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Model simulations of fungal spore distribution over the Indian region

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HIGHLIGHTS

- Fungal spore emissions based on high resolution land use data.
- Simulating fungal spore concentration for Indian region.
- Role of meteorology/seasons in fungal spore variability.
- Need for bioaerosol measurements over Indian region.

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ABSTRACT

Fungal spores play important role in the health of humans, animals, and plants by constituting a class of the primary biological aerosol particles (PBAPs). Additionally, these could mediate the hydrological cycle by acting as nuclei for ice and cloud formation (IN and CCN respectively). Various processes in the biosphere and the variations in the meteorological conditions control the releasing mechanism of spores through active wet and dry discharge. In the present paper, we simulate the concentration of fungal spores over the Indian region during three distinct meteorological seasons by combining a numerical model (WRF-Chem) with the fungal spore emissions based on land-use type. Maiden high-resolution regional simulations revealed large spatial gradient and strong seasonal dependence in the concentration of fungal spores over the Indian region. The fungal spore concentrations are found to be the highest during winter (0–70 μg m^{-3} in December), moderately higher during summer (0–35 μg m^{-3} in May) and lowest during the monsoon (0–25 μg m^{-3} in July). The elevated concentrations during winter are attributed to the shallower boundary layer trapping the emitted fungal spores in smaller volume. In contrast, the deeper boundary layer mixing in May and stronger monsoonal-convection in July distribute the fungal spores throughout the lower troposphere (~5 km). We suggest that the higher fungal spore concentrations during winter could have potential health impacts. While, stronger vertical mixing could enable fungal spores to influence the cloud formation during summer and monsoon. Our study provides the first information about the distribution and seasonal variation of fungal spores over the densely populated and observationally sparse Indian region.

1. Introduction

The Primary Biological Aerosol Particles (PBAPs), a subset of biogenic particles, often referred as bioaerosols, are ubiquitous in the atmosphere and include diverse biological material. PBAPs are primarily comprised of viruses, bacteria, fungal and fern spores, plant pollen, and fragments of plant and animal dander (Huffman et al., 2010; Despres et al., 2012; Huffman et al., 2013; and references therein), and vary in the size range of 0.01 μm for viruses to 100 μm for pollens (Jones and Harrison, 2004). Despite being mostly coarse mode particles, the prevalent winds could transport these PBAPs over large vertical distances. PBAPs also have the ability to influence the atmospheric system and hydrological cycle by acting as condensation nuclei for cloud and ice formation in the

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atmosphere (Huffman et al., 2010, 2012, 2013; Schumacher et al., 2013; Crawford et al., 2014; Poschl, 2005). Additionally, PBAPs have adverse impacts on biotracers public health, animals and agriculture (Fisher et al., 2012 and references therein). In order to assess the role of PBAPs towards aforementioned processes, information of their distribution, sources, transport, and interaction is essential on local and regional scale.

The primary sources of fungal spore emissions are plants, litter and decaying organic matter. The fungal spores are primarily emitted in the atmosphere by active processes resulting from osmotic pressure “canons” with very high g-force and surface tension catapults (Despres et al., 2012 and reference therein). Depending upon the age and atmospheric conditions, the diameter of fungal spores of various biological species may vary from ~1 to 50 μm with dominant size range of 2–10 μm (Elbert et al., 2007; Despres et al., 2012; Frohlich-Nowoisky et al., 2009, 2012). The broad range of fungal spore number and mass concentration in the atmosphere is ~10^4 m^{-3} and ~1 μg m^{-3}, respectively (Despres et al., 2012).

The potential effects of PBAPs, in particular of the fungal spores, which constitute large fraction of PBAPs, are not well understood, primarily due to lack of measurements with sufficient spatial and temporal coverage. In lack of measurements, the general circulation models have been used to investigate the distribution of fungal spores on the global scale (Heald and Spracklen, 2009). The study provides an insight about the distribution and transport of fungal spores, however, the knowledge about the sources and processes occurring from local to regional scales remain poorly understood mainly due to coarser resolution of the global models. The climatic and health impacts could be prominent and pertinent on the local/regional scales as compared to the global scales.

Indian subcontinent, home to about 18% of the total population of the world and with economy dominated by agriculture, is a region where to the best of our knowledge, no measurements and modeling studies on regional-scale have been performed. One of the largest agglomerations of human presence as well as highest pollution loadings is seen over the Indo-Gangetic plain (IGP) region in India (Fishman et al., 2003). The heavy monsoonal rainfall during June to September associated with the reversal of wind pattern is unique and specific to this region. The winds are mostly southwesterly during monsoon, which bring the cleaner marine air masses to the continental Indian region; whereas during winter and summer, the air masses mostly originate and reside over the continental region and are well exposed to the regional-pollution and the biomass burning (Sarangi et al., 2014). Considering the importance of such synoptic dynamics and the geographical extent of Indian region, the fungal spore concentrations are expected to have strong spatial and seasonal variations.

