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Impact of biomass burning on aerosol properties over tropical wet evergreen forests of Arunachal Pradesh, India

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ABSTRACT

Large spatial extent of biomass burning occurs in northeast region of India during annual dry season for shifting cultivation purposes. Characterization of optical properties of resultant biomass burning aerosols is important for the study of atmospheric radiative process and for remote sensing of both surface and atmospheric properties in these regions. In the present study, physical and optical properties of biomass burning aerosols in Arunachal Pradesh, North Eastern Region of India have been studied for the first time using ground based measurements using a MICROTOPS-II sunphotometer, an Aethalometer, a quartz crystal microbalance impactor (QCM), SO2 analyser, and an UV meter. Aerosol size distribution suggested dominance of accumulation mode particle loading during burning days compared to normal days. The slope of data points between simultaneous measurements of AOD (500 nm) and UV_{ery} suggested that every 0.1 increase in aerosol optical depth (AOD) causes 0.1 minimal erythemal dose (MED h^{-1}) reduction during normal day and reduction of 0.36 MED h^{-1} in ground reaching UV_{ery} during biomass burning periods. Diurnal variations of black carbon aerosol (BC) concentrations increased by a factor of ~2 during morning and evening hours compared to afternoon hours during biomass burning period. Daily average black carbon aerosol loading and SO_2 concentrations were found to be high during burning day compared to background values. The proportion of BC to total aerosol mass concentration was observed to be ~5% during normal days and ~14% during burning days. The changes in black carbon mass concentration values have implications for estimating radiative forcing due to aerosols over the region.

1. Introduction

Biomass burning which is widely prevalent in the tropics, serves to clear land for shifting cultivation and the expanding population. It produces large amounts of trace gases and aerosol particles, which play a pivotal role in tropospheric chemistry and climate (Arola et al., 2007; Crutzen and Andreae, 1990). Aerosol particles emitted from biomass burning are a major source of cloud condensation nuclei, which affect the microphysics of boundary layer clouds and later the radiation budget of the Earth by increasing the albedo (Penner and Novakov, 1996). Smoke particles from biomass burning may have a significant impact on climate by altering the global radiation balance. It is estimated that 114 Tg of smoke is produced per year in the tropics through biomass burning (Hao et al., 1996). Biomass burning and resultant production of aerosols containing black carbon, occurs primarily in the tropical and subtropical regions of the globe (Dwyer et al., 1998). Each year more than 100 million tons of smoke aerosols are released into the atmosphere as a result of biomass burning (Hao and Liu, 1994). More than 80% of this burning is in the tropical regions and these sub-micron smoke aerosols play a major role on the radiation balance of the earth–atmospheric system (Balis et al., 2004; Kaufman et al., 1998). They reflect incoming solar radiation back to space, thereby reducing the amount of sunlight reaching the Earth's surface.

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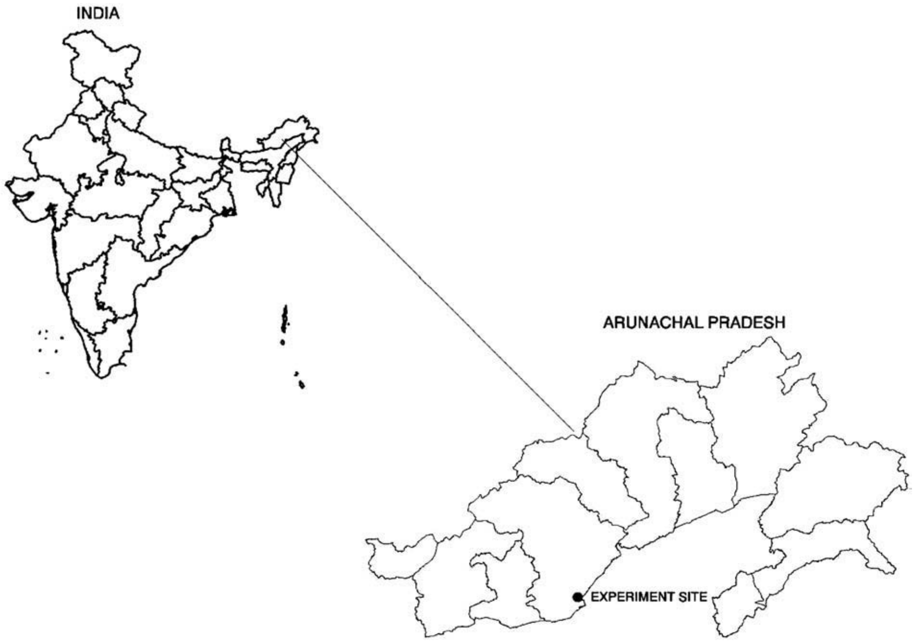

