STUDIES ON EMISSIONS FROM FOREST FIRES USING MULTI-SATELLITE DATASETS OVER NORTH EAST REGION OF INDIA

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ABSTRACT:

Tropical biomass burning and associated emissions of aerosols into the atmosphere play a vital role in atmospheric perturbation and climate change. Aerosols containing black carbon are emitted primarily in the tropical and subtropical regions of the globe accounting to the release of almost 100 million tons of smoke into the atmosphere as a result of biomass burning. The present study aims at investigating the impact of forest fires on aerosol concentration over the northeast region of India, with the use of satellite data. The forests of northeast India are subjected to severe fire episodes during the January -May period every year mainly due to slash-and-burn agricultural practices. Daily active forest fire locations over the north-eastern region were derived using the nighttime satellite data from the Defense Meteorological Satellite Program – Operational Line Scan system (DMSP-OLS). These data were compared with variations in the Aerosol Index (AI) derived from the Total Ozone Mapping Spectrometer (TOMS) along with the Aerosol Optical Depth (AOD) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS). The analysis covered the period January-May 2006. The satellite data analysis suggested a maximum number of forest fires between February and April with a significant peak in last week of March. The results clearly suggested a significant correlation between forest fire occurrences and variations in the aerosol concentrations over the study region.

1. INTRODUCTION

Forest fires have been an agent of disturbance for thousands of years, have profound impact on the physical environment including: land cover, land use, biodiversity, climate change and forest ecosystems. They also have implications for human health and on the socio-economic system of affected regions. The extent of biomass burning has increased significantly over the past 100 years due to anthropogenic disturbances, and has become much more frequent and widespread. The burning of the world's living and dead biomass for land clearing and land-use change is a significant global source of atmospheric gases and particulates that impact the chemistry of the troposphere and stratosphere and the climate of our planet (Beringer et al., 2003). To quantify the role and importance of biomass burning as a global source of atmospheric gases and particulates to the atmosphere, information is needed on the global strength of biomass burning as a source of these environmentally significant compounds (Li et al., 2006). In this context, space observations have provided the first global perspective on the spatial and temporal distribution of biomass burning. Satellite-borne sensors can detect fires in the visible, thermal and mid-infrared bands. Active fires can be detected by their thermal or mid-infrared signature during the day or night or by the light from the fires at night. Such, satellite systems that have been evaluated for fire detection include AVHRR, which has a thermal sensor and makes daily overflights (Pu et al., 2006), the Defense Meteorological Satellite Program (DMSP) Optical Linescan System (OLS) sensor, which makes daily overflights and routinely collects visible images during its nighttime pass (Fuller and Fulk, 2000; Elvidge et al., 2001; Kiran Chand et al., 2006), MODIS (Giglio et al., 2003), AATSR and the NOAA Geostationary Operational Environmental Satellite (GOES) sensor, which provides visible and thermal images (Prins and Menzel, 1990).

In India, 55% of the total forest cover is prone to fires annually (Gubbi, 2003), which are mainly attributed to anthropogenic factors, like slash and burn agricultural practices, controlled burning, deforestation, fire-wood burning and others. Therefore, monitoring of forest fires and associated emissions of aerosols over India needs more attention to understand the cause-effect scenarios. Conventional methods in the quantification of aerosols involving ground inventory aided with information given by remotely sensed data from space-borne sensors are capable of addressing the problem with well-defined scientific and technical strength. Earlier studies over the north-eastern region of India suggested high aerosol loading from biomass burning associated with shifting cultivation practices (Badarinath et al., 2004). The availability of aerosol data sets from sensors such as MODIS, TOMS-OMI, and MISR provide a unique opportunity to study the spatial and temporal variability of aerosols over large regions (Ahmad et al., 2003; Alpert et al., 2002; Levelt, 2000; Christopher and Zhang, 2002).

