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Climatological analysis of aerosol optical properties over East Africa observed from space-borne sensors during 2001–2015

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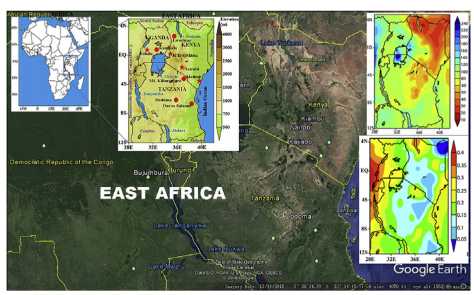
HIGHLIGHTS

- Long-term spatiotemporal distributions of aerosol properties were studied over East Africa (EA).
- High values of aerosol parameters were observed during the local dry seasons in EA.
- South-north and west-east changes in AOD were noted during the dry period.
- Impact factor analyses showed significant effect on the AOD distribution in EA.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study is aimed at analyzing spatial and temporal characteristics of aerosols retrieved from MODerate resolution Imaging Spectroradiometer (MODIS) and Ozone Monitoring Instrument (OMI) sensors over East Africa (EA). Data spanning for a period of 15 years during 2001–2015 was used to investigate aerosol optical depth (AOD_{550}), Ångstrom exponent ($AE_{470-660}$) and absorption aerosol Index (AAI) over EA and selected locations within EA. Validation results of MODIS-Terra versus the Aerosol Robotic NETwork (AERONET) AOD_{550} revealed that the former underestimated aerosol loading over the studied regions due to uncertainties in surface reflectance. The annual mean AOD_{550}, AAI, and $AE_{470-660}$ were found to be 0.20 ± 0.01, 0.81 ± 0.03, and 1.39 ± 0.01, respectively with peak values observed during the local dry seasons. The spatial seasonal distributions of mean AOD_{550} suggested high (low) values during the local dry (wet) periods. The high AOD values found along the borders of southwest of Uganda were attributed to smoke particles; while higher (lower) values of $AE_{470-660}$ (AAI) dominated most parts of the study domain. Low AOD (0.1–0.2) centers were located in high-altitude regions with relatively high vegetation cover over western and central parts of Kenya, and central and northern parts of Tanzania. Furthermore, latitudinal and longitudinal gradients in AOD_{550} showed a "southern low and northern high" and a "western low and eastern high" profile, respectively during JJA, as other seasons showed heterogeneous variations. Trend analysis revealed a general increase in AOD and AAI and a decrease in AE; while impact factors significantly affected AOD distribution over EA. HYSPLIT back

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trajectory analyses revealed diverse transport pathways originated from the Arabian Deserts, central Africa, and southwest of Indian Ocean along with locally produced aerosols during different seasons.

1. Introduction

Some of the most important climate forcing factors recognized globally include greenhouse gases, atmospheric ozone and atmospheric aerosols (Charlson et al., 1992; Zhang and Reid, 2010). Among these, atmospheric aerosols are one of the crucial constituents contributing to regional and global climate change (IPCC, 2013). They are emitted into the atmosphere or produced in the atmosphere from a wide variety of sources ranging from natural to anthropogenic. They have been described as the biggest source of uncertainty in climate change modeling and assessment (IPCC, 2013; Ramanathan et al., 2001). Aerosols affect climate directly by scattering and absorbing both incoming shortwave solar radiation and outgoing longwave terrestrial radiation (Rosenfeld, 2000). They modify cloud quantity, lifetime, and other properties (including cloud formation and precipitation) and therefore, indirectly change the Earth leaving radiation (Charlson et al., 1992). Aerosols are known to have significant and detrimental effects on human health (Gauderman et al., 2002). They decrease visibility and may lead to unfavorable conditions for transportation (Liao et al., 2015).

Because of the significance outlined above, extensive efforts have been devoted towards monitoring atmospheric aerosols using various techniques ranging from ground-based measurements to satellite remote sensing and aerosol modeling. Among the key aerosol parameters provided by various measuring techniques include aerosol optical depth (AOD), Ångström exponent (AE), and absorption aerosol index (AAI). AOD is a measure of aerosols distributed within a column of air from the Earth's surface to the top of the atmosphere (Panicker et al., 2012; Kumar et al., 2013, 2014; Adesina et al., 2016 and references therein) and constitute the main parameter used to assess the amount of aerosol burden in the atmosphere (Luo et al., 2013; Kumar et al., 2013 and references therein). AE is used to describe the spectral dependence of AOD on wavelength. Being inversely related to aerosol loading, it is a useful parameter in assessing the particle size of atmospheric aerosols (Russell et al., 2009; Luo et al., 2013; Bibi et al., 2015; He et al., 2016).

