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Retrieval of black carbon and specific absorption over Kanpur city, northern India during 2001–2003 using AERONET data

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Abstract

Column-integrated aerosol black carbon (BC) concentration, [BC] has been retrieved over Kanpur (an industrial city in the Gangetic basin, northern India) during 2001–2003 for the first time. [BC] is derived from BC volume fraction and AERONET-retrieved size distribution using Maxwell–Garnett and Bruggeman mixing rules in a mixture of water, BC and $(NH_4)_2SO_4$. In addition partly absorbing components like organic carbon (OC) and dust are added to the Maxwell–Garnett mixture depending on the season to investigate their role in the retrieval of [BC]. The volume fraction of each component is retrieved by matching the mixture refractive index (real, $n(\lambda)$ and imaginary, $k(\lambda)$) with AERONET-retrieved refractive index. [BC] shows seasonal variations with high values ($>10\,mg\,m^{-2}$) observed during the post-monsoon and winter seasons and low values ($<6\,mg\,m^{-2}$) during the monsoon season. Specific absorption cross-section (α_a) decreases non-linearly with the increase in [BC], however, the decrease becomes linear when other absorbing components are present. Yearly averaged [BC] and α_a are 9.99 ± 1.95, 5.52 ± 1.07, $7.9\pm1.53\,mg\,m^{-2}$ and 7.9 ± 1.83 and 9.67 ± 3.45, $12.74\pm2.92\,m^2\,g^{-1}$ for 2001, 2002 and 2003, respectively, using Maxwell–Garnett mixing, which differ by ~15% from those using Bruggeman mixing. [BC] shows diurnal variation with morning and afternoon peaks and mid-day minimum. The amplitude is subdued as it represents the total column, which is more influenced by anthropogenic activities than by boundary layer dynamics. In order to estimate [BC] accurately, OC has to be considered when the absolute difference between $k(0.44\,\mu m)$ and $k(1.02\,\mu m)$ becomes higher than 0.0015. The sensitivity of [BC] due to dust $n(\lambda)$ becomes important during the intense dust loading period. It was found that [BC] is more sensitive to dust $k(\lambda)$ than dust $n(\lambda)$, as [BC] increases ~10–13% for 10% rise in $k(\lambda)$. Retrieved [BC] shows good agreement with the in situ measurements. Therefore our retrieval can be used as an alternate method to infer BC and OC specific absorption globally.

Keywords: Aerosols; Black carbon; Specific absorption; Internal mixing; Effective medium approximation

1. Introduction

Black carbon (BC) is the most dominant solar radiation absorbing component of aerosols causing a global mean forcing of $0.3\,W\,m^{-2}$, reducing the direct radiative effect of sulfate aerosols by 50–100% (IPCC, 2001). Several studies have confirmed that BC forcing depends on its mixing state (Fuller et al., 1999; Jacobson, 2001; Chandra et al., 2004). Specific absorption (α_a) of BC (absorption per unit mass of BC), an important optical parameter for characterizing BC absorption, also varies depending on the mixing state, morphology, complex refractive index and density (Fuller et al., 1999; Schuster et al., 2005). BC affects the regional hydrological cycle through evaporation of cloud droplets due to absorption of sunlight (Ramanathan et al., 2001a; Menon et al., 2002) and can be a potential health hazard (Horvath, 1993).

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Sato et al. (2003) have shown that the present BC emission inventories have to be increased by a factor of 2–4 to match with the Aerosol Robotic Network (AERONET) measurements of single scattering albedo. Their results show the difficulty as well as the necessity of proper estimation of column-integrated BC concentration (in $mg\,m^{-2}$), [BC], to quantify α_a in order to assess their impact on regional climate. Studies during the Indian Ocean Experiment (INDOEX) have revealed significant amount of BC over the tropical Indian Ocean during the winter monsoon season (Ramanathan et al., 2001b; Mayol-Bracero et al., 2002; Satheesh et al., 2002). However, few measurements of surface BC concentration have been carried out in India (Babu and Moorthy, 2002; Venkataraman et al., 2002; Latha and Badarinath, 2003), which is believed to be the major source of pollution in the adjacent oceans. Recently, Tripathi et al. (2005a) have measured surface BC concentration in an industrial site in the Ganga basin (Kanpur, 80°20′E; 26°26′N, Fig. 1), northern India for 1 month (December 2004) period during Indian Space Research Organization-Geosphere Biosphere Program (ISRO-GBP) Land Campaign II. High BC concentration (6–20 $\mu g\,m^{-3}$) has been observed in the region resulting in atmospheric absorption of $\sim +71\,W\,m^{-2}$, which translates into a lower atmospheric heating rate of 1.8 K per day; three times higher than the heating rate observed over the Indian Ocean (0.5 K per day) (Satheesh et al., 2002). These results show the importance of long-term measurements of BC in the region, which is nonexistent till now. Also aerosol optical properties derived from AERONET data show high concentration of absorbing aerosols particularly during the winter season (Singh et al., 2004), which requires quantitative study to understand the radiative forcing in the region.

