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

[1]S. R. VARPE, [2]G. R. AHER, [3]G. V. PAWAR, [4]G. C. KUTAL

[1,4]Physics Department, Nowrosjee Wadia College, Pune 411 001, India.
[2]International Institute of Information Technology, Pune 411 057, India.
[3]Trinity College of Engineering and Research , Pune 411 048, India.
E-mail : sandeepvarpe@rediffmail.com

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 ($AOD_{500\ nm}$) 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 (LAH) 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

(SBDART) model by following Ricchiazzi et al., 1998.

The uncertainty in the retrieval of AOD under cloud free conditions is < ± 0.01 for wavelengths (λ) > 440 nm and < ± 0.02 for shorter wavelengths which amounts to less than ± 5% uncertainty for the retrieval of sky radiance measurements. The errors for particle size distributions retrievals in the range 0.1 ≤ r ≤ 7 μm do not exceed 10% in the maxima of the size distributions but may increase to about 35% for the points corresponding to the minimum values of dV(r)/dlnr within this size range. But, for particles outside this size range, the accuracy of the size distribution retrieval decline significantly due to low sensitivity of aerosol scattering at 0.44, 0.67, 0.87 and 1.02 μm to particles in these size ranges. Aerosol particle size distributions [dV(r)/dlnr] are known to assume low values at the edges of their retrievals and the relatively high errors do not significantly affect the deviation of the main features of aerosol size distributions. The errors in RI are found to be 30% - 50% for the imaginary part while for real part they are ± 0.04. These estimated errors are found to be high for aerosol loading $AOD_{440\ nm}$ greater than ≥ 0.5 at the solar zenith angles larger than 50^0. Uncertainties in the SSAs, however, are found to depend on aerosol type and loading and are expected to be in the range 0.03 - 0.05 (Dubovik et al., 2000; 2002). In the present work, the data on AOD, Angstrom exponent, Complex refractive index (RI), Aerosol volume size distribution [dV(r)/dlnr] and Aerosol radiative forcing at the above AERONET stations during March 2012 is analyzed to delineate aerosol optical, physical and radiative properties.

III. RESULTS AND DISCUSSION

1.1. Variations of aerosol optical parameters

The CIMEL measurements at seven AERONET stations viz., three locations in India, two locations in Pakistan and one each in Saudi Arabia (SA) and United Arab Emirates (UAE) are examined in this section in order to assess intensity of dust event and the spatio-temporal effect of dust plumes on aerosol load and optical properties (Fig.1). AOD_{500} (Fig.1a) was at its highest value of 4.41 at KAUST_Campus (SA) on March 19, 2012 which rose from 1.23 on March 18, 2012 and 0.18 on the earlier day depicting 25-fold increase with respect to the ambient value. It remained at considerably higher level (~ 2.05) on March 20, 2012 before receding to values less than 0.8 after which it gradually decreased to ambient levels. At the same time, at Mezaira (UAE) higher AODs were observed in the beginning of March. The values were found to considerably higher again during March 18-28, 2012. At the AERONET station 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_{500} 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.

The different environments divide the seven stations into three groups on the basis of AE (α) estimated in the spectral range 440-870 nm viz., $\alpha_{440-870}$ (Fig.1b). The stations with significant contribution of anthropogenic (fine-mode) aerosols present much higher α- values (> 1) while the rest of the stations with lower α- values (<0.5 and negative) point out the significant contribution of dust (coarse-mode) aerosols. The temporal variation of the $\alpha_{440-870}$ values is somewhat similar to that of fine-mode fraction at 500 nm (Fig.1d). The dominant aerosol types (fine - and coarse-mode) can be discriminated (Eck et al., 1999; Kaskaoutis et al., 2007) by means of the curvature coefficient (α_2) determined from polynomial fit to the plot of ln AOD against ln λ (Eq. 1).

$$\ln AOD = \alpha_2 (\ln\lambda)^2 + \alpha_1 \ln\lambda + \alpha_0 \qquad (1)$$

At all the stations, the polynomial fit was accurate for all the days (R^2 >0.97).The almost near zero positive values show significant contribution of the fine-mode aerosols, while the negative ones are characteristic for the presence of coarse-mode aerosols (Fig.1c).

