Satellite (GOSAT-2 CAI-2) retrieval and surface (ARFINET) observations of Aerosol Black Carbon over India

Mukunda M. Gogoi et al., https://doi.org/10.5194/acp-2022-555

Response to Referee #1

The authors use extensive measurements to retrieve BC mass concentrations and compare them with satellite-retrieved BC mass concentrations. This paper contributes to better understanding of spatial and temporal distributions of BC concentrations over the Indian regions. I believe the paper should be considered for publication only after addressing the concerned expressed below.

We appreciate the summary evaluation of the reviewer and agree to the observations. Following the valuable comments and fruitful suggestions for improving the quality of the manuscript, we have revised it incorporating the review comments of all the reviewers. Our point wise response to each of the comment is given below in bold letters, below the respective comments.

Major Issues:

1. At first, it is difficult to read this paper because of unclear and unappropriated sentences. For readers to understand clearly, many sentences need to be polished with clear and concise structure including appropriate English.

Response: We are sorry for the lack of clarity in certain areas. We have revised the manuscript and taken care of the clear and concise structures as suggested by the reviewer.

2. Secondly, this paper mostly describes how much satellite and ground-based measurement agree or not. The authors need more descriptions about why they are different and what science is behind it. For example, you may investigate less consistency between satellite-retrieved and ground-based BC concentrations in JJA compared to DJF and MAM due to the cloud contamination or a deficit of data availability during monsoon.

Response: We thank the reviewer for the valuable suggestion. Adequate descriptions are provided to explain the less consistency between satellite-retrieved and ground-based BC in the revised manuscript, as given below.

Line 318-334: "Based on the above observations it appears that the spatio-temporal distribution of BC as obtained from satellite retrievals show better consistency with the surface measured BC over the Indian region during DJF and MAM. As the rise in temperature caused by increased solar heating during MAM and JJA results in strong thermal convection over the Indian region (especially in the northern part), this leads to dilutions of near-surface aerosol concentrations. Depending upon the geographic position and local meteorological conditions, the strengths of convections vary from one location to the other. As the satellite retrieve BC is 1-km column average BC concentrations, the variation in the vertical distribution of BC may lead to variable associations between satellite-retrieved and surface measured BC concentrations at distinct geographic locations of India. More details on these aspects are discussed in the subsequent sections. Apart from the vertical heterogeneity, the various other

factors that may lead to discrepancy in the satellite retrieval of BC include the bias caused by the cloud-screening algorithm, especially during JJA when the cloud cover over the Indian region is extensive. Moreover, CLAUDIA3 is unable to detect optically thin clouds. Lack of accurate detection of cloud shadow also can cause overestimation in the retrieve values of aerosol parameters from CAI-2 measurements. Since the revisiting time of CAI-2 is long (6 days), the minimum reflection criterion based on the consideration of 2 months data (one month prior and after the measurement days) can lead to large uncertainty in cloud-shadow detection, hence the accurate estimation of minimum surface reflectance. Subsequently, these errors can propagate and add uncertainty in the accurate estimation of aerosol parameters from CAI-2 measurements."

Minor Issues and specific comments:

Page1 L11: Is the acronym of ARFINET correctly located and explained? Aerosol Radiation Forcing over India NETwork (ARFINET)

Response: Yes, Aerosol Radiation Forcing over India NETwork (ARFINET) of aerosols observatories is clearly mentioned.

P1 L12: revealed -> reveals

Response: Complied with

P1 L17: that of other in-situ -> those of other in-situ

Response: Complied with

P1 L18: satellite retrieval shows -> satellite retrievals show

Response: Complied with

P1 L33: However, the very challenging task is to accurately retrieve -> However, it is challenging is to accurately retrieve

Response: Complied with

P2 L42: have not addressed so far -> have not been addressed so far

Response: In the revised manuscript, the sentence is modified as

"… the retrieval of BC from satellite-based radiation measurement is very limited."