In the light of the above, we make the first attempt to simulate the spatial and seasonal variability in the fungal spores over the Indian region using a regional chemistry-transport model (WRF-Chem). The fungal spore emissions estimates derived based on land-use category are available in the literature (Sesartic and Dallafior, 2011). The simulations have been conducted for May, July and December representing three different seasons over India.

2. Methodology

2.1. Organic carbon as a proxy for fungal spore

The measurements reported so far revealed a dominant peak in PBAP concentrations in the size range of 2–4 μm (Huffman et al., 2010, 2012, 2013; Gabey et al., 2011; Toprak and Schnaiter, 2013; Schumacher et al., 2013; Healy et al., 2014). Fungal spores and bacteria are suggested to be the most dominant type of biological aerosols in this size rage (Hummel et al., 2015; Jones and Harrison, 2004; Despres et al., 2012; Fang et al., 2008). Measurements of Fluorescence Biological Aerosol Particles (FBAP) obtained with online measurement technique are considered to be the lower limit of PBAPs in this range and are broadly dominated by the fungal spores. Thus spores released by the fungi can be regarded as most abundant and strong source of PBAPs in the ambient atmosphere and making up considerable fraction of particulate matter (Zhang et al., 2015; Elbert et al., 2007). However, their presence may vary depending upon location, seasons, land use, and weather condition (Zhang et al., 2015).

The concentrations of mannitol and arabitol, the biotracers for fungal spores, have been used to derive the fraction of fungal spore in organic carbon (OC). The contribution of fungal spore to OC was reported to have varied from 8% at a suburban site in Vienna, Austria (Bauer et al., 2008) to 35% in Amazonian tropical rainforest, and as recently shown could account as high as 66% of the organic content in particulate matter in the size range of 2–10 μm in rural and urban areas. Under the assumption that fungal spores constitute the major fraction of OC in the tropical region (Bauer et al., 2002, 2008), we have used OC as proxy for fungal spores to simulate the spatial distribution and seasonal variation over the Indian region as described below.

2.2. Model set up

We have used the version 3.4.1 of the online regional chemistry-transport model Weather Research and Forecasting with Chemistry (WRF-Chem) to simulate the fungal spore concentrations over the Indian domain as depicted in 24 land-use category map shown in Fig. 1. As shown in Fig. 1 22°N is used to calculate the zonal average of fungal spore considering that this latitude represents the longest horizontal distance over India. WRF model is a state-of-the-art mesoscale numerical model popularly used for simulating regional meteorology and the air quality for both operational and research purposes. The meteorology and chemistry in WRF-Chem are fully consistent with each other and share the same horizontal and vertical grids, time-step, transport scheme and physics parameterizations (Grell et al., 2005). More details about the meteorology simulations by WRF model can be seen at http://www.wrf-model.org. Further details of the chemistry module of the WRF can be found at http://ruc.fsl.noaa.gov/wrf/WG11. The meteorology and air pollutants have previously been simulated using WRF-Chem model and simulation results were further validated using observational data over Indian region (Kumar et al., 2012a, 2012b).

The model simulation has been conducted at a horizontal resolution of 30 km × 30 km with 100 grid points in east-west and north-south directions and the model time step was kept as 3 min (which is 6 times the grid resolution to avoid violation of the CFL criterion for numerical stability). Model has 51 vertical levels with model top set at 5 hPa. 6-hourly meteorological initial and boundary conditions were taken from National Center for Environmental Prediction (NCEP) final analysis data (rda.ucar.edu/datasets/ds083.2). The model physics parameterization uses the Purdue Lin microphysics scheme (Lin et al., 1983), Rapid Radiative Transfer Model (RRTM) longwave radiation scheme (Mlawer et al., 1997), Goddard shortwave scheme (Kim and Wang, 2011), Monin-Obukhov surface layer scheme (Monin and Obukhov, 1954) with the Yonsei University (YSU) Planetary Boundary Layer (PBL) scheme (Hong et al., 2006), and the Noah Land Surface Model (Chen and Dudhia, 2001).

Various gas-phase and aerosol chemistry schemes are available in WRF-Chem to treat the atmospheric species depending upon the number of chemical species and reactions involved (Stockwell et al., 1997, 1990; Emmons et al., 2010; Carter and Heo, 2013; Ackermann