VARIABILITY OF AEROSOL OPTICAL, PHYSICAL AND RADIATIVE PROPERTIES AT SEVEN ASIAN AERONET STATIONS DURING MARCH 2012 DUST EVENT

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Abstract- Aerosol optical, physical and radiative properties at seven Asian Aerosol Robotic Network (AERONET) stations during the dust storm event of March 2012 have been analysed. Highest aerosol optical depth (AOD$_{500\text{nm}}$) observed at these seven AERONET stations may be due to the combined effect of natural (desert dust) and anthropogenic aerosols, thus, indicating the strong influence of dust storm induced aerosols. Aerosol system is a complex mixture of fine- and coarse-mode aerosols with coarse-mode exerting a strong influence on the system at the AERONET stations in India and Pakistan. However, it comprises of coarse-mode aerosols at KAUST_Campus and Mezaira since the origin of dust outbreak is Arabian Desert. The observed large differences in top of the atmosphere (TOA) and bottom of the atmosphere (BOA) radiative forcing demonstrate that the solar radiation is being absorbed within the atmosphere corresponding to the heating of the atmosphere while at same time the earths’ surface becomes cooler which can substantially alter the atmospheric stability and influence the dynamic system of the atmosphere.

Keywords: Aerosol optical depth, AERONET, Aerosol system, Radiative forcing

I. INTRODUCTION

Natural dust is considered as one of the major aerosol contributor in the global atmosphere which affects the Earth’s climate through interaction with both solar and thermal infrared radiation (Kim et al., 2011). It also affects atmospheric dynamics, soil characteristics, nutrient dynamics, atmospheric chemistry, ambient air quality, and ocean biogeochemistry over wide ranges of spatial and temporal scales ( Husar et al., 2001; Haywood et al., 2005; Jickells et al., 2005). On a global scale, dust contributes to about one quarter of aerosol optical depth (AOD) in the mid-visible wavelengths (Kinne et al., 2006). Dust is also light absorbing (Alfaro et al., 2004; Lafon et al., 2004, 2006) and estimates indicate that more than half of aerosol absorption optical depth (AAOD) at 550 nm may come from dust (Chin et al., 2009). The evaluation of the dust - radiation interaction is of prime importance for climate forcing assessment at both local and regional scales due to large uncertainties in assessing the dust climate impacts ( Foster et al., 2007).

One of the major sources of uncertainty in dust radiative forcing is associated with dust optical and physical properties on account of complexities in dust size distribution, morphology and mineral composition (Sokolik and Toon, 1999). In order to assess the impact of March 2012 dust event on aerosol properties, in the present study, we chose seven Asian AERONET stations viz., KAUST_Campus (KAUST) in Saudi Arabia (SA), Mezaira (MEZ) in United Arab Emirates (UAE), Lahore (LAI) and Karachi (KAR) in Pakistan and Kanpur (KAN), Jaipur (JAI) and Pune (PUN) in India.

II. AERONET SAMPLING SITES, INSTRUMENTATION AND DATA

The selected sampling AERONET stations are characteristic of different environments, such as arid, desert areas at KAUST_Campus (SA) and Mezaira (UAE) which are directly affected by dust, urban areas in South Pakistan (Karachi and Lahore) having both natural and anthropogenic emissions, and stations in India (Pune, Kanpur and Jaipur) with significant amount of urban and desert aerosols. This illustration can help in understanding the spatio-temporal variation of aerosol properties that are directly controlled by the movement of dust plume.

The CIMEL sky radiometer is the standard AERONET instrument for taking measurements of the direct Sun and diffuse sky radiances in the 340-1020 nm and 440-1020 nm spectral ranges respectively. The AERONET inversion algorithm (Dubovik, et al., 2000) provides improved aerosol retrievals by fitting the entire measured field of radiances i. e. the Sun radiance and angular distribution of sky radiances at four wavelengths: 440, 670, 870, and 1020 nm to the radiative transfer model (Dubovik et al., 2002). The inversion algorithm is used to retrieve aerosol volume size distributions in the range from 0.05 to 15 μm together with spectrally dependent aerosol optical depth (AOD), Angstrom Exponent (α) complex refractive index (RI), single scattering albedo (SSA) and asymmetry parameter(ASY) from spectral Sun and sky irradiance data. These aerosol properties are used for calculating broad band solar flux in the spectral range from 0.3 to 4.0 μm by employing the Santa Barbara DISORT Atmospheric Radiative Transfer
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1.2. Aerosol Volume Size Distribution (AVSD)

The radiative impacts of atmospheric aerosols depend on aerosol concentration in space and time, their size, and composition. Desert dust is generally found to be more absorbing at solar and infrared wavelengths and bigger in size as compared to anthropogenic sulfate aerosols. This leads to rise in atmospheric heating with consequent decrease in ground reaching solar irradiance and greenhouse trapping of outgoing thermal radiation (Lubin et al., 2002). In the present work, AERONET retrieved AVSDs were used to assess the effect of dust storm event of March, 2012 at seven AERONET stations as described above. The mean values of fine-mode peak volume concentration ($V_f$), coarse-mode peak volume concentration ($V_c$), and the corresponding mode radii $R_f$ and $R_c$, respectively are given in Table I for non-dusty and dusty days at seven AERONET stations.