P2 L50: 10-sepctral bands -> 10-spectral bands

Response: Complied with

P2 L50-51: use full word and abbreviation of UV, VIS, and NIR

Response: Complied with

P2 L59: to develop periodic and accurate estimates of aerosol radiative forcing over India and assess their impacts on regional and global climate, taking into account their heterogeneous properties in space, time and spectral domains -> to develop periodic and accurate estimates of aerosol radiative forcing over India, assess their impacts on regional and global climate, and take into account their heterogeneous properties in space, time and spectral domains

Response: Complied with. The sentence is modified as:

"In the ARFINET, the main objective of the measurements of various aerosol parameters (e.g., columnar aerosol optical depth, BC mass concentrations, etc.) is to characterize their heterogeneous properties in space, time and spectral domains, develop periodic and accurate estimates of aerosol radiative forcing over India, and assess their impacts on regional and global climate."

P2 L71: remove etc.

Response: Complied with

P3 L95: the surface albedo is derived by performing a correction removing the influence of atmospheric molecular scattering (Rayleigh scattering) -> the surface albedo is derived by removing the influence of atmospheric molecular scattering (Rayleigh scattering)

Response: This section is now modified in the revised manuscript as

"After cloud and cloud shadow correction, the influence of atmospheric molecular scattering (Rayleigh scattering) is corrected from the minimum reflectance data."

P3 L98: single scattering and multiple scattering -> single- and multiple-scattering

Response: Complied with

P3 L101: inversion algorithm developed by Hashimoto and Nakajima (2017) is used. -> inversion algorithm (Hashimoto and Nakajima, 2017) is used.

Response: Complied with

P3 L108: This sentence should be clearly stated.

aerosol light absorption (or single scattering albedo - SSA) -> aerosol light scattering (or single scattering albedo - SSA)

If you want to describe aerosol light absorption, you can use co-albedo or 1-SSA instead of SSA.

Response: Complied with. We have maintained the consistency with aerosol light scattering (or single scattering albedo - SSA).

P4 L131: Does "several sensitivity studies" means studies you performed? If not, add references.

Response: Sorry for the confusing statement. The reference "Hashimoto and Nakajima, 2017" is included.

P4 L148: Detail about the aethalometer uncertainty and correction of raw-data is available in Gogoi et al., (2017). The overall uncertainty in BC mass measured by the Aethalometer is estimated at about 10%. -> The overall uncertainty in BC mass measured by the aethalometer is estimated at about 10% and more details are available in Gogoi et al., (2017).

Response: Complied with

P5 L161: MAE = 10 m^2g^{-1} is used. -> MAE = 10 m^2g^{-1} is assumed (add references).

Response: Complied with. The following citation is included:

Kondo, Y., Sahu, L., Kuwata, M., Miyazaki, Y., Takegawa, N., Moteki, N., Imaru, J., Han, S., Nakayama, T., Oanh, N. T. K., Hu, M., Kim, Y. J., and Kita, K.: Stabilization of the Mass Absorption Cross Section of Black Carbon for Filter-Based Absorption Photometry by the use of a Heated Inlet, Aerosol Science and Technology, 43, 741-756, https://doi.org/10.1080/02786820902889879, 2009.

P5 L167: You mentioned, “As the ambient BC in the atmosphere is mostly aged in nature”

It is a vague sentence for the reason of “a value of MAE = 10 m^2g^{-1} is used” since BC is not aged in nature if it is just released from biomass burning.

Response: We thank the reviewer for pointing out the vague statement. We have revised the sentence as

“For estimating σ_{abs} for the columnar content of BC, a constant value of mass absorption efficiency, MAE = 10 m^2 g^{-1} is assumed (Kondo et al., 2009).”

P5 L175: winter, pre-monsoon, and monsoon respectively. -> winter, pre-monsoon, and monsoon, respectively.

Response: Complied with

P5 L177: You should add one more figure or add text into Fig. 1 to indicate each region like HIM, IGP, NEI, NWI and so on. Although it is written in the supplement, this straightforward figure would help readers to understand your figure better.

Response: Complied with the suggestion. We have included the following figure in the revised manuscript, clearly showing the regions of HIM, IGP, NEI, NWI, CI, PI and IL.

