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Spatial and Altitudinal Contrast in Aerosol Radiative Properties across the Indo-Gangetic Plain

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Abstract

With a view to understanding the vertical distribution of aerosols and estimating the radiative impacts of elevated aerosols in the lower free troposphere, extensive profiling of the vertical variation of the optical properties, namely the extinction/ scattering and absorption coefficients (respectively σ_{ext} / σ_{sca}t / σ_{abs}) have been carried out from three base stations in the Indo-Gangetic Plain (IGP) using an instrumented aircraft, prior to onset of the Indian Summer Monsoon. These stations represented the semiarid western IGP (Jodhpur, JDR), the anthropogenically affected central IGP (Varanasi, VNS), and the industrialized coastal location in the eastern end of the IGP, close to the northern Bay of Bengal (Bhubaneswar, BBR). The vertical profiles of the optical properties differed significantly across these locations and this resulted in a regionally significant heating rate gradient. While the integrated (ground to 3 km altitude) σ_{scat} remained quite comparable across the IGP, the highest σ_{abs} and hence the lowest single scattering albedo (SSA) occurred in the central IGP (Varanasi). Size distribution, inferred from the spectral variation of the scattering coefficient, showed a gradual shift from coarse particle dominance in the western IGP to strong accumulation dominance in the eastern coast, with the central IGP coming in-between. Source speciation of aerosol, using spectral aerosol properties, revealed aerosol system in the west IGP is predominantly natural (dust and sea-salt) and that in the east IGP is highly anthropogenic type (industrial emissions, fossil fuel and biomass combustion).The central IGP exhibited a mixture of both.

1. Introduction

Atmospheric aerosols play an important role in modulating cloud properties [1] for e.g. their lifetime, albedo, mode radius etc. Inhomogeneous altitudinal distribution of aerosols also alters the heating rate in the atmospheric column thus influencing the likelihood of cloud formation. Over the Indo-Gangetic Plain (IGP) a complex mix of dust and anthropogenic aerosols prevails during the pre-monsoon season [2]. Such anomalous loading of highly absorbing aerosols may potentially perturb the Indian Summer Monsoon (ISM) circulation patterns [3]. This can have significant implications to regional climate, onset of monsoon and even amount of rainfall received [4]. Thus knowledge of aerosol properties prior to onset of the ISM is essential in delineating it's as cloud condensation nuclei, and impact on cloud formation, its properties and associated precipitation. Such studies are scarce for the IGP region. Therefore, improved understanding of aerosol vertical distribution and their radiative properties is called for, particularly prior to the ISM onset period.

Work presented here deliberates upon the altitudinal profile of aerosols in the IGP prior to onset of the monsoon. Further it also ascertains role of aerosols in modulating the heating rate of the atmosphere and thus influencing properties of cloud precursors.

2. Campaign

South-West Asian Aerosol-Monsoon Interaction (SWAAMI) – Regional Aerosol Warming Experiment (RAWEX) campaign was conducted from 1st June, till 20th June, 2016, using an Indian Space Research Organisation (ISRO) instrumented aircraft, to study the aerosol radiative properties and its impact on regional climate. Three base stations, as shown in Figure 1, Jodhpur (JDR), Varanasi (VNS) and Bhubaneswar (BBR) were selected for they represent natural dust dominated western IGP, anthropogenic aerosols dominated central IGP, and the outflow region i.e. east IGP, respectively.

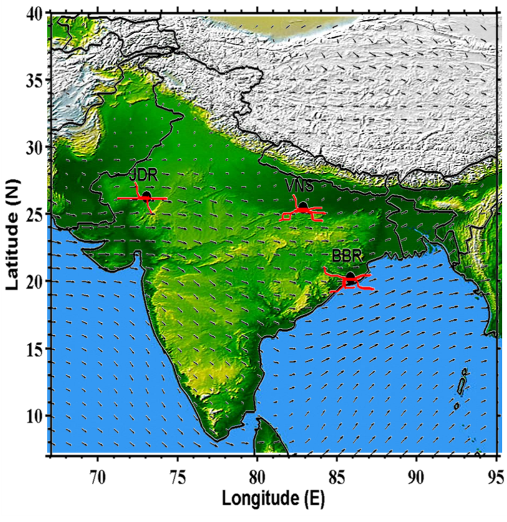

Figure 1. Geographical location of the aircraft campaign stations (solid circle) in the Indo Gangetic Plain superimposed on the topographic map of India. JDR, VNS & BBR stands for Jodhpur, Varanasi and Bhubaneswar, respectively. Daily flight tracks are superimposed on the stations with each measurement track having a horizontal span of ~ 150 km from the base station.

Five flight sorties each at BBR and VNS and four sorties at JDR were performed. Each flight sortie lasted for ~3.5 hours. Each sortie consisted of 6 vertical levels (500, 1000, 1500, 2000, 2500 and 3000 m agl). A shrouded solid diffuser inlet was used to ensure an iso-kinetic flow regime when sampling ambient air [5]. All the instruments were connected to the inlet using iso-kinetic flow splitters. Overall volumetric flow of 70 LPM was maintained during sampling at constant height levels. All data was geo-referenced using high time resolution (1s) GPS measurements onboard.