Fig. 1. Location map of study area.

This is often called the direct effect of smoke aerosols (Christopher et al., 2000; Reid et al., 2005a,b). In tropical Asia, shifting cultivation, fuel wood use, and deforestation provide for the majority of the burning with less than 10% of the burning in the savannas (Andreae, 1991). In the present study, simultaneous measurements of aerosols optical depth at different wavelengths namely 380, 400, 500, 675, 870 and 1020 nm, black carbon aerosols, SUV, SO_2 during 20th Feb to 16th March, 2005 over Arunachal Pradesh in northeast India. The data of 14th March, 2005 has been taken as biomass burning day and the remaining days have been taken as normal background concentrations.

2. Study area

Arunachal Pradesh is situated between 26°28′ N and 29°30′ N latitudes and 91° 30′ E and 97° 30′ E longitudes is the largest state in the northeastern part of India among seven sister states. It covers a geographical area of 83,743 km^2. The state is predominantly hilly and mountainous (Fig. 1). The measurements were carried out at Arunachal University Campus (27° 15′ N and 93° 77′E). Shifting or jhum cultivation is practiced in most parts of the state along the slopes in valleys (Sundriyal et al., 2002; Anon., 2002). There exists virtually no dry month in this belt and thus limiting available cloud free days for aerosol optical depth measurements. The forest types of this region are characterized by their unique structure and composition with important commercial timber species like *Dipterocarpus macrocarpus* (Hollong), *Shorea assamica* (Mekai), *Terminalia myriocarpa* (Holock), *Mesua ferrea* (Nahor), *Altingia excelsa*, *Artocarpus chaplasha*, *Michelia* spp. *Amoora wallichii*, *Tetrameles nudiflora*, *Ailanthus grandis* etc. Field experiments were carried out during 20th February to 16th March, 2005 and due to cloud cover limited cloud free measurements could be conducted.

3. Instrumentation and data analysis

Aerosol optical depth has been measured at wavelengths viz., 380, 440, 500, 675, 870 and 1020 nm using MICROTOPS-II sunphotometer having an accuracy of ±2% during available cloud free days in the experiment period (Morys et al., 2001). Continuous and near-real-time measurements of black carbon (BC) aerosol concentrations have been carried out using Aethalometer; model AE-21 of Magee Scientific, USA (Liousse et al., 1993). SO_2 was measured using UV florescent SO_2 analyser of Environment SA, France. UV-B radiation measurements were carried out using UV meter of Solar

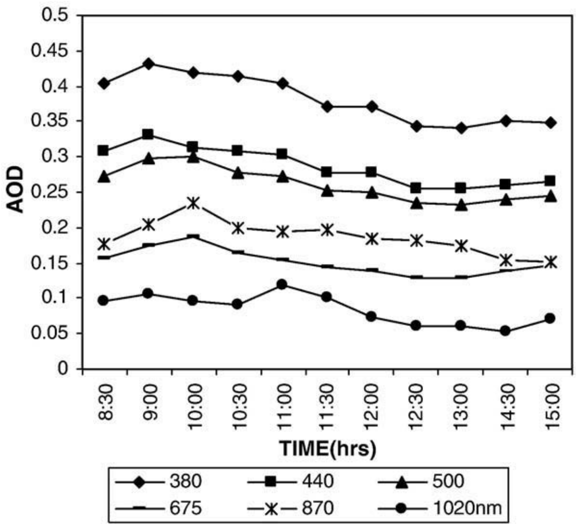

Fig. 2. Variation of aerosol optical depth during normal day.