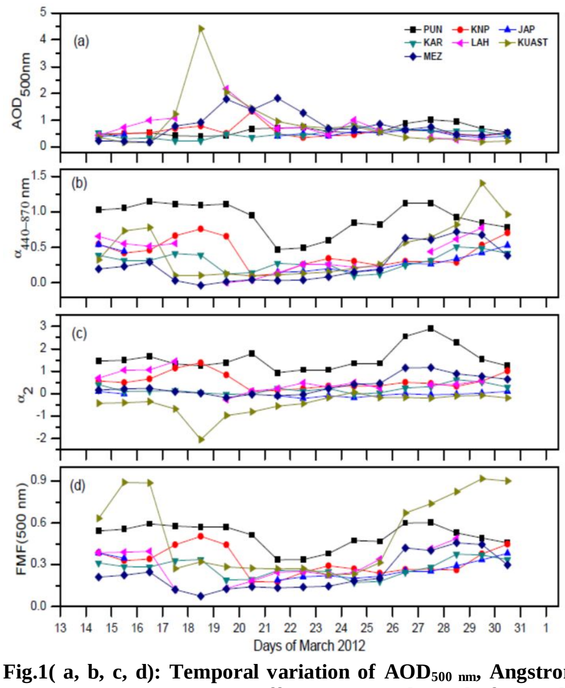

Fig.1(a, b, c, d): Temporal variation of $AOD_{500\ nm}$, Angstrom Exponent ($\alpha_{440-870\ nm}$), coefficient α_2 derived from the polynomial fit to ln AOD against ln λ plot and Fine-mode fraction from seven AERONET stations in South Asia during and after dust event of March 2012.

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_a), coarse-mode peak volume concentration (V_c), and the corresponding mode radii R_a 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, Kanpur, 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_a) 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_a 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.

Table1. 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_a and V_c are in $\mu m^3/\mu m^2$ while radii R_a and R_c are in µm)

sites	Non-Dusty Days				Dusty Days			
	V_a	R_a	V_c	R_c	V_a	R_a	V_c	R_c
PUN	0.06	0.11	0.08	3.85	0.12	0.11	0.21	2.24
KAN	0.03	0.11	0.19	2.24	0.07	0.11	0.31	2.24
JAI	0.03	0.11	0.17	2.24	0.01	0.08	0.31	1.70
KAR	0.01	0.08	0.20	2.24	0.02	0.08	0.26	1.70
LAH	0.03	0.08	0.11	1.70	0.03	0.08	0.58	1.70
KAUST	NAM	-	0.12	1.70	NAM	-	0.51	1.70
MEZ	NAM	-	0.18	2.24	NAM	-	0.66	1.70

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(λ) and imaginary: k(λ)] 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(λ) and k(λ) give an indication of highly scattering or highly absorbing aerosol types, with higher n(λ) corresponding to the scattering types while higher k(λ) pointing towards the absorbing types(Sinyuk et al., 2003). In the visible region, the mineral dust typically shows n(λ) values of 1.53 ± 0.05 and k(λ) ~ 0.006 and lesser (Koepke 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(λ) 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(λ) 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(λ) and k(λ) are found to be more at lower wavelengths. The k(λ) 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(λ) values at 870 and 1020 nm wavelengths are somewhat similar for non-dusty and dusty during the period of study. Spectral variation of n(λ) depicts a sharp rise during dust event days as compared to non-dusty days. On the other hand, the spectral variation of k(λ) shows a sharp decline on dusty days in relation to non-dusty days. The sharp changes in values of both n(λ) and k(λ) indicate an increase in the scattering state of the atmosphere.

