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Long-term (2003–2013) climatological trends and variations in aerosol optical parameters retrieved from MODIS over three stations in South Africa

K. Raghavendra Kumar [a,*], V. Sivakumar [b], Yan Yin [a], R.R. Reddy [c], Na Kang [a], Yiwei Diao [a], A. Joseph Adesina [b], Xingna Yu [a]

[a] Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, School of Atmospheric Physics, Nanjing University of Information Science and Technology, Nanjing 210044, Jiangsu Province, China
[b] Discipline of Physics, School of Chemistry and Physics, University of KwaZulu-Natal, Westville Campus, Durban 4000, KwaZulu-Natal, South Africa
[c] Aerosol and Atmospheric Research Laboratory, Department of Physics, Sri Krishnadevaraya University, Anantapur 515 003, Andhra Pradesh, India

HIGHLIGHTS

- A significant south-to-north latitudinal gradient noticed in AOD over South Africa (SA).
- AOD varies seasonally from low in the winter to high in dry seasons.
- A decadal negative trend observed in the annual mean AOD over all stations.
- Implemented pollution control measures as issued by SA legislation.

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ABSTRACT

The present study is aimed to analyze the spatial and temporal distributions, and trends and variations in aerosol optical properties during the last decade. For this we used the aerosol optical depth (AOD_{550}), Ångström exponent (AE, $\alpha_{470-660}$) and fine mode fraction (FMF) products derived from the Moderate resolution Imaging Spectroradiometer (MODIS) on board Terra satellite during the period December 2003–November 2013 over three different aerosol environments in South Africa (SA). The spatial pattern of annual mean AOD is characterized with high (low) AOD in the north (south) and with a moderate AOD in the central part of SA. A decadal decrease in AOD has been noticed by performing linear trend analysis over the three stations (Pretoria, Bloemfontein and Cape Town). The seasonal and inter-annual variability of AOD values over three locations of SA showed that the higher mean AOD values occurred during spring (September) and summer (January/February) seasons, whereas the lower values were found in the late autumn/early winter periods (June). On seasonal basis, the decadal climatological variations showed a decreasing trend in different seasons except during spring. The HYSPLIT back trajectory model was used to identify airmass transport pathways originated from aerosol source regions during the dry and wet seasons.

1. Introduction

The importance of aerosols in the Earth's climate has long been discussed in the scientific literature (Satheesh and Moorthy, 2005) which highlight the part they play in the radiation budget, air quality issues, and cloud microphysics (Charlson et al., 1992). Any changes in the atmospheric aerosol load result in associated altering of the global climate forcing by aerosols. The dominant uncertainty in the climate change, even by the best available general circulation models, is due to uncertainties in aerosols radiative forcing (IPCC, 2007) and lack of reliable measurements of aerosols on a global scale (Koukouli et al., 2010; Bennouna et al., 2013). To accurately assess this factor of climate forcing, detailed characterizations of aerosol microphysical, optical and radiative properties at different locations, which vary on many spatial and temporal scales, is required (He et al., 2012; Luo et al., 2013).

* Corresponding author.
E-mail addresses: kanike.kumar@gmail.com, krkumar@nuist.edu.cn (K.R. Kumar).

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Satellite remote sensing has provided the ability to retrieve aerosol properties over large areas in a continuous manner. It is able to serve as a surrogate measure for the monitoring of particulate matter air quality since ground-based measurements are sparse in many regions of the world (Alam et al., 2011). In recent years, among the different sensors, MODerate resolution Imaging Spectroradiometer (MODIS; Chu et al., 2003) has been widely used for atmospheric aerosol studies because it provides relatively long-term aerosol data (since early 2000), and employs very robust on board calibration techniques and cloud screening, thus providing aerosol optical depth (AOD) with high accuracy (i.e. $\pm$0.05 AOD under clear skies and $\pm$0.15 AOD under moderately contaminated atmosphere) over land (Remer et al., 2005), and has a nearly daily Earth coverage. In addition to AOD, MODIS also provides aerosol products related to aerosol size, such as fine mode fraction (FMF), effective radius (R_{eff}), and Ångström exponent (AE, α).

Recent satellite measurement studies have shown a likely decrease in the global optical thickness of tropospheric aerosols (Koukouli et al., 2010). Several studies have reported promising aerosol trend on regional scale based on MODIS Terra data. Prasad et al. (2006), Dani et al. (2012) and Sreekanth (2013) showed a sharp enhancement in AOD over different regions of Indian subcontinent, associated with increased urbanization and rapid industrialization. The studies by Koukouli et al. (2010) and Papadimas et al. (2008) found a significant decrease in MODIS AOD over Mediterranean region. Zhang and Reid (2010) also showed decadal decrease in AOD across different regions of the world associated with proper maintenance of air quality over the region. Panicker et al. (2012) reported significant decrease in AOD during last decade (2000–2010) over three stations in South Korea. Luo et al. (2013) observed positive and negative trends in AOD for the high and low AOD areas during 10-years of MODIS Terra observations over China. Most recently, Kanniah et al. (2014) also reported that the AOD shows a decadal decreasing trend over peninsular Malaysia. In this paper, we synthesize the decadal (December 2003–November 2013) datasets of aerosol optical properties obtained from MODIS Terra satellite to investigate spatial aerosol characteristics, and associated trends and changes in AOD over three selected stations in South Africa.

2. Study regions and satellite sensor

2.1. Regions of study

South Africa (SA) is known to be frequently exposed to local production of aerosols (i.e., emissions from automobiles, factories and burning activities including fossil fuels and burning of leaves, wood and trash) and forest fires. In addition, natural aerosols from dust and sea salt brought by wind all contribute jointly to the regional aerosol loading (Kumar et al., 2014). In order to derive the long-term climatological trends and variations, we have considered three stations over SA (see Fig. 1) for the present study which are representative of the three aerosol regimes (or environments) which includes: (1) Pretoria (PTR; 25.75°S, 28.19°E, 1271 m asl), a typically polluted urban/industrial area in the northern part of SA with significant anthropogenic and industrial activities and mineral dust, (2) Bloemfontein (BFN; 29.12°S, 26.22°E, 1395 m asl), a sub-urban and rural site with high vegetation located in the central SA directly influenced by smoke produced by biomass burning and (3) Cape Town (CPT; 33.92°S, 18.42°E, 1590 m asl), a remote coastal location in the southern border of SA characterized by very low aerosol loading.

2.2. MODIS satellite

In the present study simultaneous datasets of AOD (550 nm), Ångström exponent (AE, $\alpha_{470-660}$) and fine mode fraction (FMF) from MODIS were analyzed for a complete 10-year period between 2003 and 2013 used in order to evaluate the spatial distributions and seasonal, annual and inter-annual trends and changes over three locations of SA. The data products are retrieved at a spatial resolution of 1×1 as a part of MODIS Terra satellite sensor level-3 recent updated Collection 5.1 (C051) monthly gridded atmospheric data and are acquired from the website http://gdata1,sci.gsfc.nasa.

Fig. 1. Topographic map of South Africa over the African continent (shown in the inset) with three selected stations indicated with an oval (red) shape. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)