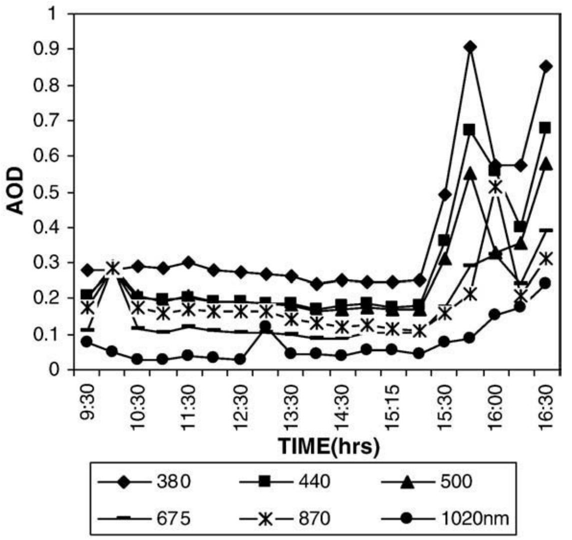

Fig. 3. Variation of aerosol optical depth during burning day.

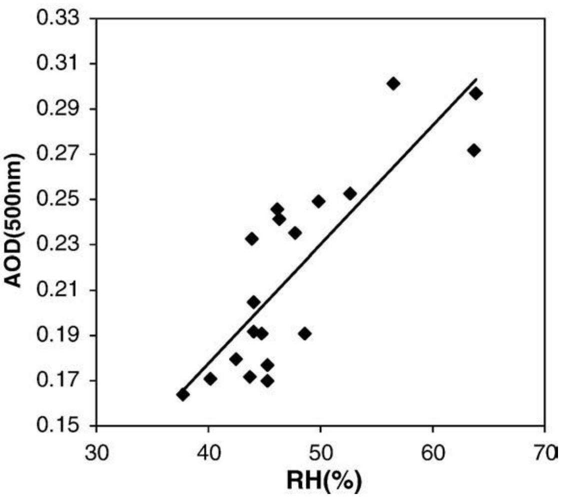

Fig. 5. Scatter plot of aerosol optical depth vs relative humidity.

Light Company, USA, which measures the radiation intensities, through a broad band, filter, in the 280–340 nm range (Singh et al., 2002). Measurements on mass-size distribution of aerosols were made regularly using a quartz crystal micro-balance (QCM) impactor model PC-2 of California Measurements Inc. (Latha and Badarinath, 2004).

4. Results and discussion

Figs. 2 and 3 show the variation of aerosol optical depth (AOD) during normal day (13th March, 2005) and burning day (14th March, 2005) in different wavelengths. AOD varies from 0.1 to 0.9 during burning period whereas normal day AOD varies from 0.1 to 0.42. High AOD was observed at 380 nm during both normal and burning days because of dominance of accumulation mode particles. Spectral variation of AOD showed peaks at 500 nm and 870 nm during normal day whereas during burning period peaks in AOD were observed at 440 and 870 nm due to different range particle loading. Good correlation has been obtained between aerosol optical depth at 500 nm and columnar water vapor (Fig. 4) and relative humidity (Fig. 5) and has been attributed to hygroscopic growth of aerosols. The wind direction has been observed to be from south over the study area during the measurement period. Wind speed showed negative correlation with aerosol optical depth at 500 nm (Fig. 6) suggesting possible scavenging of aerosols. Fig. 7 shows the variation of total aerosol mass concentrations from particle analyser measurements during normal days and burning day in 0.05 to 12.5 µm size range. In the particle analyzer measurements, less than 0.4 µm size has been considered as accumulation mode particles and above 0.4 µm size particles have been considered as coarse mode particles. Fig. 8 suggests that the accumulation mode particle loading has been found to be 14 times higher during burning day (260 µg m^{-3}) compared to the background measurements (19 µg m^{-3}). Retrieved size distributions suggest bimodal size distribution during burning

