Remote Sensing of Environment 201 (2017) 297–313

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Evaluation of MODIS Collection 6 aerosol retrieval algorithms over Indo-Gangetic Plain: Implications of aerosols types and mass loading☆

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ARTICLE INFO

Keywords:
AERONET
AOD
Fine particulates
MODIS
Spatiotemporal comparison
IGP
Validation

ABSTRACT

This study evaluates the performance of MODerate resolution Imaging Spectroradiometer (MODIS) Collection 6 (C6) AOD retrieval algorithms, including Dark Target (DT) aerosol optical depth (AOD) at 3 and 10 km spatial resolutions, Deep Blue (DB) AOD at 10 km, and the merged DT-DB AOD at 10 km across the Indo-Gangetic Plain (IGP), South Asia. A total of 14,736 collocated Aqua MODIS C6 AOD at 550 nm were evaluated against AOD from six AERONET stations over IGP, measured during the satellite overpass (± 1 h) from 2006 to 2015. The effects of aerosol heterogeneity, in terms of both aerosol loading and the aerosol type, on the uncertainty of the satellite-borne AOD retrieval were examined. The DT algorithm at both resolutions (3 km and 10 km) overestimated the AOD by 14–25%, with only 51.37–61.29% of the retrievals falling within the expected error (EE). The DT 3 km algorithm underestimates the surface reflectance in comparison to the DT 10 km, with the latter outperforming the former both in terms of number of collocations and retrieval accuracy, especially over urban areas. The DB 10 km was able to retrieve AOD over both arid/desert regions and vegetated surfaces even under low aerosol loading conditions. Yet, its performance was still poor, with retrieval accuracy of 53.76%, low RMSE (0.214), and generally underestimated AOD across the IGP. The merged DT-DB AOD product was mostly dominated by DT retrievals (73%–100%), except over bright land surfaces and 56.03% of the merged DT-DB retrievals fell within the EE. The retrieval accuracy of MODIS C6 products was found to be strongly dependent on the estimated surface reflectance and the aerosol type. Across IGP, DB predicted the surface reflectance better while DT at both resolutions overestimated the surface reflectance at varying extent. For high aerosol loading conditions with varying aerosol size, retrieval accuracy of DT 10 km poses lower sensitivity while DT at 3 km exhibits larger uncertainty in estimating surface reflectance. In contrast, DB 10 km shows greater bias that depends on the aerosol size. For very high aerosol loading conditions, dominated by fine or mixed aerosols, all the algorithms have errors in the aerosol model. The DT 10 km, DB 10 km and the merged AOD performed almost equally within the threshold level while the DT 3 km showed the poorest performance in terms of retrieval accuracy and RMSE. We conclude that across IGP, DB 10 km AOD has the highest accuracy in retrieving fine mode aerosols while DT 10 km AOD has almost identical accuracy in retrieving varying aerosol types. For coarse dominated aerosols, when the dissimilarity between DT and DB remains highest, the merged AOD is found to have higher accuracy in retrieving AOD across IGP.

1. Introduction

Aerosol is an important component of the earth's climatic system which contributes to the single largest uncertainty in Earth's radiation budget (Boucher et al., 2013; Kumar et al., 2017a; Tripathi et al., 2007). These multi-component substances evolve either through natural processes (like biogenic and volcanic emissions) or by anthropogenic activities (like combustion of fossil fuel, industrial processes, and biomass burning) before being disperse horizontally and vertically by atmospheric circulation (Singh et al., 2017a; Banerjee et al., 2015). Numerous studies have provided evidences of aerosols' influences on lateral transfer of radiant energy within the atmosphere (Boucher et al., 2013), radiative effects due to aerosol–radiation interactions (Ramana et al., 2010; Chen et al., 2010), modifications of cloud microphysical

☆ Capsule: This study compares the Aqua MODIS C6 algorithms across IGP and assesses the quality of the products under varying aerosol loading and aerosol type conditions.

