Possible impact of a major oil-well fire on aerosol optical depth at Dibrugarh

The role of atmospheric aerosols in modifying the radiation budget of the earth–atmosphere system with implications on regional to global climate is being increasingly understood and recognized[1–5]. Due to the short residence times, aerosols with varying optical properties are not uniformly mixed around the globe and consequently, their chemical and physical characteristics including radiative properties are subject to significant regional variations[6]. Over land, this arises primarily from the wide variety of source processes, while the transport of aerosols from different source regions on the continents to the remote oceans could play a significant role in the global radiative forcing. Among the various natural and anthropogenic sources of aerosols, man's domestic and industrial activities contribute a dominant share of the tropospheric aerosol burden. The major categories include combustion of fuels and incineration, industrial processing and production. Forest, and oil and gas fires continue to contribute to aerosol loading all around the globe.

A devastating fire broke out at oil well no. 15 of the Oil India Limited (OIL) at Dikom, Upper Assam on 15 September 2005 and continued to blaze for about three weeks, often reaching a height of about 10 m. There was gas leakage in the area two days ahead of the day of fire at Dikom, which resulted in the major inferno. The sky in the area was black with thick smoke, ash and debris scattered everywhere and a film of crude oil covered the ground. The site of the blaze is about 15 km east of Dibrugarh (27.3°N, 94.6°E). The area around Dibrugarh is rich in mineral deposits and has large deposits of crude oil and coal. Majority of the oil fields are located to the east and southeast of Dibrugarh town.

Aerosol optical depth (AOD) is being measured over Dibrugarh since October 2001, at ten narrow wavelength bands centred at 380, 400, 450, 500, 600, 650, 750, 850, 935 and 1025 nm using a Multi Wavelength Radiometer (MWR). The MWR works on the principle of filter wheel radiometers[7,8] and is operated from the rooftop of the building of the Physics Department, Dibrugarh University (~ 8 m above ground level) on all days when unobscured solar visibility is available for at least 2–3 h, and AOD is retrieved following the Langley technique. Details of application of this technique to analyse MWR data and the errors involved are described by Moorthy *et al.*[9,10]. The experiment conducted during September 2005 is considered to analyse the impact of the fire on AOD over the area. A total of eight days (2, 10, 12, 14, 15, 18, 26 and 28 September 2005) of MWR data during the period of observation have been analysed and the results are reported here.

Variations of daily mean AOD values at 500 nm along with the MODIS (Terra and Aqua satellites)-derived AOD[11] at 550 nm are shown in Figure 1 *a*. Comparison for the observational period shows a good agreement between the ground-based and satellite-derived AOD. AOD observed by MWR in the pre-fire days, i.e. first half of September was low and lies between a minimum of 0.06 at 935 and 1025 nm and a maximum of 0.81 at 450 nm, which is about the average September AOD observed in previous years, 2002–04. After two days of fire, on 18 September, AOD increased by 69 to 86%, within the wavelength range. No MWR observation was possible due to cloudy and rainy weather on 16, 17, 19 to 25 and 27 September. Light to moderate rainfall occurred on 19–24 September, which may have washed out the suspended aerosols. Towards the end of the month, the AOD was low as in the pre-fire days. However, on days in which the MWR observations were not available, the MODIS satellite-derived AOD data are available. AOD as observed by Aqua satellite reached a high value (~2.86) just after two days of fire and then gradually decreased towards the end of the month. On 22 September also, the MODIS AOD remained much above the September average at 1.69. Such abnormal increase in AOD is possible only when some external source