The present paper focuses on analysis of the spatial and temporal variations on atmospheric aerosol concentrations over the north-eastern region of India during fire seasons. Specifically, we have analysed the variability in MODIS derived Aerosol Optical Depth (AOD), Aerosol Index (AI) derived from Ozone Monitoring Instrument (OMI) along with MODIS (daytimes) and DMSP-OLS (nighttimes) derived active fire occurrence.

2. STUDY AREA

Figure-1 shows the map of the study area. Northeast India comprises of seven-sister states of India viz., Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. They are bordered by Bhutan and China in the north, Myanmar in the south and southeast and Bangladesh in the west. Perennial rivers like the Brahamputra flow through this region. The Brahamputra valley is a meeting ground of the temperate east Himalayan flora and the wet evergreen and wet deciduous flora. Major forest types found in the study area are tropical evergreen and semi-evergreen, moist deciduous forest, bamboo brakes, Dipterocarpus, grass lands, riverain, Sal, Teak, Pine and others (Champion and Seth, 1968). The tropical vegetation of northeast India, which typically occurs at an altitude of 900m, faces severe threat due to shifting cultivation (locally known as 'Jhum') and increasing population. The natural jhum cycle, which used to be 5-6 years, has reduced to 2-3 years because of increasing population resulting in the conversion of primary forests to secondary forests and deciduous systems with a subsequent loss of biodiversity

Figure 1: Location map of study area.

3. METHODOLOGY

In the present study, daily nighttime satellite data sets of DMSP-OLS were used to generate fire products covering the north-eastern region of India. DMSP operates F14, F15 and F16 satellites in sun-synchronous orbits with nighttime overpasses ranging from about 7 pm to 10 pm local time. The descriptions of the sensor and the processing methodology have been described elsewhere (Elvidge et al., 2001; Kiran Chand et al., 2006). The advantage of using DMSP-OLS visible band is that the DMSP-OLS instrument can detect the flame front of an order of one magnitude smaller than the actual in an area (~45m^2) (Cahoon et al., 2000). This ability of DMSP-OLS is attributed to the unique low-visible light detecting capability of the instrument, which can measure radiances down to the order of 10^{-9} watts/cm^2/sr (Cahoon et al., 2000; Croft, 1978;). The OLS visible band signal is intensified at night to enable the detection of moonlit clouds, enabling the detection of lights present at the earth's surface (Elvidge et al., 1997).

Daily data sets of AURA-OMI AI covering the study area along with MODIS AOD data at 550nm on a daily basis were analyzed to study the variation in atmospheric aerosol loading. We used the aerosol Index (AI) values from the Ozone Monitoring Instrument (OMI) flown on the EOS Aura spacecraft, which was launched in July 2004. The absorbing AI from the current OMI sensor is defined as the difference between the measured (includes aerosols effects) spectral contrast at the 360 and 331 nm wavelength radiances and the contrast calculated from the radiative transfer theory for a pure molecular (Rayleigh) atmosphere (Ahmad et al., 2003). The AI is calculated using the ratio of the upwelling radiance between observations at 331 and 360 nm as:

$$AI = -100[\log_{10}(I_{360}/I_{331})_{meas} - \log_{10}(I_{360}/I_{331})_{calc}] \quad (1)$$

Since the calculation of I_{360} uses the reflectivity derived from the I_{331} measurements, the AI definition essentially simplifies to:

$$AI = 100 \log_{10} (I_{360\_meas}/I_{360\_calc}) \quad (2)$$

where the subscripts 'meas' and 'calc' refer to measured and calculated values of upwelling radiance at 360nm respectively.

The AI detects absorbing aerosols like dust, smoke and volcanic ash over all terrestrial surfaces including deserts and snow-ice covered surfaces (Torres et al, 1998). Values of AI near zero indicate cloud presence. In interpreting these results, care has to be taken on some surface effects, such as sea glint and ocean color, which can enhance AI.