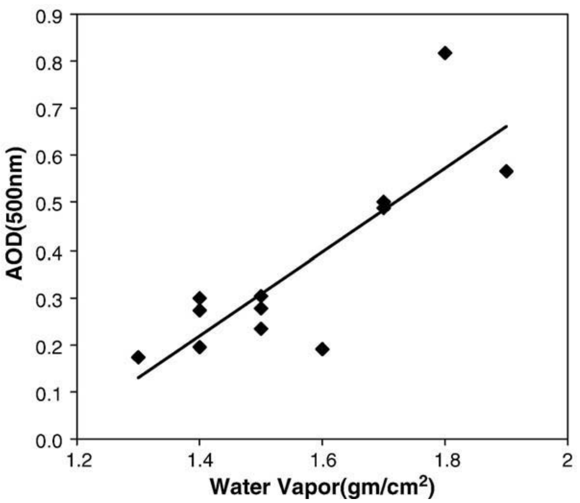

Fig. 4. Scatter plot of aerosol optical depth vs columnar water vapor.

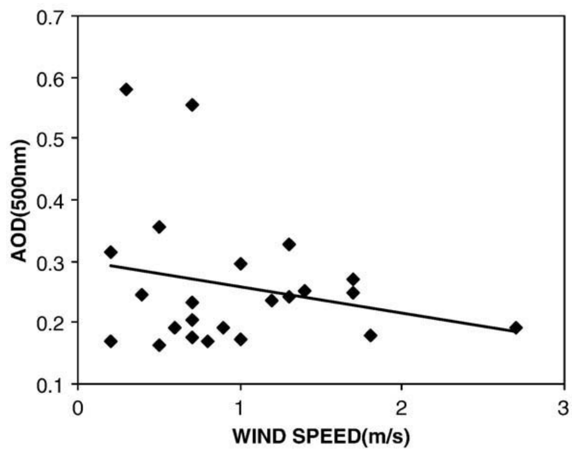

Fig. 6. Scatter plot of aerosol optical depth vs wind speed.

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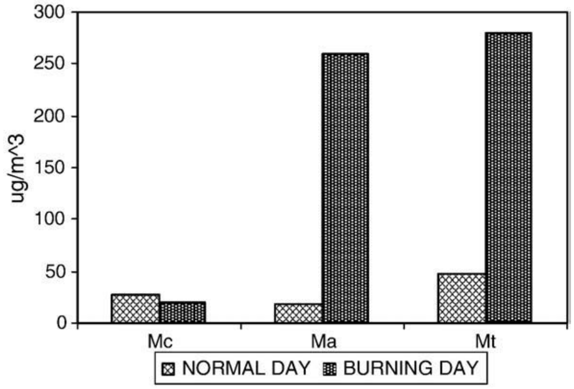

Fig. 7. Variation of total aerosol mass concentration, accumulation mode particle loading, coarse mode particle loading during normal day and burning day.

period with primary mode centered in small particle region around 0.1 μm (Fig. 9). The peaks have been found at 0.1 μm and 0.05 μm and are evident for intermediate optical depth values and accumulation mode particle loading due to addition of aerosols from burning source. There is a tendency for increasing particle size as aerosol optical depth increases with peak in distribution of accumulation mode. Increase in particle size may be related to aging of aerosols and associated changes in size distribution as a result of coagulation, condensation and gas to particle conversion. Fig. 9 suggests dominance of accumulation mode aerosols in volume size distribution and no peak has been observed above 3.2 μm in the coarse mode particle mode particles during burning day. There is no significant change in the coarse mode particle loading between normal day and burning day measurements. The fine mode ($r<0.15$ μm) particle loading has been found to be high followed by accumulation mode ($0.15<r<1.5$ μm) particle loading during burning day whereas coarse mode particle loading observed to be high during normal day (Fig. 9). Figs. 10 and 11 show the average aerosol mass-size distribution and number density during normal days and burning day over the study area. Mass-size distribution and number size distribution suggested high aerosol loading only in the accumulation mode range during burning day compared to normal days. In the coarse mode particle range, both number density and mass-size distributions have not showed any significant change between burning day and normal day. Fig. 12 shows the average diurnal variations of black carbon (BC) aerosol mass loading during 20th Feb to 16th March, 2005 over the study area. BC concentrations increased by a factor of ~2 during morning (6:00 to 9:00 h) and evening hours (19:00 to 23:00 h) compared to afternoon hours. During early morning hours, high values of BC have been attributed to the turbulence set-in by solar heating which breaks nighttime stable layer and aerosols in nocturnal residual layer are mixed up with those near the surface. Low values of BC during afternoon hours have been attributed to the dispersion of aerosols due to increase in boundary layer height. The average

