Effect of Absorbing Type Aerosols (Soot) and Vertical Distribution of Aerosols on Direct Aerosol Radiative Forcing; A Modeling Study

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Abstract **- In the present study, our aim is to quantify the effect of absorbing type aerosols and vertical distribution of aerosols in aerosol radiative forcing estimations and also in understanding the vertical profile of heating rates. The radiative forcing values were calculated for an aerosol optical depth of 0.3 at 0.5 µm. The asumed single scattering albedo changes from 0.75 to 0.95 due to changing of absorbing type arosols and the asumed elevated aerosol contribution is ~ 60% to totla aerosol optical depth. We have observed large variation in atmospheric radiative forcing from +27.71 Wm^{-2} to +41.15 Wm^{-2} due to change in absorbing aerosols. Although there was less difference found in radiative forcing at the surafce and top of the atmosphere but significant difference found in atmospheric forcing due to variation of vertical distribution of aerosols for the averaged single scatterig albedo. These observed results are interpreted in the context of current understanding of aerosol radiative forcing.**

Keywords: Aerosol Extinction; Optical Depth; Radiative Forcng.

1. INTRODUCTION

Atmospheric aerosols play vital role in global climate system since they modify global radiation budget directly by scattering and absorption of a part of solar radiation coming to the earth surface, and indirectly by modifying the cloud micro physical properties such as albedo, precipitation and life time etc (Twomey 1977; Charlson et al. 1992; Ackerman et al. 2000; IPCC 2007; Kim and Ramanathan 2008). In addition to that, aerosols cause semi-direct effect by substantially heating the atmosphere thereby causing 'burning of clouds' (Ackerman et al. 2000). However, diverse aerosol type, short residence time and lack of information on aerosol vertical profiles, direct, semi-direct and indirect effect of aerosol radiative forcing still remains a significant uncertainty for climate studies (IPCC 2007).

It is well known that the parameters needed for radiative forcing computations are aerosol optical depth, single scattering albedo (SSA), asymmetry factor, incoming solar radiation (solar zenith angle dependence), underlying reflecting surface and cloud properties etc (Ricchiazzi et al. 1998). By the definition single scattering albedo (SSA) is the ratio of scattering efficiency to the total extinction efficiency. Absorbing type (soot) aerosols are the main contributor for modifying the SSA values, which in-turn has an impact on estimation of radiative forcing (Gadhavi and Jayaraman 2010). Recent studies also showed that the importance of measured vertical profiles of aerosols to the estimation of forcing at the top of the atmospheric and also heating rate in the atmosphere (Podogorny and Ramanathan 2001; Satheesh et al. 2008; Gadhavi and Jayaraman 2010). The above studies also showed the effect of SSA (soot) and vertical distribution of aerosols in the radiative forcing calculations.

It is well known that aerosols exert cooling/warming effect in the earth's atmosphere potentially depends upon the absorbing properties of aerosols as well as underlying reflecting earth's surface (Satheesh 2002). Owing to this fact, recent studies showed that the soot like absorbing aerosols have significant warming effect which can modify the atmospheric temperature (Bond and Bergstrom 2006; Gadhavi and Jayaraman 2010). In spite of small fraction of soot in the total columnar AOD, it will significantly changes the value of radiative forcing and also heating rate (Satheesh et al. 2002; podgorney and Ramanathan 2001; Panicker et al. 2010). Recent studies also showed that the existence of elevated aerosol layers in free troposphere region because of convective lifting of aerosols and subsequent long range transport from distant locations (Hegde et al., 2008 and Kishore et al., 2011). This type of aerosol layers also found around 2-4 km height region in India during pre monsoon season (Niranjan et al., 2007; Satheesh et al. 2008).

In this context, present study deals the effect of absorbing type aerosols and vertical distribution of aerosols in the estimation of aerosol radiative forcing. Earlier studies stated above on radiative forcing are considered the average SSA and default profile of aerosol extinction (exponential), but these SSA values and vertical profile of aerosol extinctions cannot represent true values due to large special and temporal variation of aerosols and presence of elevated aerosol layers. In this work, we intend to understand the effect of absorbing type aerosols and vertical distribution of aerosols in the estimation of aerosol radiative forcing and heating rates. The obtained results are discussed in the current understanding in the context of recent developments in radiative transfer models.