Since 1980, a large number of space-borne sensors such as Advanced Very High-Resolution Radiometer (AVHRR), Total Ozone Mapping Spectrometer (TOMS), MODerate resolution Imaging Spectroradiometer (MODIS), Multiangle Imaging Spectroradiometer (MISR), and Ozone Monitoring Instrument (OMI) (Diner et al., 1998; Remer et al., 2005; Torres et al., 1998) have provided excellent spatial and temporal characteristics of aerosols both at regional and global scales. Over the last decade, a number of studies have been devoted to assessing their spatiotemporal distributions, chemical, microphysical, optical, and radiative characteristics of aerosols and their research findings have been well documented by several previous researchers (Panicker et al., 2012; Alam et al., 2011; Luo et al., 2013; Mehta et al., 2016; Floutsi et al., 2016; He et al., 2016; Kang et al., 2016; Adesina et al., 2016). Alam et al. (2011) using data from a number of space-borne sensors reported maximum AOD values during summer over multiple cities investigated in Pakistan. Using 10 years of MODIS data, Panicker et al. (2012) reported a decrease in aerosol parameters (AOD, AE and Fine mode fraction (FMF)) over three contrasting environments in South Korea. While analyzing climatology of AOD using 10 years of MODIS data, Luo et al. (2013) and He et al. (2016) reported low AOD distribution in highly vegetated and sparsely populated areas; and high AOD distribution in densely populated and industrialized regions in China. Using global MODIS and MISR data, Mehta et al. (2016) reported increasing AOD trends in economically growing parts of Asia and decreasing trends over some parts of Europe, South America, and North America. Likewise, using C006 of MODIS-Aqua dataset, Floutsi et al. (2016) reported decreasing trend in AOD (0.0030/year) over Mediterranean basin. At the regional level, de Graaf et al. (2010) reported a greater influence of monsoon precipitation on the seasonal cycles of absorbing aerosols in Africa using satellite-based remote sensing data. Furthermore, Kumar et al. (2014) analyzed the spatiotemporal distributions and seasonal trends in aerosol products obtained from the MODIS data during 2003–2013 over three metropolitan cities in South Africa (SA). They observed a decadal decrease in the annual mean AOD over all the stations. A recent study by Adesina et al. (2016) reported a decreasing trend in AOD over two distinct locations in SA from the MODIS and MISR sensors. Within East Africa, among a number of findings Ngaina and Muthama (2014) examined a high aerosol loading during the local dry period (December–February and June–August) using the MODIS data.

East Africa (EA) is one of the most unique and interesting regions for studying the atmospheric aerosols. This is due to its distinct topographic variation, compounded with fast growing population, booming economy, and diverse climate. Despite this, it continues to lag behind the rest of the world in studies related to atmospheric aerosols. Very few studies have been conducted on long-term climatic analysis of aerosols parameters, and their interrelations with factors that are likely to affect their distribution and concentrations. Such knowledge is not only key towards achieving a better and in-depth understanding of spatial and temporal variations in aerosols; but also forms a basis for regional climate change studies which is a subset to global climate change. This work, therefore, presents a climatological analysis of aerosol optical properties over EA using data retrieved from the MODIS and OMI sensors during 2001–2015.

To better understand the uncertainties in the aerosol products retrieved from the MODIS satellite over EA, MODIS AOD has been validated against the Aerosol Robotic Network (AERONET) Sun photometer retrieved AOD. This is followed by a comprehensive analysis of the spatial and temporal (monthly and seasonal) distributions of aerosol parameters (AOD, AE, and AAI). Latitudinal and longitudinal variations in AOD were also analyzed to determine seasonal variations in south-north and west-east profiles. Long-term linear trend analysis was also carried out to determine the change in trends of aerosol parameters over EA during the study period. Further, the impact factors such as precipitation, Terrain and normalized difference vegetation index (NDVI) deemed to affect the distribution of AOD were studied through their relationships over EA. At last, the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used for examining the trajectory analyses in order to reconstruct the origins of air masses in different seasons. A short overview of the contents of this paper is as follows. Section 2 gives a description of the study area and seasonal synoptic meteorological conditions prevailing over EA as well as the data and methodology related to the present work.