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http://dx.doi.org/10.1016/j.rse.2017.09.016
Received 19 March 2017; Received in revised form 16 August 2017; Accepted 15 September 2017
Available online 25 September 2017

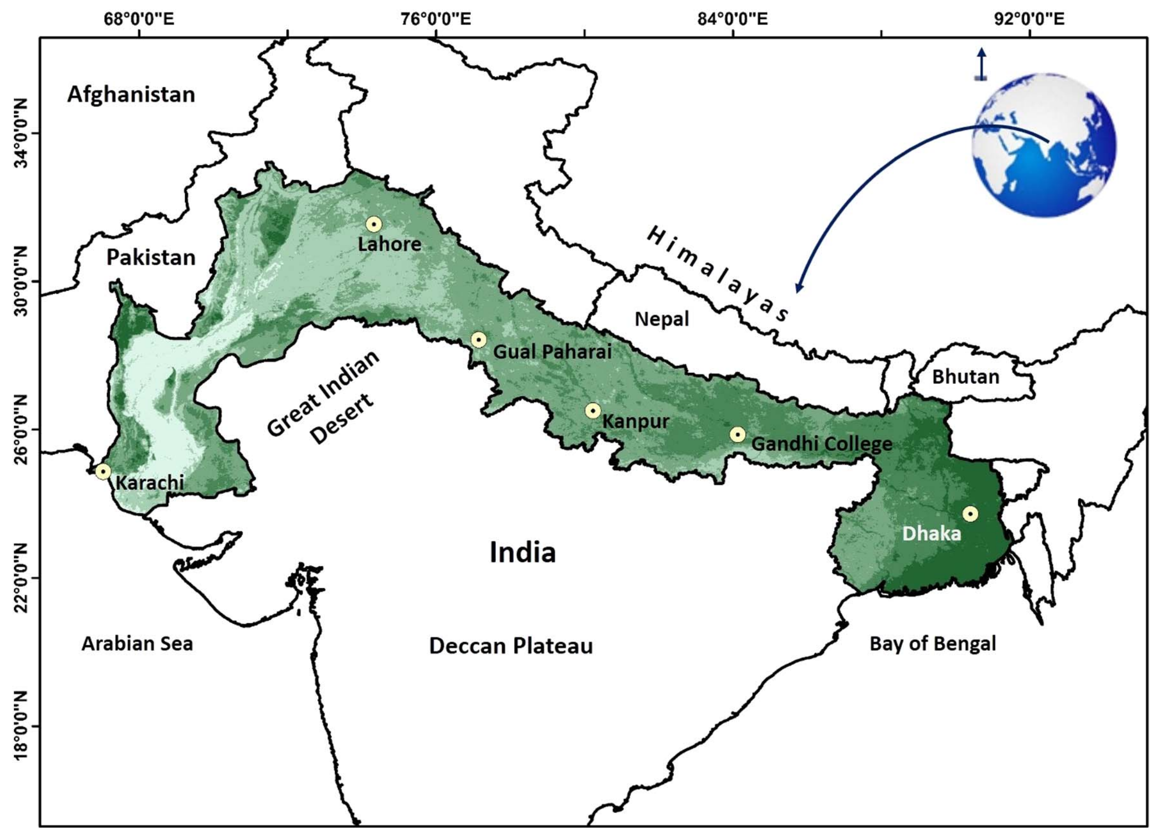

Fig. 1. Study area of the entire Indo-Gangetic Plain and the location of AERONET stations.
Note: The background image of IGP is the 2015 surface reflectance at 0.55 μm from MODIS (MOD09) The dark shade shows higher vegetated area while light shade depicts brighter surface.

