

***Interactive comment on “Contrasting aerosol trends over South Asia during the last decade based on MODIS observations” by D. G. Kaskaoutis et al.***

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Reply to the comments made by Mr. Sreedhar

General Comments:

Trends in aerosol loading are gaining increased interest due to its importance to global climate change. However, I do not favour the use of satellite data to study trends in aerosols over land due to the large uncertainties involved in the satellite retrieval of aerosol optical depth (AOD) over land. These are attributable to the complex (seasonally and annually changing) surface reflectance patterns, cloud contamination, and

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aerosol models used in the retrieval methods. The space-based remote sensing of aerosols encounters difficulties in retrieving aerosol properties over land. Difficulty in accounting for the changes in surface reflectance as a consequence of land-use changes over a rapidly growing country like India poses another problem for retrieval of optical depths for trend analysis.

Authors: Given a choice with the ground and satellite observations, ground observations will be favoured in compare to satellite data, however, due to various limitations (such as resources, high skilled man power, power availability), ground data at a very close spatial and temporal scale is lacking and as a result the scientific community is more dependent on the satellite observations. It is true that large uncertainties exist in the retrieval of AOD over land compared to oceanic regions. On the other hand, MODIS retrievals over land have been increasingly available over the globe and AOD retrievals have been significantly improved after long-term comparisons with ground-based AERONET data. The aerosol models used in the retrieval algorithms as well as the reflectance modeling have been significantly improved and the aerosol optical properties corresponding to aerosol size (Angstrom exponent, fine-mode fraction, etc) now concern of larger discrepancies, which are not used in the present work. Especially over India, several studies have dealt with comparison between ground-based observations and satellite data retrievals (Jethva et al., 2005, 2007; Prasad and Singh, 2007; Ramachandran, 2007, Ramachandran and Cherian, 2008; Kharol et al., 2011; Shaiganfar et al., 2011). Some of the above studies also used MODIS-AOD retrievals for analyzing the aerosol trends over the area, so we do not agree with Sreedhar that MODIS is incapable for analyzing AOD trends over land. Recently, Dey and di Girolamo (2011) have used MISR retrievals for AOD trends over India showing similar trends to ours. Furthermore, we note at several places throughout the manuscript that the results regarding AOD trends can be considered rather qualitatively and not quantitatively. The whole analysis has shown that these trends depend on the year-to-year AOD variations, whose influence in the retrievals are much larger than the uncertainties in the AOD values associated with the changes in surface reflectance, emissivity, etc.

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On the other hand, in the 10-year period land use land cover changes able to affect strongly the satellite retrievals are not expected especially over the large pixel areas of MODIS satellite. However, all these aspects pointed out by Sreedhar are discussed in detail in a separate section in the revised manuscript.

Comments: Zhang et al., GRL, (2005), Kahn et al., JGR (2007), Shi et al., ACPD, (2010), Levy et al., ACPD, (2010) and several others have suggested that one must be wary of mistakenly interpreting noises and biases in satellite aerosol products as legitimate signals in long-term trends analysis. Such studies would also be inundated by calibration issues. Despite the increased proficiency and use of closer-to-realistic models in the retrieval algorithms, several studies have shown that discrepancies still exist between (sensor to sensor) retrieved aerosol optical depths even over ocean regions (see Jeong et al., JGR, 2005). In summary, retrieval of aerosol optical depth over land continues to be a challenge especially over complex terrains such as Himalayan region and plains having large surface heterogeneity (Indo-Gangetic Plains, for example). Ground-based sun photometers (preferably a network such as AERONET established by NASA) and/or in situ measurements of aerosol mass are best suited for such a study.

Authors: As noted above, satellite remote sensing for analyzing AOD trends over land is a real challenge and we strongly agree that discrepancies may be also revealed between the different sensors. However, as we stated in the manuscript, for a qualitative approach such retrievals can be used especially in the case that MODIS results (this study) are in general agreement with MISR and AERONET regarding the declining AOD trends over IGP during pre-monsoon and monsoon months. We thank Mr. Sreedhar for suggesting some of important papers which are included in the revised manuscript.

Comments: There have been several publications and reports on aerosol trends over India. A recent review paper by Lawrence and Lelieveld (2010) discusses a figure adapted from an Indian Ocean Experiment (INDOEX) publication (JGR, 2002, Fig. 10).