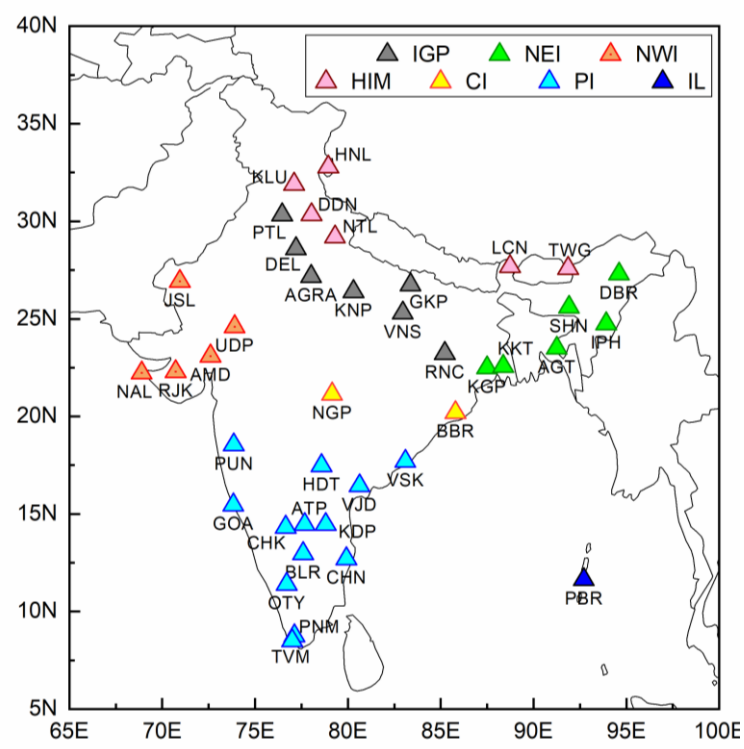

Figure-1: The network of aerosols observatories over India, distributed in the Indo-Gangetic Plains (IGP); North-eastern India (NEI); North-western India (NWI); Himalayan, sub-Himalayan and foothills regions (HIM), Central India (CI), Peninsular India (PI) and Island Locations (IL). More details about the ground-based observational locations in the ARFINET are provided in Supplementary Table-T1.

P5 L195-197: You mentioned satellite retrievals and surface observations of BC are more consistent in DJF and MAM than JJA. Is less consistency in JJA caused by cloud contamination during monsoon? Or how many data used for this analysis for each season? Are the number of data used during monsoon fewer compared to other seasons?

Response: We are thankful to the reviewer for the valuable suggestion. The discussions regarding the associations/ discrepancy between satellite-retrieved and surface measured BC are modified in the revised manuscript. The following section is also added to highlight the possible causes of higher discrepancy in the spatio-temporal distribution of BC over the Indian region during JJA as compared to that during DJF and MAM.

<u>Line 318-334</u>: "Based on the above observations it appears that the spatio-temporal distribution of BC as obtained from satellite retrievals show better consistency with the surface measured BC over the Indian region during DJF and MAM. As the rise in temperature caused by increased solar heating during MAM and JJA results in strong thermal convection over the Indian region (especially in the northern part), this leads to dilutions of near-surface aerosol concentrations. Depending upon the geographic position and local meteorological conditions, the strengths of convections vary from one location to the other. As the satellite retrieve BC is 1-km column average BC concentrations, the variation in the vertical distribution of BC may lead to variable associations between satellite-retrieved and surface measured BC concentrations at distinct geographic locations of India. More details on these aspects are discussed in the subsequent sections. Apart from the vertical heterogeneity, the various other factors that may lead to discrepancy in the satellite retrieval of BC include the bias caused by the cloud-screening algorithm, especially during JJA when the cloud cover

over the Indian region is extensive. Moreover, CLAUDIA3 is unable to detect optically thin clouds. Lack of accurate detection of cloud shadow also can cause overestimation in the retrieve values of aerosol parameters from CAI-2 measurements. Since the revisiting time of CAI-2 is long (6 days), the minimum reflection criterion based on the consideration of 2 months data (one month prior and after the measurement days) can lead to large uncertainty in cloud-shadow detection, hence the accurate estimation of minimum surface reflectance. Subsequently, these errors can propagate and add uncertainty in the accurate estimation of aerosol parameters from CAI-2 measurements."

P6 L204: better associations -> better agreement

Response: Complied with.

P6 L205: the association between the two data sets -> the correlation between the two data sets

Response: Complied with.