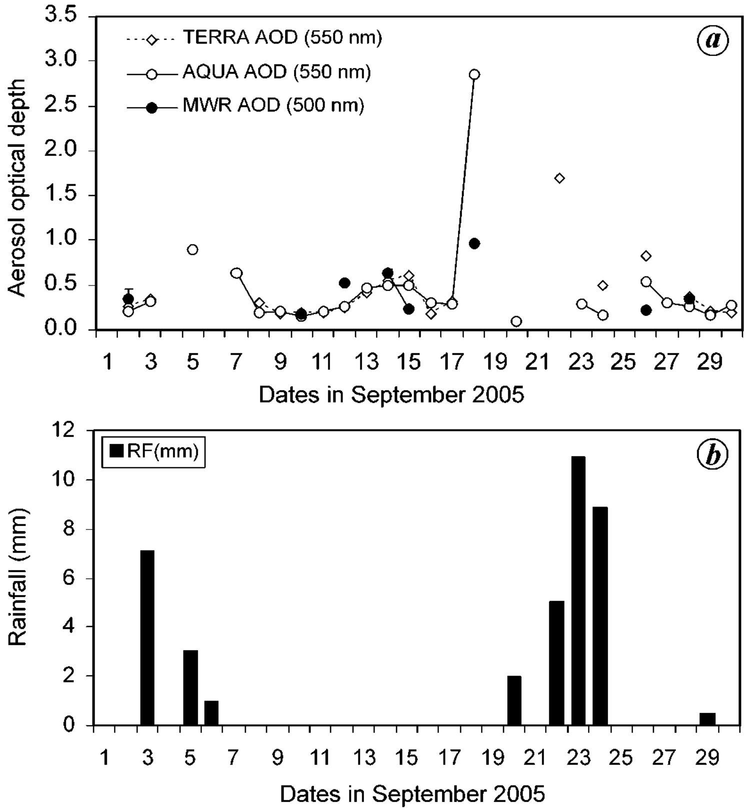

Figure 1. ***a***, Variation of daily mean AOD values measured using MWR at 500 nm and MODIS satellite at 550 nm. ***b***, Daily total rainfall during September 2005.

mechanism contributes significantly to aerosol concentration in the atmosphere. The Terra satellite observation was not available on 18 September. We shall now investigate the possible impact of the fire on the total aerosol loading in the atmosphere over this location and on the distribution of finer and coarse-mode aerosols.

The spectral variation of AOD bears the signature of the columnar size distribution of aerosols. Inferences on the size spectra of aerosols can be obtained readily from the corresponding AOD spectra [$\tau_p(\lambda)$] by estimating the Ångström parameters in the expression[12]

$$\tau_p(\lambda) = \beta\lambda^{-\alpha}, \quad (1)$$

where wavelength exponent α is related to aerosol size distribution and is a measure of the relative dominance of fine, submicron aerosols over coarse aerosols, while β represents the total aerosols present in the atmosphere in the vertical direction, and λ is the wavelength (in μm). A higher value of α indicates a sharper aerosol size spectrum, dominated by smaller aerosols. Estimates of α and β were made by least square fitting eq. (1) to the measured AOD spectra on a log–log scale. The values of α and β having correlation coefficient ρ lying in the range –0.60 to –0.99 on the respective days of observation are given in Table 1, along with the corresponding values of AOD at 500 nm. Values of α range from 0.86 to 1.38 during the pre-fire days. During post-fire days, the highest value of α was 1.66 along with the highest value of β (~0.39). This indicates increased abundance of fine as well as coarse-mode particles on a post-fire day. The aspect is critically examined by estimating columnar size distribution of aerosols.

From the aerosol spectral optical depths, the columnar size distribution (CSD) functions of aerosols have been deduced by numerical inversion of the Mie integral equation

$$\tau_{p\lambda} = \int_{r_a}^{r_b} \pi r^2 Q_{ext}(m,r,\lambda) n_c(r)\, dr, \quad (2)$$

where Q_{ext} is the aerosol extinction efficiency factor which depends on the aerosol refractive index (m), radius (r) and wavelength of incident radiation (λ), $n_c(r)$ is the columnar size distribution function of aerosols, and r_a and r_b are respectively, the lower and upper radii limits for integration. Equation (2) is solved following the iterative inversion procedure described by King[13] and as applied by Moorthy *et al.*[9].

The size distributions for all days showed unimodal characteristics, except on 28 September in the radius range used in the present study. To reproduce the gross features of the size distribution in a quantitative manner, the observed changes in the retrieved CSD are represented in terms of appropriate analytical functions, and the physical parameters of the aerosol size distributions such as geometric mean (mode) radii (r_{mi}), geometric mean standard deviations (σ_i), effective radius (r_{eff}), columnar mass loading (m_L), columnar concentration of small particles (N_a) and coarse particles (N_c) are deduced from CSD. The various parameters thus determined are given in Table 2.

The columnar mass loading m_L was highest on 18 September during the post-fire period and then decreased towards the end of the month. Higher value of r_{eff} (~0.40 μm) was seen towards the end of the month. Mass loading is sensitive to the large particle end of the distribution, and small changes in the number of large particles can influence mass loading significantly, whereas r_{eff}, the ratio of the total volume to area of aerosols depends more on the relative dominance of large aerosols over smaller ones. Changes in the number of aerosols in the small particle end of the distribution do not affect mass loading significantly, whereas effective radius is affected. Increase in r_{eff} towards the end of the month is indicative of an increase in the relative concentration of larger particles.

This aspect is examined further by estimating the columnar concentration of small particles (N_a) and coarse particles (N_c). Table 2 gives the relative dominance of the number concentration of coarse particles N_c with reference to N_a. It is clear that the relative abundance of large particles (N_c/N_a) was highest at the end of the month. However, concentration of both fine-mode (N_a) and coarse-mode (N_c) aerosols was highest on 18 September.

