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Aerosol radiative forcing controls: Results from an Indian table-top mining region

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HIGHLIGHTS

- Emphasizes the seminal role of SSA in quantifying ARF at surface.
- ARF-top is mainly determined by SSA.
- A multiple linear regression is obtained between ARF and AOD, SSA.
- Model and equation derived ARF are in agreement within ± 4 Wm^{-2}.

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ABSTRACT

Aerosol radiative forcing (ARF) over intense mining area in Indian monsoon trough region, computed based on the aerosol optical properties obtained through Prede (POM-1L) sky radiometer and radiative transfer model, are analysed for the year 2011 based on 21 clear sky days spread through seasons. Due to active mining and varied minerals ARF is expected to be significantly modulated by single scattering albedo (SSA). Our studies show that radiative forcing normalized by aerosol optical depth (AOD) is highly correlated with SSA (0.96) while ARF at the surface with AOD by 0.92. Our results indicate that for a given AOD, limits or range of ARF are determined by SSA, hence endorses the need to obtain SSA accurately, preferably derived through observations concurrent with AOD. Noticeably, ARF at the top-of the atmosphere is well connected to SSA ($r = 0.77$) than AOD ($r = 0.6$). Relation between observed black carbon and SSA are investigated. A possible over estimation of SSA by the inversion algorithm, SKYRAD.pack 4.2, used in the current study is also discussed. Choice of atmospheric profiles deviating from tropical to mid altitude summer or winter does not appear to be sensitive in ARF calculation by SBDART. Based on the 21 clear sky days, a multiple linear regression equation is obtained for ARF_{bot} as a function of AOD and SSA with a bias of ± 2.7 Wm^{-2}. This equation is verified with an independent data set of seasonal mean AOD and SSA to calculate seasonal ARF that compares well with the modeled ARF within ± 4 Wm^{-2}.

1. Introduction

Radiative forcing by aerosols is the most uncertain term while considering anthropogenic modification of global radiation budget that in turn controls global warming, precipitation pattern, day-to-day human comfort levels and health effects. Aerosols have the potential to modify circulations and convection viz., black carbon (BC) aerosols heat the atmosphere and cools the surface leading to increase in atmospheric stability and reduction in convection and precipitation; the other aspect is that abundance of BC over Indian land mass, depending on the location can heat the atmosphere thus increasing the meridional atmospheric temperature gradient between the Indian ocean and Indian land mass that strengths monsoon flow leading to enhanced convergence over the region which can overcome the vertical static stability thus increasing convection and precipitation. In short aerosols have the potential to either increase or decrease monsoonal convection over India under certain conditions, leading to "sitting on a wall" type situations due to uncertain role of aerosols. Manoj et al. (2011) elaborates this type of situation by explaining how the break in monsoon turns to active depending on the dominance of absorbing aerosols heating over Central India. A study of similar situation over Indo-Gangetic Plains earlier by Ramanathan et al.

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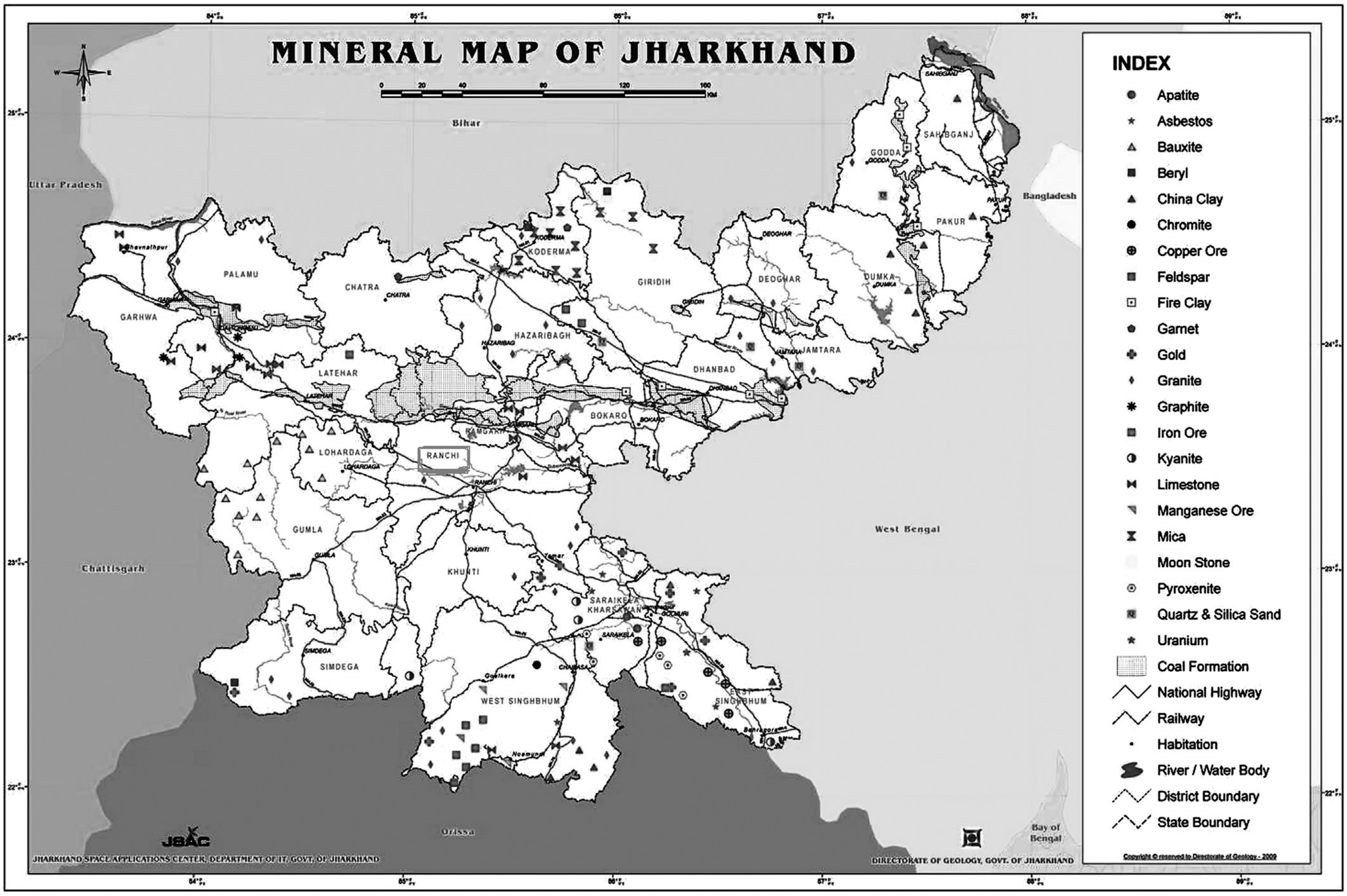