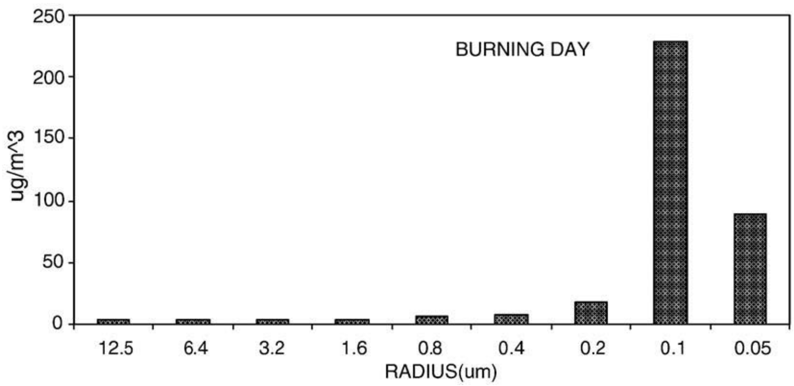

Fig. 8. Variations of total aerosol mass concentrations in different size ranges during burning day.

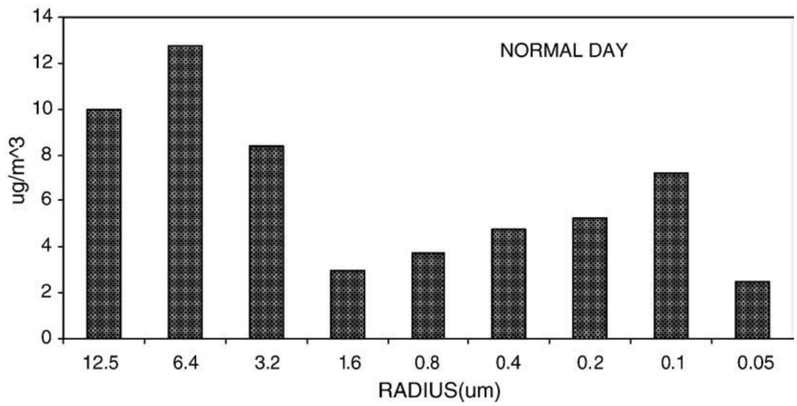

Fig. 9. Variations of total aerosol mass concentrations in different size ranges during normal day.

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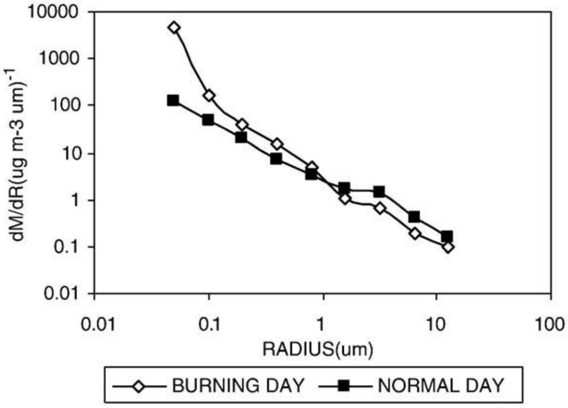

Fig. 10. Variation of aerosol mass-size distribution during burning day and normal day.

