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Atmospheric Chemistry and Physics
Discussions
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Interactive comment on "Vertical profiles of sub-micron aerosol single scattering albedo over Indian region immediately before monsoon onset and during its development: Research from the SWAAMI field campaign" *by* Mohanan R. Manoj et al.

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We appreciate the summary evaluation and the positive recommendation of the reviewer. Our point-by-point responses to the comments of reviewer/ clarification sought are given below and the manuscript is revised accordingly.

Major Comments:

1. At several places (for example lines 16-20 in page 12), it is mentioned that the present results matches well with previous reported results (not all but at least few) where they have used single SSA values. Is it not contradicting in saying that height profiles of SSA will give more information when compared to use of single value?

We are sorry that this paragraph, discussing figure 9 was a bit confusing and thank the reviewer for pointing this out. We have revised the manuscript to avoid confusing statements.

It has been revealed in this study that using height resolved SSA measurements in radiative forcing estimates (rather than a single columnar value) has resulted in the sharp increase in the aerosol induced atmospheric heating around 3 km altitude (Figure 9), rather than the high value near the surface (where aerosol loading and extinction is high) when the single value was used (Figure 9a). In such cases, the heating rates profiles would tend to show higher values where extinction is higher, rather than where SSA is lower, which should be more realistic. This is because of the absence of altitude resolved SSA information, when a single value is used. This under-estimation of heating rate while using a single SSA value becomes severe when the elevated aerosol layers have more absorbing aerosols leading to lower SSA than those closer to the surface as can be seen in Figure 9c. In addition to the effect due to lower SSA, elevated aerosol layers will tend to increase the heating rate at higher altitudes, because for the same amount of radiation absorbed, more heating would be produced at higher regions of the atmosphere, where the air is rarer. Consequence of this is clearly seen in Figure 9d, where the heating rate profiles using single SSA and using height resolved SSA are quite similar, yet there is significant underestimation in the instantaneous atmospheric forcing by as much as $\sim$2.4 W/m2. In some of the previous studies, which have reported peaks in the heating rate profiles around 2-4 km altitude region, would have this under-estimation, as those did not use height resolved SSA information. With the use of height resolved SSA, our study provides a more realistic estimate of the heating; with higher values around more absorbing aerosol layers.

In Figure 9b the SSA values vary between 0.95 and 0.87. To clearly demonstrate the effect of altitude resolved SSA on heating rate profiles, we have shown the heating rate profiles below (Fig. 1) in which we have plotted the heating rate profiles calculated for the same extinction profile, but with two single SSA values at the extremes (0.87 and 0.95) and also the realistic altitude varying SSA. Though the position of the peak occurs around the same altitude, the peak heating rate as well as integrated heating rates differ significantly. The importance of our study is to demonstrate this through measurements. This is now clearly provided in the revised manuscript (page 12, line numbers 10 and 12-15).

2. Page 12, Lines 18-20: 'Strong meridional and zonal gradients in aerosol induced heating rates over AS and BoB across the peninsular landmass (from <0.1 K/day over the south - western Arabian Sea, increasing to 0.5 K/day over the north - eastern Bay of Bengal).'

Here we have referred to a result reported earlier by Nair et al., 2013. This study, though used altitude resolved temperature, pressure and humidity in RF estimation, did use only columnar value of SSA, because the height resolved SSA was not available. This was recognized as a major gap area and SWAAMI made special efforts to close this gap as much as possible. Our measurements providing height-resolved SSA up to 6 km is a major contribution towards this. This is made explicit in the revised manuscript (page 12, line numbers 27-29).

2a. It is mentioned that realistic observations are used in estimating the heating rates. However, it is not mentioned anywhere on what is the uncertainty in estimating the heating rates? Have you considered the uncertainty in several parameters that are used in estimating the heating rates?

Yes, we have considered the uncertainties due to the parameters used to estimate the forcing. The sensitivity of various parameters including Aerosol Optical Depth (AOD), SSA and asymmetry parameter has been estimated following McComiskey et al. (2008). The uncertainty due to the combined effect of AOD, SSA and asymmetry parameter on the top of the atmosphere forcing was found to be ~ 1.8 W/m2. Estimation of uncertainty has been discussed in detail in many papers from the group (Moorthy et al., 2009, Satheesh et al., 2010) and hence not repeated here. We also found that the uncertainty in the instantaneous atmospheric forcing for the cases shown in figure 9 was ~4.2 W/m2. Unfortunately, the value was not explicitly mentioned in the manuscript. The magnitudes of the atmospheric forcing estimated with and without the use of SSA profiles are shown in Figure 9. The atmospheric forcing estimates increased by ~14.6% (8.7% to 24.09%) on an average, on using the measured SSA profiles. This is made explicit in the revised manuscript (page 10, line numbers 28-29 and page 11, line numbers 1-2).

