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Simulating aerosols over Arabian Peninsula with CHIMERE: Sensitivity to soil, surface parameters and anthropogenic emission inventories

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HIGHLIGHTS

- Modeling of aerosol optical depth using the chemistry transport model CHIMERE.
- Adaption of the CHIMERE model for the Arabian peninsula.
- Integration of new datasets on soil/surface properties and anthropogenic emissions.
- Significant improvement in AOD simulation with the new datasets.

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ABSTRACT

A three dimensional chemistry transport model, CHIMERE, was used to simulate the aerosol optical depths (AOD) over the Arabian Peninsula desert with an offline coupling of Weather Research and Forecasting (WRF) model. The simulations were undertaken with: (i) different horizontal and vertical configurations, (ii) new datasets derived for soil/surface properties, and (iii) EDGAR-HTAP anthropogenic emissions inventories. The model performance evaluations were assessed: (i) qualitatively using MODIS (Moderate-Resolution Imaging Spectroradiometer) deep blue (DB) AOD data for the two local dust events of August 6th and 23rd (2013), and (ii) quantitatively using AERONET (Aerosol Robotic Network) AOD observations, CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) aerosol extinction profiles, and AOD simulations from various forecast models. The model results were observed to be highly sensitive to erodibility and aerodynamic surface roughness length. The use of new datasets on soil erodibility, derived from the MODIS reflectance, and aerodynamic surface roughness length (z_0), derived from the ERA-Interim datasets, significantly improved the simulation results. Simulations with the global EDGAR-HTAP anthropogenic emission inventories brought the simulated AOD values closer to the observations. Performance testing of the adapted model for the Arabian Peninsula domain with improved datasets showed good agreement between AERONET AOD measurements and CHIMERE simulations, where the correlation coefficient (R) is 0.6. Higher values of the correlation coefficients and slopes were observed for the dusty periods compared to the non-dusty periods.

1. Introduction

Mineral dust is one of the dominant components of the total atmospheric aerosol loading (Kohfeld and Tegen, 2007). On average, an annual total of ~2000 Tg of dust is emitted in the atmosphere, and around 20% of these emissions are from the Middle-East region (Iran, north-eastern Iraq and Syria, and the southern Arabian Peninsula) (Shao et al., 2011). During its lifetime in the atmosphere, mineral dust has great impact on the Earth-Atmosphere system (IPCC, 2013), cloud formation (DeMott, 2003), air quality, visibility and human health (Giannadaki et al., 2014), and marine ecosystem (Al-Shehhi et al., 2014). These implications emphasize the importance of understanding the occurrence and intensity of dust events, as well as their spatiotemporal

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distribution. Though the observations (ground/satellite based) are the key to validating and refining the models; three dimensional dust forecast models with appropriate dust emission schemes and datasets can provide accurate AOD simulations over the domain of interest.

During the last few decades, a large number of regional and global models have provided dust forecasts. These include GOCART: Goddard Chemistry Aerosol Radiation and Transport model operated by National Aeronautics and Space Administration-Goddard Space Flight Center (Chin et al., 2000), MACC-ECMWF: Monitoring Atmospheric Composition and Climate model operated by European Centre for Medium-Range Weather Forecasts (Morcrette et al., 2009), MetUM: Unified Model from UK Met Office (Woodward, 2001), GEOS-5: Goddard Earth Observing System Model Version 5 (Colarco et al., 2010), and NGAC: NEMS-GFS Aerosol Component model from National Centers for Environmental Prediction (Lu et al., 2010), BSC-DREAM8b: Dust REgional Atmospheric Model operated by the Barcelona Supercomputing Center (Pérez et al., 2006), NMMB/BSC-Dust: non-hydrostatic multi-scale model operated by Barcelona Supercomputing Center (Pérez et al., 2011), DREAM-NMME-MACC: non-hydrostatic multi-scale model by the coupling between DREAM and MACC models, and CHIMERE: A multi-scale chemistry transport model for air quality and dust forecasts (Menut et al., 2005). These models were coupled online or offline with either short/medium ranges regional weather forecast models or large scale global climate models to simulate the mineral dust cycle. Global models reproduce the seasonal dust features at a coarse spatial resolution (1.5°–5°), while the regional models are efficient to simulate the mesoscale dust events. In addition, the regional models use more complex dust emission schemes as their resolution is closer to the small-scale dynamical processes. Furthermore, the comparison and validation with observations of dust events are better suited for regional models.