Rainfall and wind can change the relative abundance of aerosols at any location. As already mentioned, light to moderate rainfall occurred from 19 to 24 September, which may be the reason for decreased concentration of both fine- and coarse-mode aerosols. The higher values of α and β (Table 1) as well as those of N_c and N_a (Table 2) on 18 September indi-

Table 1. Daily mean aerosol optical depth (AOD) at 500 nm and Ångström parameters

Dates in September 2005	Mean AOD at 500 nm	α	β
2	0.35	0.86	0.17
10	0.18	1.38	0.06
12	0.53	1.34	0.17
14	0.64	1.30	0.25
15	0.24	0.87	0.11
18	0.97	1.17	0.39
26	0.22	1.66	0.06
28	0.34	0.72	0.22

Table 2. Parameters deduced from aerosol size-distribution analysis

Dates in September 2005	r_{m1} (μm)	σ_1	r_{m2} (μm)	σ_2	m_L (mg m^{-2})	r_{eff} (μm)	N_c (10^{10} m^{-2})	N_a (10^{13} m^{-2})	N_c/N_a (10^{-3} m^{-2})
2	0.06	0.77			116.9	0.25	0.98	0.27	3.58
10	0.11	0.54			67.6	0.27	0.53	0.13	3.82
12	0.08	0.59			158.1	0.18	0.56	0.72	0.76
14	0.04	0.78			236.1	0.16	1.24	1.62	0.76
15	0.1	0.64			85.6	0.19	0.59	0.41	1.42
18	0.12	0.56			328.2	0.18	1.97	1.69	1.16
26	0.16	0.39			65.8	0.16	0.14	0.38	0.38
28	0.17	0.40	1.15	0.25	176.7	0.40	0.65	0.12	5.49

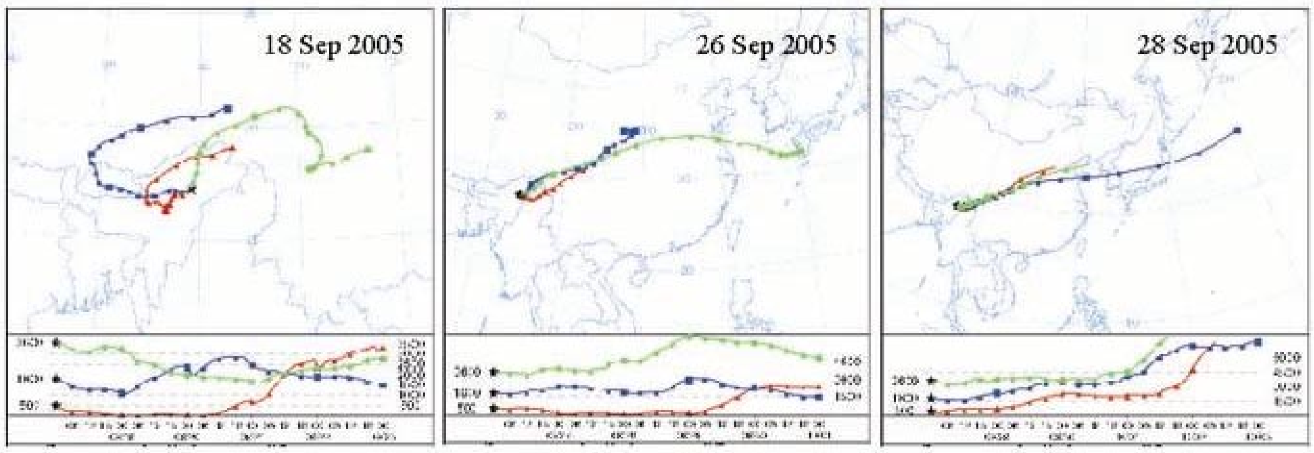

Figure 2. Plots showing forward wind trajectories obtained from NOAA HYSPLIT on selected post-fire days. Trajectories originate from the site of fire.

cate that the fire released higher than normal aerosols into the atmosphere. Decrease in AOD towards the end of the month may also be the result of wind blowing away the aerosols from over the area of observation in addition to rain wash. Surface winds over Dibrugarh are generally ~2–3 ms^{-1} and easterly for most of the year. Analyses of surface winds as well as forward trajectory analysis using the NOAA HYSPLIT model show that till 18 September, winds at the surface and higher levels were northeasterly and southeasterly that brought forth aerosols generated by the fire towards the observational site. As seen in Figure 2, after 18 September, winds at all levels changed direction by about 180° or became southwesterly, thus carrying away the aerosols in the opposite direction from the observational site. This accentuated by rain wash may be the reason for gradual decrease of AOD from 18 September onwards and low AOD on 26 and 28 September.

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M. M. GOGOI[1]
P. K. BHUYAN[1,]*
K. KRISHNA MOORTHY[2]

[1]*Department of Physics,*
Dibrugarh University,
Dibrugarh 786 004, India
[2]*Space Physics Laboratory,*
Vikram Sarabhai Space Centre,
Thiruvananthapuram 695 022, India
**For correspondence.*
e-mail: pbhuyan@gmail.com