Recently, Schuster et al. (2005) have used Maxwell–Garnett mixing rule (MG) to retrieve [BC] globally from a mixture of BC and $(NH_4)_2SO_4$ (AS) embedded in water host. They have found that the yearly averaged α_a varies in between 7.7 and $12.5\,m^2\,g^{-1}$. In addition to MG, we have used Bruggeman effective medium approximation (Brug) to retrieve [BC] from AERONET data for the measured columnar volume size distribution and refractive indices. We have also considered additional partly absorbing components in our retrieval, which will be discussed in detail in the next section. The proposed retrieval technique has been validated against in-situ data from Kanpur and INDOEX. In this paper, we present, for the first time, long-term [BC] and α_a and their variability over Kanpur.

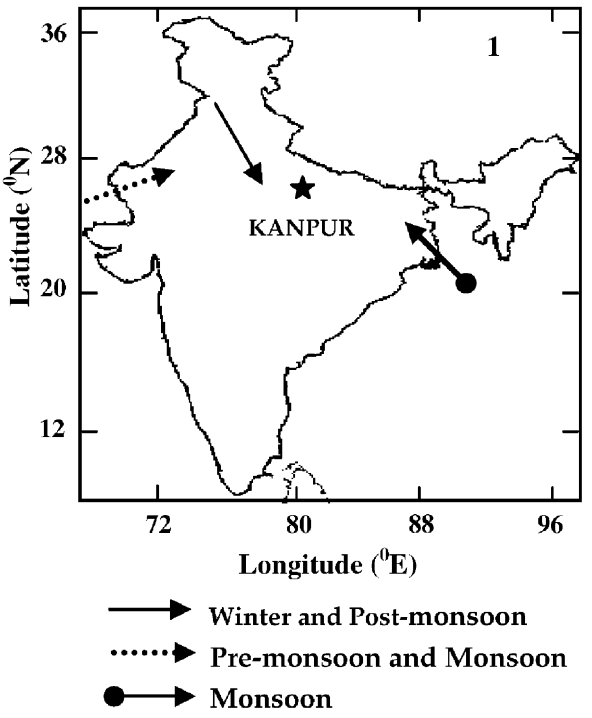

Fig. 1. Location of the study area with the regional air mass in different seasons shown by arrows.

4. Summary and conclusions

1. Schuster et al. (2005) have calculated yearly averaged [BC] in different regions of the world and they have found [BC] 0.22–0.28 $mg\,m^{-2}$ at remote islands, 0.96–3.47 $mg\,m^{-2}$ at continental sites and 2.7–3.7 $mg\,m^{-2}$ in biomass burning sites. Compared to these values, [BC] in Kanpur is much higher and it may have significant impact on the regional climate forcing. [BC] in Kanpur exhibits strong seasonal variation. Maximum [BC] ($>10\,mg\,m^{-2}$) has been found during October–January months. Yearly averaged values of $[BC]_{MG}$ and $[BC]_{Brug}$ show a difference of $\sim 1.5\,mg\,m^{-2}$, although higher difference exists in few months due to the difference in the mixing rules.
2. α_a decreases non-linearly with increase in [BC] using both MG and Brug, as increase in f_{BC} would lead to higher number of BC particles in the eccentric position of the mixture reducing the efficiency in absorption. The decrease in α_a becomes almost linear when partially absorbing OC/dust is added to the mixture. Presence of dust results in higher rate of reduction of α_a, as larger dust particles reduces $\alpha_{a,BC}$ more efficiently than smaller OC particles.