The data given in Table I reveal that the mean non-dusty and dusty AVSDs are bi-modal in nature at the stations Pune, Kampur, Jaipur, Karachi, and Lahore. It is also found that the volume concentration of the coarse-mode ($V_c$) at these stations on non-dusty days is larger as compared to volume concentration of the fine-mode ($V_f$) by a factor of 1.2 to 15.8, the least being at Pune while the maximum at Karachi. Similarly, the ratio of $V_c$ to $V_f$ on dusty days varies from 1.72 to 18.35. On the other hand, at the stations KAUST_Campus (SA) and Mezaira (UAE) only mono-modal size distributions are strongly dominant.

Table 1. Characteristics of columnar volume size distributions at environmentally different AERONET sites on non-dusty and dusty days during March 2012. (Note: “NAM”, refers to the absence of accumulation mode in the volume size distribution, volume size concentrations $V_f$ and $V_c$ are in $\mu m^3/\mu m^2$ while radii $R_f$ and $R_c$ are in $\mu m$)

<table>
<thead>
<tr>
<th>Sites</th>
<th>Non-Dusty Days</th>
<th>Dusty Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V_f$</td>
<td>$V_c$</td>
</tr>
<tr>
<td>PUN</td>
<td>0.06</td>
<td>3.85</td>
</tr>
<tr>
<td>KAN</td>
<td>0.03</td>
<td>2.24</td>
</tr>
<tr>
<td>JAI</td>
<td>0.03</td>
<td>2.24</td>
</tr>
<tr>
<td>KAR</td>
<td>0.01</td>
<td>2.24</td>
</tr>
<tr>
<td>LAH</td>
<td>0.03</td>
<td>2.24</td>
</tr>
<tr>
<td>KAU</td>
<td>NAM</td>
<td>0.12</td>
</tr>
<tr>
<td>ST</td>
<td>M</td>
<td>0.18</td>
</tr>
</tbody>
</table>

These observations reveal that at the first five stations, as stated above, the aerosol system is a complex mixture of fine- and coarse-mode aerosols with coarse-mode exerting a strong influence on the system. However, at the latter two stations aerosol system comprise of coarse-mode aerosols since the origin of dust outbreak is Arabian Desert. Pandithurai et al., (2008) have reported an increase in coarse volume concentration by a factor 2 to 3 for April-June, 2006 over New Delhi during active dust event. The present dust storm event appears to be the most intensified event as a consequence of enormous rise in coarse-mode concentration at the studied environmentally different observing sites.

1.3. Index of Refraction

The refractive index is [real: $n(\lambda)$ and imaginary: $k(\lambda)$] is one of the important optical parameters providing information relating to the nature of aerosols and is highly dependent on the chemical composition of the aerosols. Values of $n(\lambda)$ and $k(\lambda)$ give an indication of highly scattering or highly absorbing aerosol types, with higher $n(\lambda)$ corresponding to the scattering types while higher $k(\lambda)$ pointing towards the absorbing types (Sinyuk et al., 2003). In the visible region, the mineral dust typically shows $n(\lambda)$ values of 1.53 ± 0.05 and $k(\lambda) ~ 0.006$ and lesser (Koepeke et al., 1997). The day-to-day spectral variation of both real and imaginary components of refractive index at the seven AERONET sites during non-dusty and dusty days of March 2012 are shown Fig. 2(a, b, c, d). In the present investigation, the $n(\lambda)$ values ranged between 1.471 ± 0.03 for Pune and 1.543 ± 0.04 for Karachi on non-dusty days and 1.466 ± 0.04 at Pune and 1.553 ± 0.02 at 675 nm while the $k(\lambda)$ are found to lie between 0.0069 ± 0.001 on non-dusty and 0.0032 ± 0.001 on dusty days at the same wavelength during March 2012. Further, the changes in the $n(\lambda)$ and $k(\lambda)$ are found to be more at lower wavelengths. The $k(\lambda)$ values at 440 nm wavelength is about 2 to 3 times than at higher wavelength which is common observation for the dust episodes (Dey et al., 2004). In fact, $k(\lambda)$ values at 870 and 1020 nm wavelengths are somewhat similar for non-dusty and dusty during the period of study. Spectral variation of $n(\lambda)$ depicts a sharp rise during dust event days as compared to non-dusty days. On the other hand, the spectral variation of $k(\lambda)$ shows a sharp decline on dusty days in relation to non-dusty days. The sharp changes in values of both $n(\lambda)$ and $k(\lambda)$ indicate an increase in the scattering state of the atmosphere.