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They show that aerosol optical depths over India increase from 0.2 to 0.4 during 1986 to 1999 period based on ground-based sun photometer data. Recently, Moorthy et al., 2009 (WCC-3, Climate Sense, World Meteorological Organization, ISBN 978-92-63-11403-5, 2009) have shown an increasing trend in AOD using data over two decades based on data from a network of sun photometers from India. Zhang and Reid, JGR (2010) reported increasing trend in aerosols over oceanic regions adjacent to Indian subcontinent. Central Pollution Control Board (CPCB), Government of India is executing a nation-wide programme of ambient air quality monitoring known as National Air Quality Monitoring Programme (NAMP). The network consists of 342 monitoring stations covering 127 cities/towns in 26 States and 4 Union Territories of the country. A recent report by Ministry of Environment and Forests (MoEF), Government of India (State of Environment, Report, 2009; [http://moef.nic.in/soer/2009/SoE%20Report\\_2009.pdf](http://moef.nic.in/soer/2009/SoE%20Report_2009.pdf)) using data from these monitoring sites have reported a decreasing trend in particulate mass contraction over several cities while no trend was observed over many other locations. Therefore, reports on decreasing trend in aerosols over India is not a new result.

Authors: In the Introduction section, we have also cited several papers regarding AOD trends over India using MODIS retrievals. We thank Mr. Sreedhar for the valuable comments and suggestions of some more studies that are included in the revised manuscript. Infact, while writing this paper, we did not find any paper highlighting decreasing aerosol trends over India either from satellites or ground-based measurements. Now the studies by Dey and di Girolamo (2011) and the report of MoEF as mentioned by Mr. Sreedhar are very important. We thank Mr. Sreedhar for pointing out these two important references.

Comments: I am skeptical about the applicability of GOCART data in trend analysis. First of all, comparison of Gocart data over India with measurements show large discrepancies. Secondly, trends in any model output depends on the input used.

Authors: Actually, GOCART simulations and ground-based AOD retrievals over India

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have large uncertainties (see Chin et al., 2009), however both agree to the monthly and yearly variations. In the present manuscript, GOCART simulations are used in order to justify our statements for decreasing dust activities and dust AOD over south Asia. After analyzing model SPRINTARS results we also concluded to similar findings about dust attenuation. Of course, the model outputs depend on inputs; however, the aerosol emission rates in both models are simulated with considerable accuracy. On the other hand, GOCART simulations and comparisons with MODIS AODs are well analyzed by several workers, we have cited these studies in the manuscript. So, we fail to understand why GOCART is not applicable for such retrievals as pointed out by Mr. Sreedhar. Once again, we clearly state that the GOCART model is used qualitatively to justify the dust attenuation over south Asia that is responsible for the declining trend in MODIS AOD over IGP. GOCART simulations were found to be in general agreement with MODIS retrievals and that is main aim of this paper.

Comments: In summary, this paper represents only a follow up study. There have been several publications and reports on aerosol trends over India. Large uncertainties involved in aerosol optical depth retrieval over land (which is seasonally changing as well as a function of location) without validation make the conclusions unconvinced.

Authors: In the revised manuscript a quick “validation” of the present results is given by comparing with the MISR retrievals and the Kanpur-AERONET AOD trends. On the other hand, the MODIS results (present study) are in agreement with previous studies analyzing the AOD trends over India either by using satellite sensors or ground-based instrumentation. However, the present study is the very first that uses the MODIS retrievals and trends over Indian sub-continent covering the last decade and can constitute the basis for several studies in the future.

Specific Comments: Abstract: The authors state that "The present study shows an evidence of a decreasing AOD<sub>550</sub> trend over the densely-populated Indo-Gangetic Plains (IGP) during the period April–September, which has never been reported before". This aspect is already well documented in several reports. See the CPCB report, 2009

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(cited in general comments).

Authors: In the revised manuscript we have avoided such statements, since now there are published articles showing declining trend. Once again, we are grateful to Mr. Sreedhar for providing information about the CPCB report.

Comments: Aerosol Optical Depths: In this paper, authors have used MODIS-derived optical depth. Authors should validate the AOD product (2001-2009) using data from ground-based sun photometers, but not limited to just one AERONET site. Earlier studies have showed that difference between MODIS AOD with that measured by ground-based sun photometers over Indo-Gangetic basin is seasonally dependent and also vary from location to location. In this context authors may justify use of satellite data in trend analysis.

Authors: The comparison between MODIS and Kanpur-AERONET AODs has been reported by several authors showing the seasonal dependence in the correlations. Other AERONET sites over the region have a limited time period for such retrievals and this is beyond the scope of the present analysis. However, all these aspects are well documented in the Data Section of the manuscript. Note also that the present manuscript is too long to further include additional analysis on these aspects. The justification for the use of MODIS retrievals for AOD trend analysis is based on MODIS capability to represent aerosol field and spatio-temporal distribution over Indian sub-continent, numerous references are cited in the manuscript dealing with spatio-temporal distribution.

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