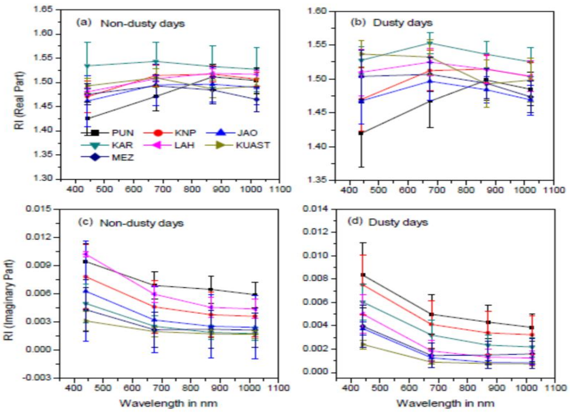

Fig.2: Spectral variation of real n (λ) and imaginary k (λ) components of index of refraction (RI) at seven AERONET stations on non-dusty and dusty days during March 2012 dust event.

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),

$$(\Delta F)_{TOA,\ BOA} = (F_{NA})_{TOA,\ BOA} - (F_A)_{TOA,\ BOA} \qquad (2)$$

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:

$$(\Delta F)_A = (\Delta F)_{TOA} - (\Delta F)_{BOA} \qquad (3)$$

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

In the present case, the net flux in the spectral range 0.3 - 4.0 μm 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 a reliable physical models 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 16th -21st 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.

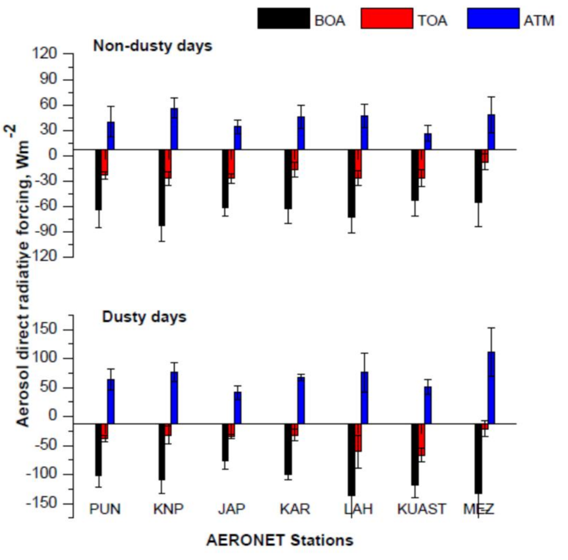

Fig.3: Variation of the daily averaged AERONET retrieved aerosol radiative forcing (W m^{-2}) at the TOA, BOA and in atmosphere at the seven AERONET station during March 2012.

The highest AOD_{500} 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 earths' surface becomes cooler which can substantially alter the atmospheric stability and influence the dynamic system of the atmosphere.

ACKNOWLEDGEMENT

Authors thank the Principal, Nowrosjee Wadia College, Pune (India) and the Secretary, Modern Education Society, Pune (India) for encouragement and support. Thanks are also due to the Director, ISRO-UoP Space Science Technology Cell for providing funding support for the research work carried out under ISRO-UoP research project. Finally, the authors are thankful to Dr. Brent Holben, Principal Investigator and Project Head, NASA AERONET Network and the Principal Investigators and Site Managers of the AERONET sites at Pune, Jaipur and Kanpur (India), Lahore and Karachi (Pakistan), KAUST_Campus (Saudi Arabia) and Mezaira (United Arab Emirates).

REFERENCES

[1] Alam et al., (2011) Aerosol optical and radiative forcing over mega city Karachi. Atmospheric Research. 101:773-782.

[2] Alfaro et al. (2004) Iron oxides and light absorption by pure desert dust: An experimental study. J. Geophys. Res. 109: D08208, doi: 10.1029/2003JD004374.

[3] Chin et al., (2009) Light absorption by pollution, dust, and biomass burning aerosols: a global model study and evaluation with AERONET measurements. Ann. Geophys. 27: 3439-3464.