Fig. 2: Spectral variation of real $n(\lambda)$ and imaginary $k(\lambda)$ components of index of refraction (RI) at seven AERONET stations on non-dusty and dusty days during March 2012 dust event.
1.4. Aerosol radiative forcing

The aerosol radiative forcing is defined as the change (ΔF) in the net flux (F), either at the top of the atmosphere (TOA) or at the bottom of the atmosphere (BOA, i.e. at the surface) produced due to the change in the environment. This change is ascribed to the natural and anthropogenic perturbation in the atmospheric composition, nature of the constituent species, cloudiness, or surface properties. In case of aerosol radiative forcing (ARF),

\[
(\Delta F)_{TOA, \text{ ARF}} = (F_{\text{TOA}, \text{ARF}}) - (F_{\text{BOA}, \text{ARF}})
\]

Where, \( F_A \) and \( F_{NA} \) are respectively the net fluxes with and without aerosols. As a result of both BOA and TOA, the net atmospheric forcing is defined as:

\[
(\Delta F)_A = (\Delta F)_{TOA} - (\Delta F)_{BOA}
\]

If \( \Delta F_{TOA} \) is negative, aerosols cause net loss of radiative flux to the atmosphere leading to cooling, while for positive \( \Delta F_{TOA} \), the warming effect is produced.

In the present case, the net flux in the spectral range 0.3 - 4.0 \( \mu \)m with and without aerosols, at TOA and at the bottom of the atmosphere is computed separately using the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model (Ricchiazzi et al., 1998). This model is based on a reliable physical model developed by the atmospheric science community and is being widely used for the radiative transfer calculations. The important optical parameters for estimating aerosol radiative forcing employing this model include AOD, single scattering albedo (SSA), asymmetry parameter (ASY) and surface albedo. The other input parameters in SBDART model include the solar geometry which is calculated using a code in the SBDART by providing a particular date, time, latitude and longitude. On the basis of measured parameters and the prevailing weather conditions, we used the mid-latitude summer atmospheric model for the present work. For accurate estimation of ARF and to have improved representation of relevant atmospheric parameters, daily mean values of columnar water vapour and total column ozone concentrations obtained from the Sun/sky radiometer and the Ozone Monitoring Instrument (OMI) on board NASA’s Aura satellite are used. The ozone concentration and surface albedo values were obtained from the AURA OMI version 3 reflectivity data through the Giovanni online data system, developed and maintained by the NASA GSFC DISC. Model was run at 1-hour interval for 24-hour period and the daily average forcing was determined during the dust event of March 2012 at the seven AERONET stations listed above. Fig. 3 shows the AERONET retrieved ARF at these stations on non-dusty and dusty days. From the figure, it is seen that the daily average surface aerosol radiative forcing is found to be maximum at Lahore (-137 Wm\(^{-2}\)) and minimum at Jaipur (-76 Wm\(^{-2}\)) while the top of the atmosphere (TOA) forcing showed maximum at KAUST_Campus (-68 Wm\(^{-2}\)) and minimum at Mezaira (-22 Wm\(^{-2}\)). As a result of this, the average atmospheric forcing is found to be in the range 41 Wm\(^{-2}\) (Jaipur) - 111 Wm\(^{-2}\) (Mezaira). Large differences between TOA and BOA forcing demonstrate that the solar radiation is being absorbed within the atmosphere corresponding to the heating of the atmosphere while at same time the earths’ surface becomes cooler (Alam et al., 2011; Ge et al., 2010). This can substantially alter the atmospheric stability and influence the dynamic system of the atmosphere.

CONCLUSIONS

Aerosol optical, physical and radiative properties over seven Asian AERONET stations viz., KAUST_Campus in Saudi Arabia (SA), Mezaira in United Arab Emirates (UAE), Lahore and Karachi (Pakistan), Kanpur, Jaipur and Pune (India) during the dust storm event of March 2012 have been analysed. AOD\(_{500}\) showed highest value of 4.41 at KAUST_Campus (SA) on March 19, 2012 depicting 25-fold increase with respect to ambient value. Higher AODs were observed at Mezaira (UAE) observed in the beginning of March and during March 18-28, 2012. At Lahore in Pakistan, AODs were found to be consistently higher (in the range: 0.73 - 2.17) during 16\(^{th}\) - 21\(^{st}\) March while at Karachi values were slightly less as compared to those at Lahore during the same period. Over the Indian AERONET station Pune, the effect of dust storm was seen from March 21 to 30, 2012. At Kanpur, AODs were found to be relatively higher (between 0.61 - 1.33) during the same period. At Jaipur, however, AODs were relatively less than those at Kanpur and Pune.
The highest AOD$_{550}$ observed at these seven AERONET stations may be due to the combined effect of natural (desert dust) and anthropogenic aerosols, thus, indicating the strong influence of dust storm induced aerosols. Aerosol size distribution analysis reveals that at the AERONET stations in India and Pakistan, the aerosol system is a complex mixture of fine- and coarse-mode aerosols with coarse-mode exerting a strong influence on the system while at KAUST_Campus and Mezaira aerosol system comprises of coarse-mode aerosols since the origin of dust outbreak is Arabian Desert. The sharp changes in values of both n(λ) and k(λ) indicate an increase in the scattering state of the atmosphere. The observed large differences in TOA and BOA forcing demonstrate that the solar radiation is being absorbed within the atmosphere corresponding to the heating of the atmosphere while at same time the earth’s surface becomes cooler which can substantially alter the atmospheric stability and influence the dynamic system of the atmosphere.

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REFERENCES