The Moderate Resolution Imaging Spectroradiometer (MODIS) is one of the five sensors on-board TERRA/AQUA satellites with 36 spectral bands and acquires data in three different spatial resolutions of 250m (bands 1 and 2), 500m (bands 3 to 7) and 1000m (bands 8 to 36) covering the visible, near infrared, short-wave infrared and thermal-infrared bands. The MODIS data sets over the region were processed for the occurrence of forest fires with the methodology described elsewhere (Kiran Chand et al., 2006; Giglio et al., 2003). Daily column integrated aerosol optical depths from February to May were retrieved with the MODIS instrument onboard TERRA satellite. The data reported by the MOD04 Level-2 10 x 10 km resolution atmospheric aerosol product at the wavelengths of 470, 550, 660 nm, were also used to estimate the spatial distribution of the biomass burning aerosol (King et al., 2003). Ground data pertaining to AOD over test site of Hyderabad, India were used to compare MODIS derived AOD. The analysis showed correlation coefficient of the order of 0.7.

The fire occurrences derived from MODIS and DMSP were compared with optical data from the Indian Remote Sensing Satellite (IRS-P6) Advanced Wide Field Sensor (AWiFS). The Advanced Wide Field Sensor (AWiFS), on-board IRS-P6 operates in four spectral bands, i.e. green (0.52 – 0.59μm), red (0.62 – 0.68μm), near infrared (0.77 – 0.86μm) and short-wave infrared (1.55 – 1.70μm) with a 56-meter spatial resolution. The AWiFS camera is realized using two separate electro-optic modules, which are tilted by 11.94 ^{o} with respect to nadir in order to cover the wide field imaging with minimum geometric distortion. Each module covers a swath of 370km providing a combined swath of 737km with a side lap between them. Fire detection using DMSP-OLS nighttime data is based on the identification of lights outside the set of known persistent (stable) lighting sources. Basic procedures used to generate the stable lights image have been described elsewhere (Elvidge et al., 1997). The stable lights database is used as a mask, which is applied to the incoming data stream. Lights found on land, but outside the stable lights mask, are possible fires.
The initial steps for generating OLS fire product, including the identification of lights and clouds, missing data, and bad scan lines, plus geolocation are fully automated and are described elsewhere (Elvidge et al., 2001). The light detection algorithm settings are altered during nights with full nights to reduce the

number of light detections reflecting by moonlit clouds. Pixel identities (e.g. lights, clouds, clouds with light, missing scan lines) are marked in a flag file which overlays the OLS image data. In case of lights that are coinciding with clouds, particularly during moonlight conditions, the light detections are filtered based on the stable lights mask and a mask for water bodies. The remaining lights are overlaid with stable lights data and thermal band image and visually reviewed to identify and remove light sources that are not from to fires. This may include bad scan lines, lightning, city lights not fully removed, or heavily lit clouds. After final editing of the DMSP-OLS fire image, fires that fall within forest regions of the study area have been extracted using a forest mask to eliminate additional lights that are not part of forest regions.

4. RESULTS AND DISCUSSION

Figure-2 shows the monthly composites of nighttime forest fire locations over the study area during the fire season from January to May 2006. It is obvious from figure-2, that forest fires started early in February and continued till May with a significant peak in March and April. The majority of the forest fires were detected in Meghalaya, Mizoram, Manipur, Nagaland and Tripura. This is primarily attributed to the slash-and-burn agricultural practices, which are highly applied in the study area during February to May over moist deciduous and wet evergreen forests. This also leads to high biomass burning aerosol loading during March – April over the northeastern region of India each year (Badarinath et al., 2004).