3. Page 6, Lines 22-25: It is mentioned that 'Extinction coefficient', decreases near exponentially with altitude over most of the mainland, while over the oceanic regions of the Arabian Sea and Bay of Bengal, an increase in extinction is indicated above 2 km, attributed to elevated layers of aerosols. These layers appear to be stronger over the Arabian Sea than over Bay of Bengal. In general, highest values are observed within 3 km from the surface where the aerosol abundance is more.' This paragraph has several contradicting statements. Why elevated aerosols are not seen over mainland? In fact several earlier studies have reported elevated aerosol layers over mainland (Mishra et al., 2010; Ganguly et al.,2006; Niranjan et al., 2007; Sinha et al., 2013; Venkat Ratnam et al., 2018). Further, it is mentioned that highest values are observed within 3 km from the surface. Then question arises why they are not washed out after the onset of monsoon?

Thank you for pointing out this, we have revised the sentences to avoid confusion and to make the point clear (page 6, line numbers 23-24). The variation in the extinction coefficient profiles is much sharper over the land compared to the oceanic region. At an altitude of 3 km over the land, the extinction coefficient values fall to less than 50% of the value near the surface. Elevated aerosol layers are observed all over the

Indian mainland and the surrounding oceans during pre-mosoon and early monsoon season, due to lofted dust (regional as well as advected). Over the oceanic region the magnitudes of extinction coefficients as well as the fall in the magnitudes of extinction coefficients with height are lower compared to that over the mainland. Over the Arabian Sea and Bay of Bengal elevated aerosol layers are observed above 2 km. The magnitude of extinction coefficient in these layers are larger over the Arabian Sea than over the Bay of Bengal, because of the proximity of Arabian Sea to major dust sources of west Asia and western India. In general, the strongest elevated layers appear within 3 km from the surface.

Minor comments:

1. Page 7, Lines 23-26. ‘Examining our values with those reported earlier for this region, based on airborne measurements, Earlier observations over this region have reported a columnar (up to 3 km altitude) mean SSA of 0.86 at 520 nm over Lucknow during pre-monsoon period (Babu et al., 2016) which is just a shade higher than our value of 0.83 $\pm$0.08 (for the altitude range 0-3 km for the same season).’ Previously you have mentioned that SSA has been estimated for 550 nm (Equation 2). Are you comparing the values for same wavelengths?

No, we are not comparing the SSA here as the values are reported for different wavelengths. Although SSA has a wavelength dependence, the magnitude of SSA is almost the same in 520-550 nm range. Mishra et al. (2015) have shown that the SSA has very small variation (approximately $\pm$0.02) in this wavelength region for dust, polluted dust and pollution aerosols. We want to show that low SSA values similar to our observations have been reported earlier from the region in the 0-3 km altitude range, for the same season. We have modified the statement to convey this clearly (page 7, line numbers 25-26).

2. Page 10, Lines 3-5 and also Page 12, Lines 8-9: ‘At Lucknow, as stated earlier, signiïňĄcant washout leads to very low extinction above 3 km, while at the lower altitudes,

the SSA has increased compared to the pre-monsoon with values remaining around 0.9 up to 2 km and decreasing above to be less than 0.8 at 3 km.' Why washout should happen only above 3 km. Are you talking about rainout? In fact washout should happen throughout the altitude as mentioned in many recent papers (for example Venkat Ratnam et al., 2018).

Yes, it is mostly washout. In the IGP region (near Lucknow) high altitude aerosols mainly consist of transported dust, while near the surface it is a mixture of transported and locally produced aerosols. The effect of rain is seen throughout the column. The magnitude of extinction coefficients reduces even at lower altitudes during monsoon. The aerosols removed from near the surface are quickly replenished, due to large local production. The aerosols are not replenished as quickly at higher altitudes. We agree that the sentence gives the wrong impression that the removal of aerosols is happening only above 3 km. We have modified the statement to convey this clearly (page 10, line number 4 and page 12, line number 10). Our observations cannot be completely explained by the cases discussed in Ratnam et al., (2018) as 1) our measurements do not show the extinction profiles immediately after rain and 2) the measurements were made around the local noon when the local sources are active.