[4] Dey et al., (2004) Influence of dust storms on the aerosol optical properties over the Indo-Gangetic basin. J. Geophys. Res. 109:D20211, doi: 1029/2004JD004924.

[5] Dubovik et al., (2002) Variability of absorption and optical properties of key aerosol types observed in worldwide locations. J. Atmos. sci. 59:590 -608.

[6] Dubovik, et al., (2000) Accuracy assessment of aerosol optical properties retrieved from Aerosol Robotic Network (AERONET) Sun and sky radiance measurements. J. Geophys. Phys.105:9791 - 9806.

[7] Eck et al., (1999) Wavelength dependence of the optical depth of biomass burning, urban, and desert dust aerosols. J. Geophys. Res. 104(D24):31,333–31,349.

[8] Foster et al., (2007) Changes in Atmospheric Constituents and in Radiative Forcing, in: Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L." Cambridge University Press, Cambridge, UK and New York, NY, USA.

[9] Ge et al., (2010) Dust optical properties retrieval and radiative forcing over northwestern China during the 2008 China- US joint field experiment. J. Geophys. Res. 115:D00k12, doi: 1029/2009JD013263.

[10] Haywood et al., (2005) Can desert dust explain the outgoing longwave radiation anomaly over the Sahara during 25 July 2003?. J. Geophys. Res., 110, D05105, doi: 10.1029/2004JD005232.

[11] Husar, et al., (2007) Changes in Atmospheric Constituents and in Radiative Forcing, in: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L.,Cambridge University Press, Cambridge, UK and New York, NY, USA.

[12] Jickells et al., (2005) Global iron connections between desert dust, ocean biogeochemistry, and climate. Science, 308, 67–71.

[13] Kaskaoutis et al., (2007) Aerosol climatology: on the discrimination of aerosol types over four AERONET sites. Atmos. Chem. Phys. 7:7347-7397.

[14] Kim et al., (2011) Dust optical properties over North Africa and Arabian Peninsula derived from AERONET dataset. Atmos. Chem. Phys.Discuss.11:20181-20201, doi: 10.5194/acpd-11-20181-2011.

[15] Kinne et al., (2006) An AeroCom initial assessment- optical properties in aerosol component modules of global models. Atmos. Chem. Phys.6: 1815-1834, doi: 10-5194/acp-6-1815-2006.

[16] Koepke et al., (1997) Global aerosol data set, Rep., 243, pp. 24, Max Planck Inst. for Meteorol., Hamburg, Germany.

[17] Lafon et al., (2004) Quantification of iron oxides in desert aerosol. Atmos. Environ. 38:1211-1218.

[18] Lafon et al., (2006) Characterization of iron oxides in mineral dust aerosols: Implication for light absorption. J. Geophys. Res.111: D21207, doi: 10.1029/2005JD007016.

[19] Lubin et al., (2002) Longwave radiative forcing of Indian Ocean tropospheric aerosol. J. Geophys. Res. 107(D19): 8004, doi: 10.1029/2001JD001183.

[20] Pandithurai et al., (2008) Aerosol radiative forcing during dust events over New Delhi, India. J. Geophys. Res. 113: D13209, doi: 10.1029/2008JD009804.

[21] Ricchiazzi et al., (1998) SBDART: a research and teaching tool for plane parallel radiative transfer in the Earth's atmosphere, Bulletin of American Meteorological Society 79:2355-2358.

[22] Sinyuk et al., (2003) Combined use of satellite and surface observations to infer the imaginary part of the refractive index of Saharan dust. Geophys. Res. Lett. 30 (1081). doi: 10.1029/2002GL023062.

[23] Sokolik and Toon (1999) Incorporation of mineralogical composition into models of the radiative properties of mineral aerosol from UV to IR wavelengths. J. Geophys. Res. 104 (D8): 9423-9444.

★★★