Fig. 1. Mineral map of the Jharkhand, India; Ranchi, the observation station is marked with a rectangle.

(2005) predicts through GCM sensitivity study that negative feedback between aerosols and surface evaporation leading to possible reduction in agriculture production.

Aerosol characteristics, the causative mechanism for its inherent temporal and spatial variability and short life time (e.g. Coen et al., 2013) at best can be described locally and at the most regionally, necessitating many studies preferably over typical stations so that the results can be integrated or interpolated further for assessing its net effect. Hence it will be worthwhile to represent ARF in terms of the parameters causing it and find an empirical relation among them. Radiative forcing efficiency, i.e. forcing caused by unit change in AOD, specifically applied to radiation reduction at the surface is a widely used term to characterize interaction of aerosols with radiation at many places (Ramanathan and Ramana, 2005).

ARF is generally computed using radiative transfer models (e.g. Pandithurai et al., 2004) in which temperature-humidity profiles are also used as input variables along with AOD, SSA, water vapor, surface albedo, angstrom exponent, etc (Panicker et al., 2010). Wherever simultaneous SSA is not derived directly from the measured components, as in the case of sunphotometer measurements, researchers have widely used optical-chemical model (like OPAC) to derive SSA with certain additional assumptions (e.g. Singh et al., 2010). It reiterates that AOD is not the singular factor that wholly determines ARF.

It is expected that this station (Ranchi) with a variety of mineral mines around apart from emitted BC, is likely to have different aerosol mixtures as well as strongly absorbing aerosols. While AOD indicates total columnar extinction of radiation, SSA provides more information about the scattering/absorbing nature of aerosols, therefore SSA variation in general and for this station in particular is very important for the role it plays in deciphering ARF. Hence it was decided to choose clear sky days, additionally verified through independent solar radiation measurements strictly to assure that change in radiation apart from the natural zenith angle variation is caused exclusively by aerosols.

2. Site and instrument details

The observation station Ranchi (85.44°E, 23.41°N, 650 AMSL) is a part of Chota Nagpur Plateau with highly polluted (Ramanathan and Ramana, 2005) Indo-Gnagetic Plain (IGP) to the North West, chains of plateaus on the north, east and south with heavy mining activity and Bay of Bengal coast to the South East. Fig. 1 is the mineral map of Jharkhand with Ranchi, (the observational site) marked with a rectangle. The mining stations are beyond 20 km of the observation site and the campus is densely populated with tall Sal trees but with limited vehicular traffic. Along the boundary of this vast campus there are some brick kilns largely using wood/coal as fuel. This station experiences rains during pre-monsoon (March15 -June11), monsoon (June-12 - September15) and post monsoon (September16 - November 15) and a few winter rains.

The sky radiometers, Prede make, model POM1L measures sun and sky radiances in 7 wavelengths (315, 400, 500, 675, 870, 940 & 1020 nm); of these 315 nm and 940 nm are not used due to interference with ozone and water vapor in these wavelengths. The instrument is set to conduct sky scans on both sides of Sun at 0 – 180 scattering angle at every 10 min interval and 'Sun' scan every 1 min. Sun tracker direction is always adjusted well within ±5° so