References:

Mishra, A.K., Koren, I., Rudich, Y., 2015. Effect of aerosol vertical distribution on aerosol-radiation interaction: A theoretical prospect. Heliyon 1.

McComiskey, A., Schwartz, S.E., Schmid, B., Guan, H., Lewis, E.R., Ricchiazzi, P., Ogren, J.A., 2008. Direct aerosol forcing: Calculation from observables and sensitivities to inputs. Journal of Geophysical Research: Atmospheres 113.

Moorthy, K. K., Nair, V. S., Babu, S. S., and Satheesh, S. K.: Spatial and vertical heterogeneities in aerosol properties over oceanic regions around India: Implications for radiative forcing, Quarterly Journal of the Royal Meteorological Society, 135, 2131-2145, 10.1002/qj.525, 2009.

Nair, V.S., Babu, S.S., Moorthy, K.K., Prijith, S.S., 2013. Spatial Gradients in Aerosol-Induced Atmospheric Heating and Surface Dimming over the Oceanic Regions around India: Anthropogenic or Natural? Journal of Climate 26, 7611-7621.

Ratnam, M.V., Prasad, P., Roja Raman, M., Ravikiran, V., Bhaskara Rao, S.V., Krishna Murthy, B.V., Jayaraman, A., 2018. Role of dynamics on the formation and maintenance of the elevated aerosol layer during monsoon season over south-east peninsular India. Atmospheric Environment 188, 43-49.

Satheesh, S. K., Vinoj, V., and Krishnamoorthy, K.: Assessment of aerosol radiative impact over oceanic regions adjacent to Indian subcontinent using multisatellite analysis, Advances in Meteorology, 2010, 2010.

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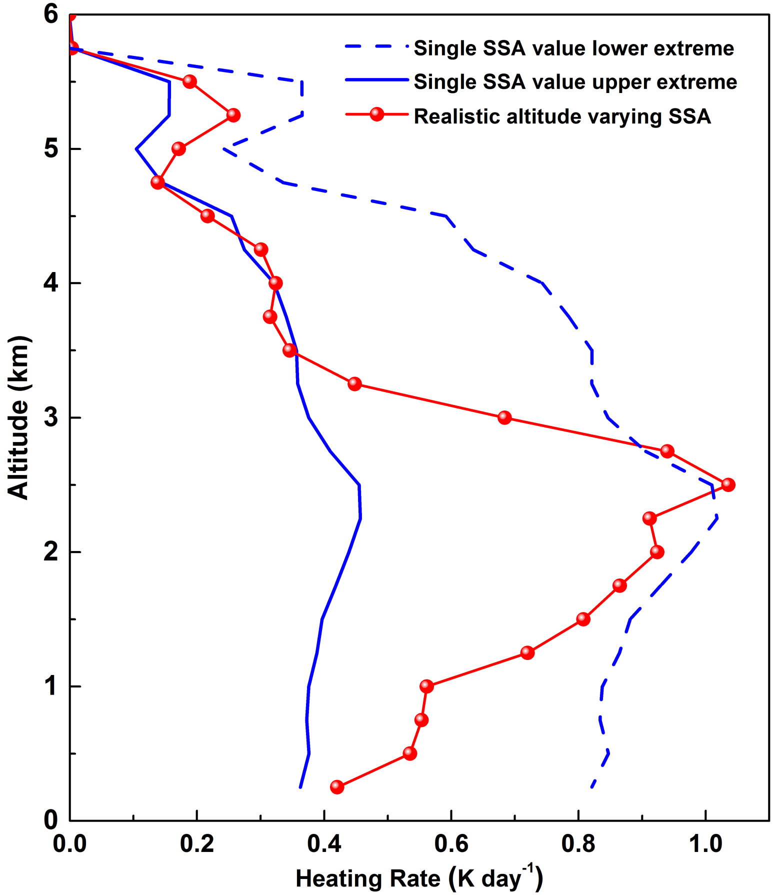

Fig. 1. Fig. 1: The heating rate profile shown in Figure 9b in the manuscript is reproduced along with the profiles corresponding to single SSA values 0.87 and 0.95.

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Discussion paper