properties (Seinfeld et al., 2016) and thereby influencing hydrological cycle (Ramanathan et al., 2001; Creamean et al., 2013), affecting regional food security (Burney and Ramanathan, 2014; Gupta et al., 2017) and ultimately deteriorating human health (Apte et al., 2015; Kumar et al., 2015a; WHO, 2014; Banerjee et al., 2017a, 2017b). The emissions, micro-physical properties, mixing-states of aerosols and its precursors provide unique evidences of its impacts on climate change. However, precise quantification of the aerosols feedback on climate still pose considerable uncertainties due to inconsistency across studies (Boucher et al., 2013) and high spatio-temporal variations in physio-chemical characteristics of aerosols (Kumar et al., 2017b; Sen et al., 2017; Banerjee et al., 2015). Although, ground-based measurement recognizes the optical and microphysical properties of aerosols, satellite based retrievals mostly complement this information by providing systematic retrieval on both local and global scales (Kaufman et al., 2005; Kahn et al., 2010) and by constraining aerosol parameterization in atmospheric models. Due to availability of diversified datasets, applications of satellite retrieved information has been exploited in numerous researches for estimating ground-level particulate concentration (Sorek-Hamer et al., 2013a), exposure and mortality studies (Van Donkelaar et al., 2010; Apte et al., 2015), crop yield/health simulation (Fang et al., 2011), recognizing pollution episodes (Kumar et al., 2016, 2017a) and forecasting of climate extremes (Sorek-Hamer et al., 2013b; Dey et al., 2004). However, satellite based information includes some fundamental errors due to instrumentation and retrieval algorithms which necessitate extensive validation against ground-based measurements (Li et al., 2014a, 2014b). Possible validation of satellite products will therefore help in reducing various uncertainties for recognizing aerosol ground-level concentrations, and for simulating aerosol-climate interactions and to forecast air quality at both the local and regional scales.

Among various sensors that routinely provide aerosols columnar properties throughout the globe, Moderate Resolution Imaging Spectrometer (MODIS) on board the Terra and Aqua satellites are recognized as the most extensively studied and validated one (Remer et al., 2008; Levy et al., 2010; He et al., 2017). The MODIS sensor observe the earth from 700 km altitude with ± 55° view scan, having a swath of about 2330 km and covering nearly the entire globe in every 1 to 2 days, with 16 days of repeat cycle. It employs three separate operational algorithms for retrieving aerosol properties over land and oceans: the Dark Target (DT) algorithm over land, the DT algorithm over ocean and the Deep Blue (DB) algorithm over land. Both collection 5 (C5) and 5.1 DT and DB algorithms have been evaluated extensively on the regional scale (Li et al., 2007; Sayer et al., 2014), over IGP (Bilal et al., 2016) and on the global scale (Remer et al., 2008; Levy et al., 2010). The evaluation of MODIS Collection 6 (C6) data is still limited (Sayer et al., 2014; Bilal and Nichol, 2015; Nichol and Bilal, 2016). Recently launched C6 products contain refinements in terms of retrieving high radiometric quality of MODIS top-of-atmosphere (TOA) radiance and observations of reported contextual biases of the previous algorithms (Levy et al., 2010; Shi et al., 2013). Additionally, in order to recognize the aerosol climatology in a finer scale, a new daily global DT AOD data product with 3 km spatial resolution (MYD04_3K; Remer et al., 2013) is available in addition to standard DT (Levy et al., 2013) and DB (Hsu et al., 2013) AOD at 10 km resolution. The 3 km DT product is expected to perform better, especially in severely polluted atmosphere and for identifying exposure gradients over urban regions (Remer et al., 2013; He et al., 2017). To date, very few attempts were performed to evaluate the 3 km AOD products on a global scale (Remer et al., 2013), in urban/semi-urban regions (Munchak et al., 2013), and over specific regions (He et al., 2017; Nichol and Bilal, 2016; Ma et al., 2016). All these studies emphasized the need to evaluate the new product for other geographical regions. Further, C6 is also unique in merging scientific data sets (SDS) by including a 'best of' both DT and