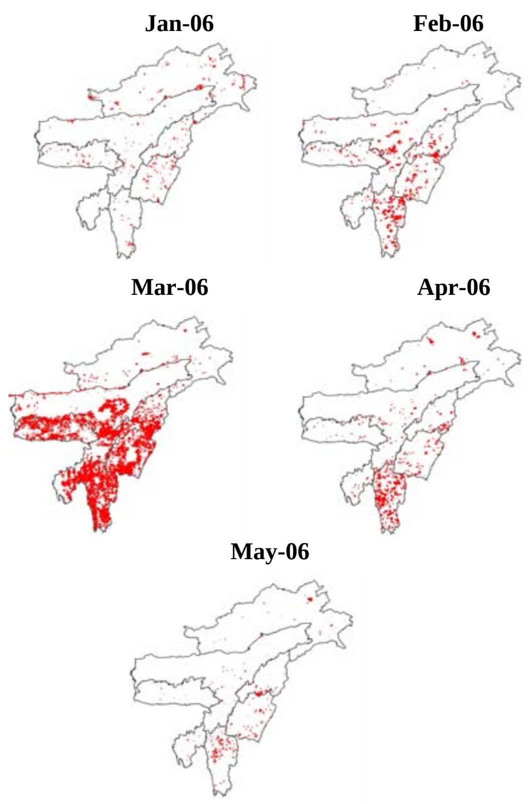

Figure 2: Monthly occurrence of nighttime active forest fires over north-eastern region of India.

To understand the influence of forest fires on atmospheric aerosol properties, satellite datasets of two independent instruments MODIS and OMI were analysed together with DMSP-OLS nighttime forest fire occurrence over the study region.

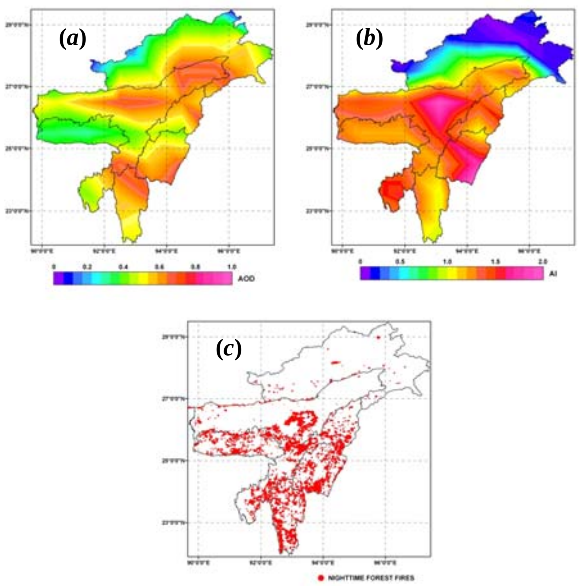

Figure 3: (a) Spatial distribution of MODIS aerosol optical depth at 0.55 µm over the north-eastern region of India during 25-31 March, 2006, (b) Spatial distribution of the OMI aerosol index for 25-31 March, 2006, (c) Spatial distribution of DMSP-OLS derived nighttime active forest fire occurrences over North-eastern region of India during 25-31 March, 2006.

Major forest fire events observed during last week of March, 2006. Figure-3 (a-c) shows the spatial distribution of Terra-MODIS aerosol optical depth at 0.55 µm, AURA OMI aerosol index and DMSP-OLS derived nighttime active forest fire occurrences over the north-east region of India during 25-31 March, 2006. Comparing the figures 3(a), (b) and (c) it is obvious that increased values of MODIS AOD_{550} and OMI aerosol index in accordance with the increase in the number of fire occurrences over the region. The AI values varied from a minimum of 0.2 to a maximum value of 1.9, suggesting higher concentration of absorbing aerosols over the region during the last week of March (Figure-3b).

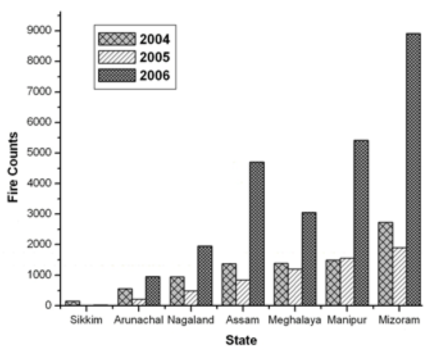

Figure 4: State wise DMSP-OLS derived nighttime forest fire counts during 2004, 2005 and 2006 over north-east region of India.

