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Discussion on linear long-term trends in aerosol and cloud properties over India and its surrounding waters

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Abstract

Spatial and seasonal variations in the linear long-term trend estimates of aerosol and cloud properties over Indian subcontinent and the surrounding oceanic regions of Bay of Bengal (BoB) and Arabian Sea (AS) are studied and discussed utilizing 12 complete years (2003–2014) of Moderate Resolution Imaging Spectroradiometer (MODIS) derived Aerosol and cloud products. Annual Aerosol Optical Depth (AOD) trends (in terms of AOD/year) are found to be positive (upward) over most of the study region with a spatial mean (median) value of ∼0.0065 (0.0064) and exhibited significant spatial and seasonal heterogeneity. Over Indian landmass AOD trends and their statistical significance decreased towards north along the Indo-Gangetic plains (IGP), for which the probable causes are discussed. Same kind of pattern in AOD trends has been observed as we move deeper into the oceanic regions of BoB and AS, away from Indian subcontinent. Observed trend patterns are discussed in light of the possible increase in emissions (over Indian landmass) and transported aerosol component, co-variation with trends in meteorological parameters and their possible feedbacks. Trend maps in seasonal AOD are shown to understand the aerosol build up over the study region under varying meteorological conditions. Seasonal AOD trend patterns resembled the synoptic scale wind circulation over the study region revealing that the upward trend in aerosol abundance over the adjoining oceanic regions of India is a result of effective transport of increasing emissions over India on to them. No significant trends in cloud properties (over the whole study region) are depicted in concert with that of aerosols, except over few pockets. The study also highlighted the role of large scale atmospheric processes in modulating the shape of the AOD time series over the regions with significant abundance of natural aerosol component (dust).

Keywords: MODIS; Linear trend; Aerosol Optical Depth; Cloud fraction

1. Introduction

High-resolution global trend estimates of atmospheric aerosol abundance has gained increasing attention from the scientific community due their potential climate impacts such as (i) perturbation to Earth's hydrological cycle (Ramanathan et al., 2005); (ii) inducing changes in regional precipitation patterns (Lau et al., 2006) etc. Due to the spatio-temporal heterogeneity and smaller lifetime of the atmospheric aerosols, high resolution (both in space and time) observations are required for accurate estimation of global trends. Aerosols not only perturb the radiative energy balance by interacting with solar and terrestrial radiation (Ramanathan et al., 2001) but also indirectly influence cloud microphysics and cloud radiative forcing (Haywood and Boucher, 2000) further effecting precipitation in a complex manner (Rosenfeld et al., 2008). Utilizing the long-term (1981–2004) radiation (all sky) data collected by India Meteorological Department (IMD) over 12 widely distributed stations over the Indian region, Kumari et al. (2007) showed a declining trend in surface reaching solar

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radiation. They concluded that the observed decreasing trends are heterogeneous in space and time and are function of AOD values. Using satellite derived climatological data for aerosols and rainfall over different regions of India, Ramachandran and Kedia (2013) provided observational evidence for the aerosol indirect effect by inferring decrement in cloud effective radius (CER) with increase in aerosols. Based on the analysis of the daily rainfall data set prepared by IMD, Goswami et al. (2006) showed significant rising trends in the frequency and the magnitude of extreme rain events and a significant decreasing trend in the frequency of moderate rain events over central India during the monsoon seasons from 1951 to 2000. Using the same data set, Dash et al. (2009) demonstrated changes in the frequencies of different categories of rain events (in terms of intensity and duration), suggesting weakening of the summer monsoon circulation over India. Due to the seasonally changing synoptic meteorological conditions over Indian subcontinent, the surrounding oceanic regions of BoB and AS are prone to get polluted with Indian emissions during particular seasons. All the above facts call for a comprehensive study addressing the build-up of aerosol abundance over Indian subcontinent and surrounding oceanic regions.

