionally, we quantified the underestimations of anthropogenic BC emissions in the inventories used these two models and three other widely used emission inventories. Our analysis indicates that all these emission inventories underestimate the emissions of BC over India by a factor that ranges from 1.5 to 2.9. We have also studied the model simulations of aerosol optical depth over the Indian region. The models differ significantly in simulations of AOD, with WRF-Chem having a better agreement with satellite observations of AOD as far as the spatial pattern is concerned. It is important to note that in addition to BC, dust can also contribute significantly to AOD. The models differ in simulations of the spatial pattern of mineral dust over the Indian region. We find that both meteorological forcing and emission formulation contribute to these differences. Since AOD is column integrated parameter, description of vertical profiles in both models, especially since elevated aerosol layers are often observed over Indian region, could be also a contributing factor. Additionally, differences in the prescription of the optical properties of BC between the models appear to affect the AOD simulations. We also compared simulation of sea-salt concentration in the two models and found that

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http://dx.doi.org/10.1016/j.atmosenv.2015.10.065

WRF-Chem underestimated its concentration vis-a-vis SPRINTARS. The differences in near-surface oceanic wind speeds appear to be the main source of this difference. In-spite of these differences, we note that there are similarities in their simulation of spatial patterns of various aerosol species (with each other and with observations) and hence models could be valuable tools for aerosol-related studies over the Indian region. Better estimation of emission inventories could improve aerosol-related simulations.

1. Introduction

Aerosols are tiny (10^{-9} m–10^{-4} m) solid or liquid particles suspended in air. They are capable of affecting the Earth's radiation budget through direct (Haywood and Ramaswamy, 1998; Haywood and Boucher, 2000; Kaufman et al., 2002; Takemura et al., 2005; Yu et al., 2006; Myhre, 2009) and indirect (Twomey, 1977; Lohmann and Lesins, 2002; Lohmann and Feichter, 2005; Ravi Kiran et al., 2009) pathways, besides having severe effects on human health (Krzyzanowski et al., 2005; Janssen et al., 2011). The South Asian region is known to be a hot spot of natural as well as anthropogenic aerosols (Ramanathan et al., 2001; Lelieveld et al., 2001). There has been an increasing trend in AOD over this region (Porch et al., 2007; Ramachandran et al., 2012; Babu et al., 2013). Such an aerosol loading over the region is capable of altering the radiation budget and potentially offsetting the large scale monsoonal circulation, resulting in modification in the rainfall distribution over the region (Chakraborty et al., 2004; Ramanathan et al., 2005; Lau et al., 2006). Additionally, a few recent studies (Lau et al., 2010; Qian et al., 2011; Yasunari et al., 2010; Gautam et al., 2013) have shown that the build-up of high concentrations of absorbing aerosols over the Indo-Gangetic Plains (IGP) and the Himalayan foothills appears to cause a reduction in snow albedo and subsequent accelerated snow/ice melt in the Himalayas during the pre-monsoonal months. Combining models and measurements, Nair et al. (2013) have brought out the importance of BC deposits on Himalayan glaciers in impacting the radiation budget through snow albedo forcing. Understanding the similar effects of such aerosols on the regional climate and local air quality thus becomes very important. To understand the regional heterogeneity of the aerosols, the Indian Space Research Organisation (ISRO) under ISRO-GBP (Geosphere Biosphere Programme) has set up a network of surface observatories for the measurement of aerosol related properties under the ARFI (Aerosol Radiative Forcing over India) (Moorthy et al., 2009; Moorthy and Satheesh, 2011; Babu et al., 2013) project; has carried out aircraft and high altitude balloon measurement campaigns under the ICARB (Integrated Campaign for Aerosols, gases and Radiation Budget) (Moorthy et al., 2008; Babu et al., 2011) and RAWEX (Regional Aerosol Warming EXperiment) projects respectively. While such observational campaigns help us develop a strong understanding about the aerosol scenario over specific locations, the numerical simulations of aerosols bring out such information for a larger spatial domain. Aerosol model simulations play an instrumental role in understanding the effect of aerosols on regional weather and climate processes. Studies like Chakraborty et al. (2004); Ramanathan et al. (2005); Lau et al. (2006); Bollasina et al. (2011) etc. have employed aerosol simulating numerical models to examine the interaction between the aerosol burden over the south Asian region and the monsoonal rainfall over the region. However, while the use of models is essential to understand the climate implications, it is equally important to evaluate the model performances against the actual measurements. There have been a few recent efforts in this direction (Reddy et al., 2004; Chin et al., 2009; Ganguly et al., 2009; Henriksson et al., 2011; Goto et al., 2011; Kumar et al., 2011, 2012; Nair et al., 2012; Cherian et al., 2013; Moorthy et al., 2013; Sanap et al., 2014; Pan et al., 2015; Govardhan et al., 2015). Ganguly et al. (2009) have examined the performance of the online-aerosol model GFDL-AM2 over the Indian region. The model underestimated the total column AOD over the belt of IGP by a factor close to 6 and BC mass concentrations by a factor of 10. A study by Govardhan et al. (2015) with WRF-Chem shows that AOD and BC concentrations are underestimated by this model by a factor of 2 or more during the pre-monsoon and post-monsoon periods. They have identified over-estimation of boundary layer height, stronger winds and possible underestimation of emissions as causes for this underestimation. Their results are in agreement with those of Nair et al. (2012); Moorthy et al. (2013) who have evaluated the performance of RegCM4, GOCART and CHIMERE chemistry transport models over the Indian region in simulating the mass concentration of BC aerosols, and compared these with concurrent measurements. Recently, Pan et al. (2015), examined the performance of 7 chemistry transport models in simulating AOD and mass concentrations of different aerosol species over Indian region. They also found under-estimations in AOD and species mass concentration by the models vis-a-vis satellite and surface observations. They attributed such shortcomings in the model to the unrealistic inventory of biomass-burning emissions and simulations of RH within the models. All these point to the dire need for more such evaluations, primarily to improve the applicability of such models for regional and global studies.

Driven by the reasons above, in this paper, we evaluate the performance of WRF-Chem simulations over the Indian region with the concurrent simulation using another established global chemistry transport model viz. SPRINTARS. The 2 chemistry transport models differ in many aspects including a). Horizontal resolution, b). Physical domain, c). Meteorological formulation. SPRINTARS uses grid nudging technique and corrects its meteorological component by nudging it with NCEP-NCAR reanalysis dataset (generally considered a good proxy for actual observations) once every 6 h. WRF-Chem on the other hand, does not nudge its meteorological fields with observations. The model simulated aerosol parameters like AOD and surface concentrations of BC are inter-compared and evaluated against the concurrent observational data from satellites, and ground based network measurements. We have attempted to understand the reasons behind similarities and the differences in model simulations of AOD and BC. Additionally, with the help of such inter-comparison and evaluation of model simulated BC, we have suggested quantitative modifications in the anthropogenic BC emissions inventories used in these models as well as in three other widely used emissions inventories, for the BC emissions over Indian region. Model-to-model comparisons of sea-salt and dust simulations are also done to examine the consistency between the models, especially in view of the absence of direct measurements of these species.

This paper is organised as follows- Model and simulation details are presented in Section 2. Section 3 describes the various observational datasets used in this study. Results can be found in Section 4 and conclusions are written in Section 5.