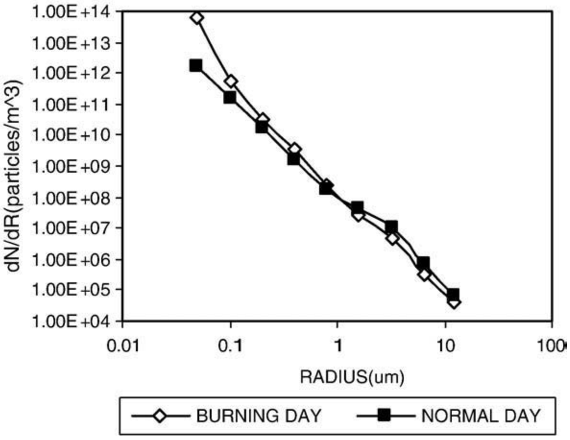

Fig. 11. Variation of aerosol number density during burning day and normal day.

diurnal BC concentrations during 20th Feb to 16th March, 2005 varies from 520–6000 ng/m^3 and are found to be in agreement with other studies cited in literature. In India, at Trivandrum, diurnal concentrations of BC observed to be in the range of ~300 ng/m^3 to 6000 ng/m^3 (Babu et al., 2002) and over Southern Indian Ocean, it ranges from 80–2800 ng/m^3 (Bhugwant et al., 2000). Fig. 13 shows the day average black carbon aerosol mass loading from 20th Feb to 16th March, 2005. The horizontal line in Fig. 13 shows the average value of BC concentrations from the background measurements over the study area. The day average BC concentrations found to be 6 times higher during burning day (~12,200 ng m^{-3}) than the background values (~2770 ng m^{-3}). This increase in BC concentrations during the burning day has been attributed to the emissions from biomass burning (Fig. 13). Black carbon aerosol levels came down to back ground levels in the subsequent day immediately after biomass burning. Fig. 14 shows day average values of SO_2 from 22nd Feb to 16th March, 2005 over the study area. During burning day, SO_2 concentrations have been found to be ~3 times higher (8.19 PPB) compared to normal day (2 PPB). We have used the total aerosol mass loading (M_t) obtained using the QCM Particle analyser in conjunction with BC (M_b) measurements during burning day and normal days to understand the contribution of biomass burning emissions to BC loading over the study area. The results suggest that the share of BC to total aerosol mass concentration observed to be ~5% during normal days and ~14% during biomass burning day. Such a large share of BC can have serious implications on surface and atmospheric radiative forcing. A mere 6% of soot contributes 11% to the aerosol optical depth (Satheesh et al., 2002); a 35% reduction in total solar radiation over the ocean surface and an increase of ~50% in atmospheric heating (Podgorny et al., 2000). In the present study we have made an attempt to study the impact of biomass burning aerosols on the UV erythemal radiation during over the study area. A statistical fit through the data points suggests negative gradient between AOD and UV_{ery} as reported in other studies (Latha et al., 2004). The slope of the data points between simultaneous measurements of AOD (500 nm) and UV_{ery} suggests every 0.1 increase in AOD causes for 0.1 MED/h reduction during normal day and reduction of 0.36 MED/h in ground reaching UV_{ery} during biomass burning period. This is the average direct radiative forcing efficiency at surface by biomass burning aerosols in the UV erythemal region during normal day and biomass burning day over the study area. The

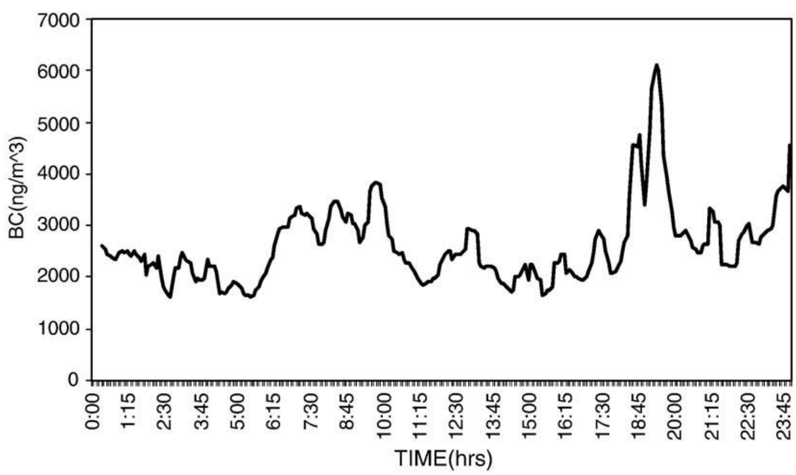

Fig. 12. Average diurnal variation of black carbon aerosols during normal days.