CHIMERE is one of the chemistry transport models dedicated to provide dust and air quality forecast at regional scale. Several sensitively analyses were carried out for CHIMERE using different: (i) meteorological data set (De-Meij et al., 2009), (ii) meteorological data grid resolution (Srivastava et al., 2014), (iii) soil and surface data sets (Menut et al., 2013, 2005), (iv) soil size distribution (Menut et al., 2005), (v) soil moisture data (Briant et al., 2014), and (vi) number of aerosol size bins (Foret et al., 2006). The dust emission parameterization scheme (Alfaro and Gomes, 2001) is found to be strongly related with the wind speed and therefore accurate meteorological parameter is an essential factor for realistic aerosol simulations (De-Meij et al., 2009). The spatial interpolation of the meteorological parameters is observed to reduce the accuracy of the simulated aerosol concentrations (Srivastava et al., 2014). In addition, Menut et al. (2013) have analyzed the sensitivity of the dust emission scheme in Northern Africa using different datasets of soil texture (LISA, STATSGO-FAO) and roughness length (LISA, ERS,USGS) and their results indicate that ERS (European Remote Sensing) and STATSGO-FAO data sets provide realistic spatial patterns of dust emission. Even though all these sensitivity studies have improved the performance of CHIMERE model in general, the fine-tuning of the model over the Arabian Peninsula with realistic datasets on soil and surface properties is virtually non-existent.

The objective of the study is to forecast the atmospheric dust over the Arabian Peninsula using the CHIMERE model. For this purpose, different configurations with new datasets describing soil/surface properties and emission inventories are tested to fine-tune the CHIMERE model over the domain. This adaptation process of the model includes: (i) default configuration with the built-in soil/surface properties at lower (500 hPa) and higher (200 hPa) vertical levels (ii) MODIS soil erodibility and ERS scatterometer derived surface roughness length (iii) MODIS soil erodibility and ERA-Interim surface roughness length (iv) keeping the latest configuration with EDGAR-HTAP anthropogenic emission inventories, and (v) nested runs at 9 km resolution with final configuration. These datasets are the best available database in view of the existing literature survey over the region. Since simulating the background dust-concentration in good accuracy is a challenge for any dust models rather than simulating strong dust storm events, we have selected August (2013), which has moderate dusty and normal days, for the adaption of the model. Qualitative and quantitative validations of the adapted model AOD simulation are performed using different satellites-based products (MODIS DB and CALIPSO vertical profiles), AERONET observations, and other forecast model outputs.

2. Methodology

2.1. CHIMERE model description

CHIMERE is an open access multi-scale Eulerian chemistry transport model mainly intended to produce hourly forecasts of several aerosol and pollutant gas species concentrations (Bessagnet et al., 2008; Chimere documentation, 2014). The concentrations are computed by solving the continuity equation for processes such as emissions, transport, deposition, chemical reactions, and aerosol dynamics. The selection of appropriate parameterization schemes for the aforementioned processes is generally based on previous modeling studies, as detailed in Chimere documentation (2014). The 3rd order Parabolic Piecewise method (PPM) is found to be the most accurate scheme for horizontal advection, while the 2nd order Van Leer scheme is mostly considered for vertical advection. A K-diffusion parameterization scheme is used for vertical turbulent mixing. The deposition module includes both wet (in-cloud and sub-cloud) and dry scavenging processes for aerosols in eight size bins. The aerosol hygroscopic growth factor is taken into account in the deposition processes using a thermodynamic equilibrium model (ISORROPIA) by computing the transition relative humidity between the phases.

CHIMERE accounts for five types of emissions: (i) biogenic emissions, (ii) sea-salt emissions, (iii) anthropogenic emissions, (iv) fire emissions, and (v) dust emissions. The biogenic emissions are calculated using the MEGAN model (Guenther et al., 2006), while the marine aerosol production is based on the scheme proposed by Monahan et al. (1986). The anthropogenic emissions are incorporated into the CHIMERE model domain using the EDGAR-HTAP global emission inventories, collected as a part of HTAP (Hemispheric transport of Air Pollutants project) (Janssens-Maenhout et al., 2012). Dust emissions are calculated using the parameterization scheme proposed by Alfaro and Gomes (2001) (referred to hereafter as AG2001). This dust emission scheme is well validated over the deserts of Middle-East and North-African region (Gherboudj et al., 2015; Menut et al., 2013; Mokhtari et al., 2012). The soil and surface parameters, such as land-use, soil composition (percentage of clay, silt and sand), soil erodibility, and surface roughness length (z_0), are required for the AG2001 scheme. While the soil composition over the world is provided from the STATSGO-FAO database, the soil erodibility and surface roughness can be derived from different sources.

2.2. Model domain

The CHIMERE model has been set up in one-way hourly nesting (no feed-back from inner to outer domain) configurations with 27 km and 9 km for the outer and inner domains, respectively. The