P6 L205: Thus, despite satellite retrievals during winter and pre-monsoon months showing the regional hotspots of BC over India fairly well, there appears to be a lack of consistent associations between the two datasets in winter at some of the ARFINET observational sites. -> Thus, satellite retrievals and surface observations show good agreement at the regional hotspots of BC over India during wither and pre-monsoon months. However, there are a lack of consistency between the two datasets in winter.

Response: Complied with. We have modified the sentence as:

"This indicates that even though satellite retrievals and surface observations show good agreement at the regional hotspots of BC over India during winter and pre-monsoon months, there is a lack of consistency between the two datasets in winter at some of the other ARFINET observational sites."

P6 L208: The above observations point to -> The discrepancies between satellite retrievals and ground-based observations can be attributed to

Response: Complied with.

P6 L215: Do not use "Despite this" and use specific words

Response: We have removed the term "Despite this"

P6 L215: the satellite retrievals differ from surface measured BC -> the satellite-retrieved BC differ from surface-measured BC

Response: Complied with.

P6 L228: we will now examine simultaneous day-to-day values -> we examine simultaneous day-to-day concentrations

Response: Complied with.

P6 L223-L225: This sentence needs to be polished.

Response: Complied with. The sentence is modified as:

<u>Lines 359-365</u>: "In general, the surface measurements of BC concentrations over the entire Indian region show a gradual decline from its highest values in DJF (2.54 ± 0.11 µg m-3) through MAM (2.06 ± 0.47) to its lowest value in JJA (1.11 ± 0.17 µg m-3). Similar to this, the 1-km column average satellite retrieved BC also show highest BC concentrations over the collocated locations of India during DJF and their gradual decline in MAM. However, the satellite retrieved BC are found to be higher in JJA than in MAM, as opposed to the pattern seen in the case of surface measured BC. These observations hint again the discrepancy between satellite retrievals and surface measured BC in JJA, while their absolute magnitudes and regional distributions are nearly consistent during DJF and MAM in most locations."

P7 L239: play important role -> play an important role

Response: Complied with.

P7 L242: Add references of ERA5

Response: Complied with. The following reference is included.

"Hersbach H., Bell, B., Berrisford P. et al.: The ERA5 global reanalysis. Quarterly Journal of Royal Meteorological Society, 146, 1999–2049, https://doi.org/10.1002/qj.3803, 2020."

P7 L246: in all three periods of DJF, MAM and JJA -> during all periods

Response: Complied with.

P7 L249: It has also been observed that absolute differences between the two data sets -> Absolute differences between the two data sets

Response: Complied with.

P7 L249: peninsular Indian locations -> PI

Response: Complied with.

P7 L251: It is further evident from the figure -> It is further evident from Fig. 6

Response: Complied with.

P7 L259: Provide the reason of the sentence "Especially, the association between the two data sets significantly improves in JJA."

Response: We sincerely thank the reviewer for suggesting a very important point to include in the discussions. Accordingly we have elaborated the discussion as given blow.

Line 389-405: "During winter, even though the abundance of BC is confined near to the surface due to shallow PBL condition, the noon time PBL is much extended (close to or beyond 1-km) over most of the Indian locations (the spatio-temporal variability in PBL height is shown in supplementary Fig. S6). Thus, BC_{SUR-N} follows the same general trend as the BC_{SUR}, indicating that noon-time surface measured BC concentrations during winter are similar to the 1-km column average BC. During MAM, the locations with PBL heights extended above 1-km are found to show good association of BC_{SAT} with BC_{SUR-N} than that of BC_{SAT} with BC_{SUR}. In JJA, the height of PBL is found to be highly region specific. At some of the locations, the PBL is much above 1-km (e.g., CHN and KDP), while some other locations show the opposite pattern (i.e., TVM, PBL height below 1 km). The locations with PBL heights below 1-km are found to show lower absolute difference between BC_{SAT} and BC_{SUR-N} than that between BC_{SAT} and BC_{SUR}. However, it is also to be noted that the simultaneous data of satellite-retrieved and surface measured BC are less in JJA as compared to DJF and MAM. Overall, it is observed that, in most of the locations, the absolute difference between BC_{SAT} and BC_{SUR-N} is lower than that between BC_{SAT} and BC_{SUR}. This leads to better correlation between BC_{SAT} and BC_{SUR-N}, especially during JJA where the correlation between BC_{SAT} and BC_{SUR-N} is much better (R ~ 0.61) than that between BC_{SAT} and BC_{SUR} (R ~ 0.38)."