2. METHODOLOGY

The direct aerosol radiative forcing (DARF) is defined as the difference between the clear-sky net shortwave radiative flux in aerosol case and net shortwave radiative flux in the aerosol free atmosphere. More details of methodology employed to estimate diurnally averaged radiative forcing from modelled radiative fluxes is provided elsewhere (Satheesh and Ramanathan 2000; Ramana et al. 2004; Satheesh et al. 2006) and are not repeated here. In the present work, the optical properties of aerosols have been used as an input parameters to Santa Barbara DISORT Radiative Transfer (SBDART) model to estimate radiative fluxes in the wavelength band of 0.25 – 4.0 µm. In addition to that, the concentration of ozone and water vapours are used as per the standard atmospheric profile.

3. RESULTS AND DISCUSSIONS

Absorbing type aerosols (black carbon) mass concentration is highly variable over space and they also exhibit large temporal variation over any site (Tripathi et al. 2005; Gadhavi and Jayaraman 2010). In addition, the vertical distributions of aerosols are also highly variable both spacially and temporally (Satheesh et al., 2008).

In this context, it is very important to quantify the role of black carbon mass contribution and aerosol vertical profiles which will directly affect the aerosol radiative forcing and heating rates. The concentration of absorbing type aerosols are very sensitive and linearly affects the single scattering albedo. This variation of absorbing aerosols causes the variation of radiation budget and a small mass fraction of absorbing aerosols can cause huge difference in radiation budget (Satheesh et al. 2002; Panicker et al. 2010). This aspect motivated us to study variation in radiative forcing with respect to the variation in SSA values. We have calculated aerosol radiative forcing at different SSA at 0.5 µm in the range of 0.75 – 0.95 region with an average value 0.85.

In addition, the existence of an elevated aerosol is also one of the dominant processes in the atmosphere. This type of aerosols causes large uncertainties in the estimation of radiative forcing (Sathhesh et al., 2008; Kishore et al., 2013). Recent studies also showed the existence of elevated aerosol layers those could be due to long range transport from distant locations (Hegde et al. 2009; Kishore et al. 2011). This aspect motivated us to study variation in radiative forcing and heating rates with the existence of elevated aerosol layer.In the above context, we have assumed the elevated aerosol layer in the height range of 0.5 – 1 km and this layer contributed about 40% to total aerosols optical depth at 0.5 µm. This profile has been used in the estimation of radiation fluxes.

3.1. Effect of absorbing type aerosols

Optical properties chosen for different cases of SSA values have been used to study the variation of radiative forcing due to absorbing type aerosols. For these estimations we have taken constant AOD at 0.5 µm; which is 0.3. Figure 1 shows the Surface, top and atmospheric radiative forcing for different SSA at 0.5 µm values namely 0.95, 0.85 and 0.75. The surface forcing are -20 Wm^{-2}, -30 Wm^{-2} and -33 Wm^{-2} and forcing at the top of the atmosphere are -8 Wm^{-2}, -6 Wm^{-2} and -2.5 Wm^{-2} and subsequent atmospheric radiative forcing are +12 Wm^{-2}, +24 Wm^{-2} and +30.5 Wm^{-2} respectively for different SSA values namely 0.95, 0.85 and 0.75 as shown in figure 1. Large variation in the atmospheric radiative forcing has been observed due to change in SSA, and it is decreased by about 12 Wm^{-2} that is about 50% from average SSA to high SSA case, it is increased by 6.5 Wm^{-2}, which is almost 27% from average SSA to high SSA.

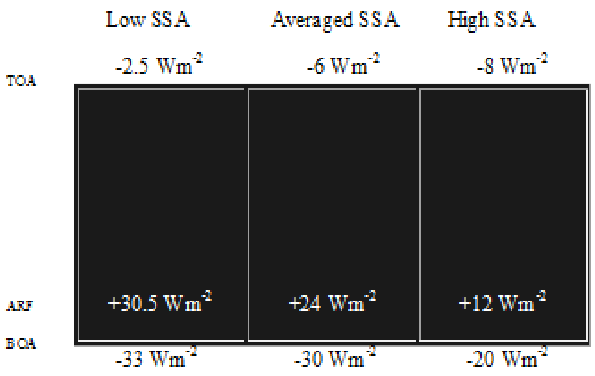

Figure 1 : Radiative forcing at the top, surface and in the atmosphere due to aerosols at different single scattering albedos.