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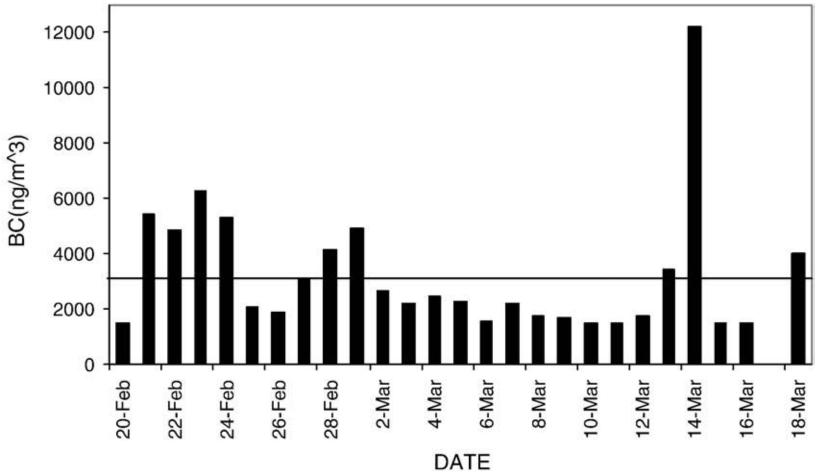

Fig. 13. Day average variation of black carbon aerosols during 20th Feb to 16th March, 2005 (horizontal line shows average background values of BC).

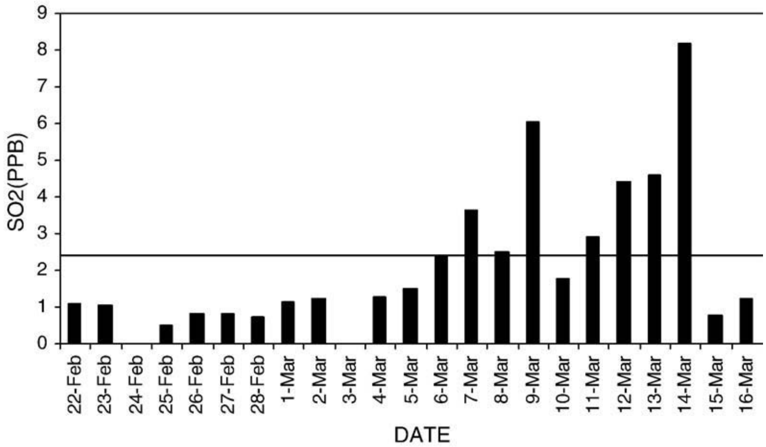

Fig. 14. Day average variation of SO_2 during 20th Feb to 16th March, 2005 (horizontal line shows average background values of SO_2).

high direct radiative forcing efficiency in the UV_{ery} region during burning day has been attributed to emissions from biomass burning.

5. Conclusions

Systematic measurements on biomass burning aerosols in tropical wet evergreen forests of Arunachal Pradesh, North-east India were conducted. Results of the study suggested that:

(1) High AOD at 380 nm during both normal day and burning day suggesting dominance of accumulation mode particles over the study area.
(2) AOD is positively correlated with RH and Columnar Water Vapour and negatively correlated with wind speed.
(3) Size distribution of biomass burning aerosols suggests that accumulation mode particle loading is 14 times high during biomass burning day compared to back ground.
(4) Simultaneous measurements of AOD (500 nm) and UV_{ery} suggest every 0.1 increase in AOD causes for 0.1 MED/h reduction in ground reaching UV_{ery} during normal day whereas reduction of 0.36 MED/h during burning day.
(5) SO_2 concentrations found to be ~3 times and BC concentrations ~6 times high during burning day compared normal day.
(6) Fraction of BC to total aerosol mass concentration observed to be ~5% during normal days and ~14% during burning day.

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