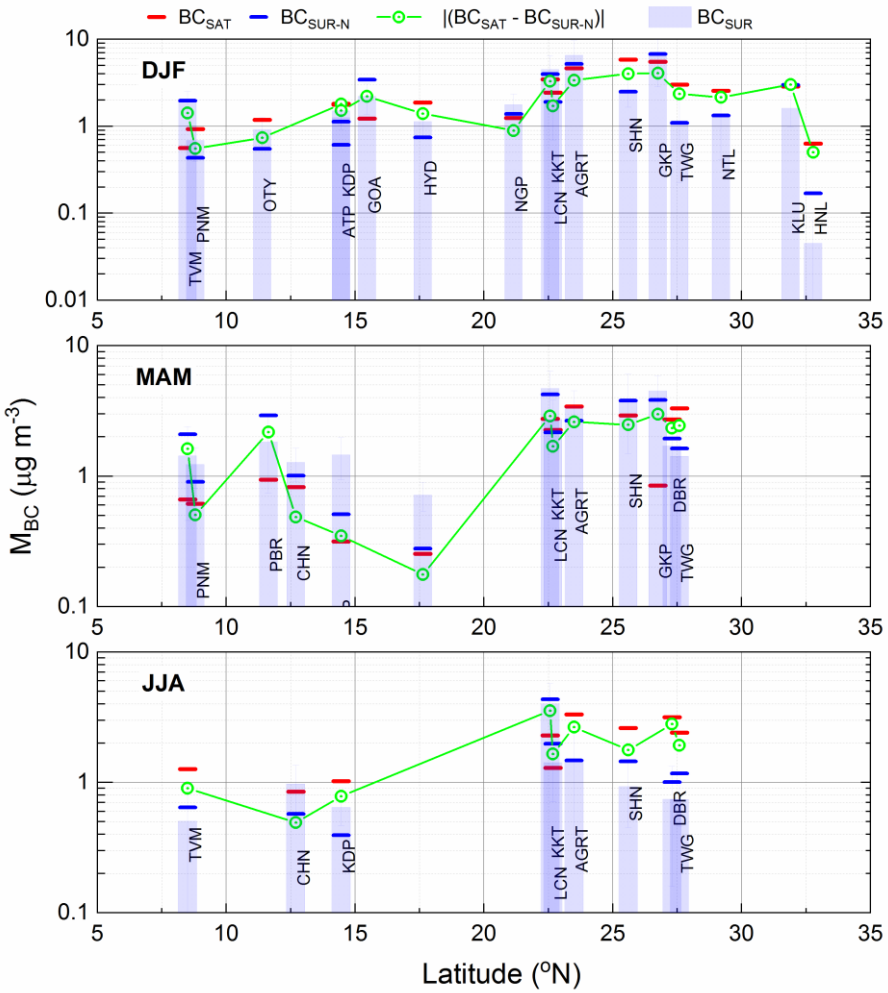

Figure 7: Seasonal mean values of satellite-retrieved (BC_{SAT}) and surface-measured (BC_{SUR} and BC_{SUR-N}) BC concentrations at different ARFINET sites (shown with respect to their latitudes) of India. The absolute difference between BC_{SAT} and BC_{SUR-N} are also shown. The top panel shows the seasonal values of BC_{SAT}, BC_{SUR}, BC_{SUR-N} and $|(BC_{SAT} - BC_{SUR-N})|$ around each of the observational sites during December-January-February

(DJF). Same parameters are shown in the middle panel for March-April-May (MAM) and bottom panel for June-July-August (JJA). The letters in the histograms represent the names of individual stations (details in supplementary Table-T1). The simultaneous data available for inter-comparison are highest in DJF (17-stations) and least in JJA (9-stations).

P7 L261: add references

Response: The following references are included in support of the seasonal changes in the incoming ground reaching solar radiation in the northern part of India.