3. Results

Aerosol light extinction/scattering/absorption coefficient's (σ_{ext} / σ_{scat} / σ_{abs} at 530 nm) showed high variability in the central IGP owing to proximity to the diverse source regions beneath. While column integrated σ_{scat} values were comparable for the west and central IGP, ~ 65 Mm^{-1}, column integrated σ_{abs} values were maximum in central IGP leading to highly absorbing aerosol atmosphere over the region. A shift in the aerosol size mode, indicated by Ångström exponent (α_{scat}), is observed in the IGP with aerosol population changing from super-micron mode dominant natural aerosols (dessert dust), α_{scat} ~ 0.9, in the west to sub-micron mode dominant anthropogenic aerosols (mix of aerosols from industrial sources, fossil fuel and biomass burning), α_{scat} ~ 2.0, in the east IGP, as shown in Figure 2a. From Figure 2b it is evident that a system of highly absorbing aerosols, with single scattering albedo (SSA) values as low as ~0.73, prevails over the entire IGP during the monsoon onset. West IGP is least influenced by anthropogenic aerosols with SSA values ~ 0.84. While SSA in central IGP increases vertically that in east IGP decreases.

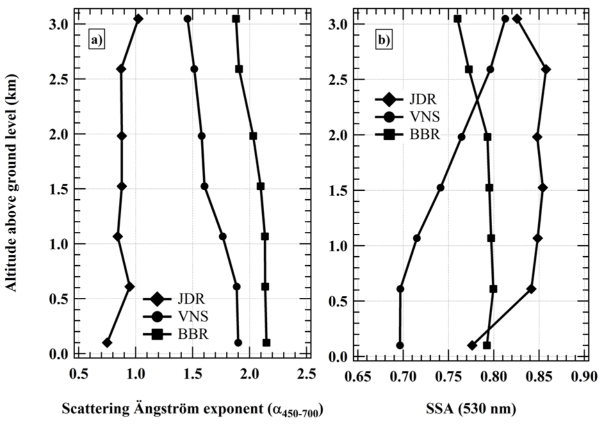

Figure 2. Altitudinal variation of a) $\alpha_{450-700}$ and, b) SSA for the stations JDR (diamond), VNS (circle), and BBR (square), respectively.

Comparison of SSA during the monsoon onset to that with winter and spring values, reported by Babu et al. [5], indicates that the aerosol population over the entire IGP systematically becomes highly absorbing in nature during the onset of ISM due to combined effect of lower horizontal ventilation of anthropogenic pollutants from the IGP and reduced influx of dust aerosols from the western regions.

Figure 3 shows the variation of $\alpha_{abs\_450-700}$ with respect to $\alpha_{scat\_450-700}$. It is evident from the figure that larger size aerosols (lower $\alpha_{scat\_450-700}$) are dust dominated (higher $\alpha_{abs\_450-700}$) and smaller size aerosols (higher $\alpha_{scat\_450-700}$) are fossil fuel source dominated (lower $\alpha_{abs\_450-700}$). Also, western IGP (JDR) is dominated by dust which is coarse in nature while eastern IGP (BBR) is dominated by fine mode aerosols mainly from fossil fuel and biomass burning sources. Central IGP (VNS) shows a mix of aerosols having dust and fossil fuel sources as origin.

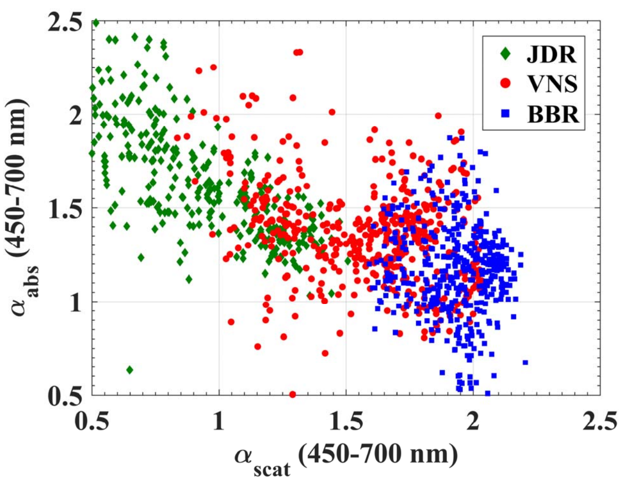

Figure 3. Variation of $\alpha_{abs\_450-700}$ with respect to $\alpha_{scat\_450-700}$ for the stations JDR (diamond), VNS (circle), and BBR (square), respectively. Larger size aerosols (lower $\alpha_{scat\_450-700}$) are dust dominated (higher $\alpha_{abs\_450-700}$) and smaller size aerosols (higher $\alpha_{scat\_450-700}$) are fossil fuel source dominated (lower $\alpha_{abs\_450-700}$).

4. Conclusions

SWAAMI-RAWEX aircraft campaign was conducted prior to onset of the Indian Summer Monsoon, from 1st - 20th June, 2016, to characterize aerosol radiative properties, both extensive and intensive, and its souces. The three base stations, Jodhpur (JDR), Varanasi (VNS) and Bhubaneswar (BBR) were aptly selected to represent west, central and east IGP, respectively. Exhaustive measurements of aerosol light scattering and light absorption properties were carried out to quantify enhanced absorption by aerosols. Major findings from the study are as following:

1. As we move from west to east in the IGP the aerosol population changes from super-micron mode dominant natural aerosols (dessert dust), α_{scat} ~ 0.9, to sub-micron mode dominant anthropogenic aerosols (mix of aerosols from industrial sources, fossil fuel and biomass burning etc.), αs_{cat} ~ 2.0.
2. While SSA in central IGP increases vertically that in the east IGP decreases. Significantly low values of SSA, ~0.73, during the monsoon onset has implications to atmospheric stability and regional precipitation patterns.

To sum up, a system of highly absorbing aerosols, with SSA values as low as ~0.69, prevails over the entire IGP during onset of the Indian Summer Monsoon. This has implications to atmospheric stability, time of monsoon onset and regional precipitation patterns. Further studies, combining aerosols radiative properties with cloud parameters viz. cloud optical depth, cloud albedo and fraction etc. will help in discerning the effects of enhanced absorption during onset of the South-Asian Summer Monsoon on regional climate.

5. Acknowledgements

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