Estimation of global trends can be achieved by long-term aerosol observations by establishing a network of observatories worldwide, operating at a common protocol or by monitoring aerosols from space. Using aerosol data from a global network of ground based observatories (AErosol RObotic NETwork, an international initiation by NASA, Holben et al., 1998), Yoon et al. (2012) derived and discussed linear trends of Aerosol Optical Depth (AOD) and Angstrom Exponent (AE, a proportional index for inferring on the relative dominance of fine, submicron particles in the aerosol size spectrum produced mostly by anthropogenic activities). Several studies on long-term trends based on the data acquired by well-calibrated space-based passive remote sensing instruments (e.g., Sea-viewingWide Field-of-view Sensor – SeaWiFS, Multi-angle Imaging SpectroRadiometer – MISR, and MODIS) improved the understanding of the aerosol community on global aerosol build-up. Initially, satellite based trend analysis studies are limited to oceanic regions (Mishchenko et al., 2007; Zhao et al., 2008; Zhang and Reid, 2010). This is due to the fact that 90% of the top-of-the-atmosphere (TOA) radiance received by a satellite sensor over ocean comes from contributions of the atmosphere such as molecular and aerosol scattering, less than 10% of the signal is attributable to the ocean itself (Gordon, 1997). Consequently, the level of accuracy, precision, and long-term stability needed in radiometric measurements from such a sensor are much higher for ocean retrievals compared to that of land retrievals. With the recent advancements and improvement in the satellite retrieval algorithms/collections and rigorous on-orbit calibration techniques, trend estimates using satellite data have been extended over to land regions and are reported and discussed by several investigators (Yoon et al., 2011; Guo et al., 2011; Hsu et al., 2012; Ramachandran et al., 2012).

The present study aims at characterizing the trends in aerosol abundance (AOD) in conjunction with cloud properties over India and surrounding oceanic regions (5–40°N, 60–100°E) using MODIS/Aqua derived datasets. Few earlier studies reported quantitative trend estimates of AODs using variety of datasets (satellite and ground based observations) across various geographical locations over Indian subcontinent. Using primary data derived from network of observatories over India, Moorthy et al. (2013) depicted a near-linear increasing trend in AOD values (at 500 nm) during the period 1985–2012. Babu et al. (2013) using same set of database discussed in detail the potential causes for the observed trends and examined possible climate impacts. Dey and Di Girolamo (2011) using ten years of MISR data quantified seasonal AOD linear trends and indentified several hotspot regions over Indian subcontinent. Ramachandran et al. (2012) derived seasonal and annual mean trends in AODs using decadal (2000–2009) level 2 MODIS data. In addition to the above major studies, several investigators reported single station AOD trends over various mega cities of India (e.g., Kaskaoutis et al., 2012; Sreekanth, 2013; Lodhi et al., 2013). Up to my knowledge, no other study has reported the trends in cloud optical and microphysical properties in connection with that of aerosols. This aspect makes the present study unique over the study domain.

2. Data

Modern passive satellite sensors (POLDER, MISR, OMI and MODIS) have now collected sufficiently long data records to generate spatial and temporal aerosol climatologies. In the present study level 3 collection 5 (C005) aerosol and cloud data derived from MODIS satellite sensor are utilized. The first MODIS instrument was launched onboard the Terra satellite on 18 December 1999, with daytime equator crossing at 1030 LT, as part of the NASA's Earth Observing System (EOS) mission and the second one on 4 May 2002 on-board the Aqua platform with daytime equator crossing at 1330 LT. These are uniquely designed (wide spectral range, high spatial resolution, and daily global coverage) to observe and monitor the changes in the Earth's atmosphere. MODIS with its 2330 km viewing swath provides daily global coverage. Since February 2000, MODIS has been continuously acquiring measurements at 36 spectral bands between 0.415 and 14.235 μm with spatial resolution of 250 m, 500 m and 1000 m. Orbit stability and radiometric calibration are both rigorously maintained by the MODIS Characterization Support Team (MCST), to within ±2–3% at typical situations (Xiong et al., 2007). The current suite (C005) of MODIS aerosol products is derived separately over three environments: (1) dark-surface (far from sun glint) ocean targets (Remer et al., 2005), (2) dark-surface (vegetation, soils) land targets (Levy et al., 2007), and (3)