Soni, V.K., Pandithurai, G., Pai, D.S.: Evaluation of long-term changes of solar radiation in India. International Jouirnal of Climatology, 32 (4), 540–551, https://doi.org/10.1002/joc.2294, 2012.

Subba, T., Gogoi, M. M., Moorthy, K. K., Bhuyan, P. K., Pathak, B., Guha, A., Srivastava, M. K., Vyas, B. M., Singh, K., Krishnan, J., Lakshmikumar, T. V. S., Babu, S. S.: Aerosol Radiative Effects over India from Direct Radiation Measurements and Model Estimates, Atmospheric Research, 276, 106254, https://doi.org/10.1016/j.atmosres.2022.106254, 2022.

P7 L267: show -> shows

Response: Complied with.

P7 L276: more wet soils -> wetter soils

Response: Complied with.

P8 L288: The forgone observation -> The prior observation

Response: Complied with.

P8 L298: Based on in-situ vertical profiling of aerosol scattering and absorption properties on a research aircraft, Babu et al., (2016) have reported the values of SSA between 0.86 and 0.94 over different West Indian and IGP locations during the pre-monsoon (April-May) period. -> Babu et al., (2016) have reported the values of SSA between 0.86 and 0.94 over different West Indian and IGP locations during the pre-monsoon (April-May) period using aircraft measurements.

Response: Complied with.

P8 L305: Over the oceanic regions, the values of SSA are, in general, high -> Over the oceanic regions, the values of SSA are generally high

Response: Complied with.

P8 L310-311: Mar -> Mar.

Jun -> Jun.

You may use abbreviations of the months consistently: decide full name or abbreviations of the months.

Response: Complied with. The consistency is maintained.

P8 L315: during Mar/Apr/May -> during March to May

Response: Complied with

P9 L319: Figs. 8, 9 and 10 -> Figs. 8, 9 and 10, respectively

Response: Complied with.

P9 L322: day time FRP -> day-time FRP

Response: Complied with.

P9 L343: add references after “Several studies”

Response: Complied with. The following references are included in the revised manuscript.

Dixon, R. K., Krankina, O. N.: Forest fires in Russia: carbon dioxide emissions to the atmosphere, Canadian Journal of Forest Research, 23, 700-705, 1993.

Leskinen, P., Lindner, M., Verkerk, P.J., Nabuurs, G.J., Van Brusselen, J., Kulikova, E., Hassegawa, M. and Lerink, B. (eds.).: Russian forests and climate change. What Science Can Tell Us 11. European Forest Institute, 2020.

P9 L345: evaluate and validate -> evaluate

Response: Complied with.

P9 L349: remove unnecessary sentence (The main findings are as follows:)

Response: Complied with.

P9 L351: do not use “fairly”. It sounds informal.

Response: Complied with.

P9 L354: for > 60% of the observations (for all the locations considered in this study) the absolute difference between the two data sets is < 2 μgm^{-3}. -> the absolute difference between the two data sets is less than 2 μgm^{-3} for over 60% of the locations in this study.

Response: Complied with.

P10 L365: during times of biomass burning -> during the biomass burning season

Response: Complied with.

P22 L654: Need more description about the plot (e.g., upper, center, and bottom panels indicate what) in the caption

Response: Complied with. The figure caption is modified as

“Figure 7: Seasonal mean values of satellite-retrieved (BC_{SAT}) and surface-measured BC (BC_{SUR} and $BC_{SUR\text{-}N}$) BC concentrations at different ARFINET sites (shown with

respect to their latitudes) of India. The absolute difference between BC_{SAT} and BC_{SUR-N} at different locations are also shown. The top panel shows the seasonal values of BC_{SAT}, BC_{SUR}, BC_{SUR-N} and $|(BC_{SAT} - BC_{SUR-N})|$ around each of the observational sites during December-January-February (DJF). Same parameters are shown in the middle panel for March-April-May (MAM) and in the bottom panel for June-July-August (JJA). The letters in the histograms represent the names of individual stations (details in supplementary Table-T1). The simultaneous data available for inter-comparison are highest in DJF (17-stations) and least in JJA (9-stations).”

P24-26: Need more description about the plot (e.g., upper, center, and bottom panels indicate what) in the caption

Response: Complied with.

-END-