3.2. Effect of vertical distribution of aerosols

In the present analysis, we have used average single scattering albedo (0.85), the estimated surface radiated radiative forcings were -31, -30 Wm^{-2} and radiative forcings at the top of the atmosphere were -5.5, -6 Wm^{-2}. Subsequently, the atmospheric forcings were 25.5 and 24 Wm^{-2} respectively, in the case of elevated aerosol layer present and in case of absence of elevated aerosol layer. We found that the difference in radiative forcing 1Wm^{-2} at surface, 1.5 Wm^{-2} at the top of the atmosphere and 2.5 Wm^{-2} in the atmosphere due to change in the vertical distribution of aerosols.

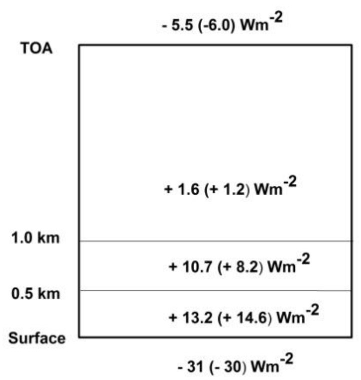

Figure 2 : Radiative forcing at different levels of the atmosphere in case of elevated aerosol present (in case of absence of elevated aerosols).

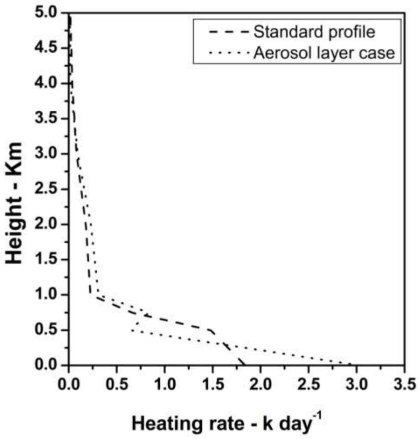

Figure 3 : Vertical profile of heating rates (k/day) in the atmosphere in case of elevated aerosol present and in case of absence of elevated aerosols.

The reduction in radiative fluxes is re-distributed in atmosphere which ultimately reflects in the heating rate leading to modification of the thermal structure of the atmosphere. The heating rate of the atmosphere is calculated as Liou (2002)

$$\partial T/\partial t = g/ Cp\ (dF/dP)$$

Where ($\partial T/\partial t$) is the heating rate (k/day); Cp is the specific heat capacity of air at constant pressure; g is the acceleration due to gravity; dF is the observed radiative forcing; dP is the atmospheric pressure difference between the top and bottom of each layer; T is the air temperature; and t is the time. Figure 3 shows the vertical distribution of heating rates.

It is also clearly evident that the vertical profiles of radiative forcings are quite different in case of elevated aerosol layer present and in case of elevated aerosol layer is absence cases at each altitude for the same optical properties of aerosols as shown in figure 2. It is interesting to note from the figure 3 that enhancement in heating rate is clearly visible in the elevated aerosols case at 0.75 km due to aerosol layer; whereas no enhancement in heating rate found in standard profile case.

Previous studies also showed the importance of vertical distribution of aerosols in the estimation of radaitive forcing with specific emphasis on change of the sign of the forcing at tropopause level on improper selection of vertical profile of aerosol extinction (Gadhavi and Jayaraman 2010). Here, present study reconfirm and emphasizes the importance of vertical profile of aerosol extinction along with the properties of aerosols in the estimation of aerosol radiative forcing.

5. SUMMERY AND CONCLUSIONS

Owing to the increasing importance to the radiative forcing and global warming aspects our study aimed to give a comprehensive picture of the parameters which govern the aerosol radiative forcing and subsequent heating rates. Two aspects have mainly been concentrated in this particular study: (a) Effect of absorbing aerosols and (b) Importance of vertical distribution of aerosols in the estimation of aerosol radiative forcing.

Our results showed that the large difference in atmospheric aerosol radiative forcing due to variation of absorbing type aerosols. The present results also also showed the importance of vertical distribution of aerosols in the atmospheric radiation budget (Heating rate) calculations as the thermal structure of atmosphere plays very important role in convection (boundary layer dynamics) and cloud formation process.

Although the uncertainties in aerosol radiative forcing could be because of various parameters like surface reflectance, asymmetry parameters and phase function etc. We have considered only variation in absorbing type aerosols and vertical distribution of aerosols. Hence, considering the all other aerosol properties along with the above studied parameters will yeild exact estimation of aerosol radiative forcing and heating rates.

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