Figure-4 shows the forest fire counts per state derived from DMSP-OLS satellite data over the north-eastern region of India, during 2004, 2005 and 2006. It is observed that each year Mizoram state experienced more number of fires followed by Manipur and Assam. Earlier studies done by (Badarinath et al., 2004) suggested intensive practices of slash-and-burn agriculture, which are the main sources of forest fires and emission of aerosols over Mizoram.

Figure – 5 (a) shows the day-to-day variation of DMSP-OLS derived nighttime forest fire events together with the TERRA MODIS aerosol optical depth (AOD) at 550 nm over Mizoram, where the majority of fires were observed (figure-2). It can be noticed that higher values of MODIS AOD are in accordance with high fire counts independently from the wavelength, suggesting the contribution of forest fires to atmospheric aerosol loading over the region. Figure – 5 (b) shows the day-to-day variation of DMSP-OLS derived nighttime forest fire events together with the TOMS – OMI Aerosol Index (AI) over Mizoram. The positive values of TOMS –OMI AI were only considered, corresponding to biomass burning aerosol (BBA) loading. AI is a very useful qualitative indicator of the presence of absorbing aerosols (Duncan et al., 2003). It can be noticed from the figure-5 (b), that higher AI values are observed in regions with high forest fires, a fact which is attributed to the contribution of biomass-burning aerosols from forest fires over the region.

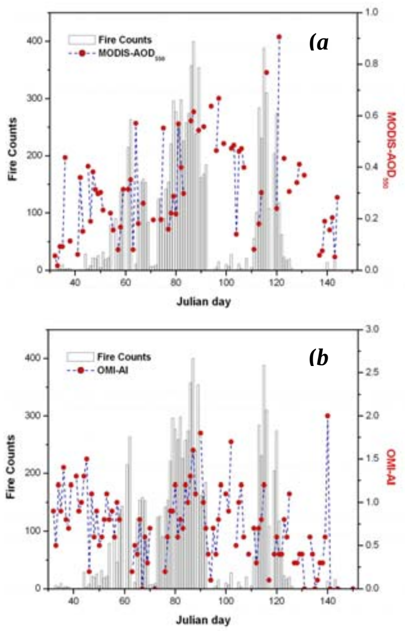

Figure 5: Variations of DMSP-OLS derived nighttime forest fire counts, together with Terra MODIS AOD_{550} (a) and OMI-AI (b) over Mizoram state during January-May, 2006.

Figure-6 shows IRS-P6 AWiFS data of 21[st] March 2006 for the state of Mizoram overlaid with DMSP-OLS derived fire locations for the same day. It can be observed in figure-6 that there is a large incidence of smoke due to forest fires and fire pixels observed in DMSP-OLS and MODIS match with the optical data on slash-and-burn patches. Mizoram state has 87 percent forest area with 51 per cent dominated by Melocanna baccifera bamboo species. The bamboo species had flowering in the year2006. The bamboo species die after flowering and there was extensive clearing and burning resulting in higher incidence of forest fires as observed in satellite data.

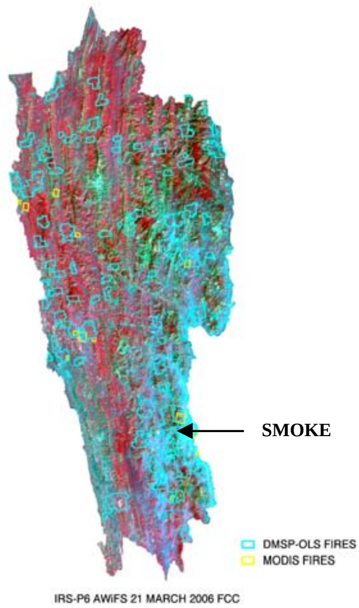

Figure 6: DMSP-OLS derived nighttime and MODIS derived daytime active fire locations overlaid on IRS-P6 AWiFS FCC of 21 March, 2006.

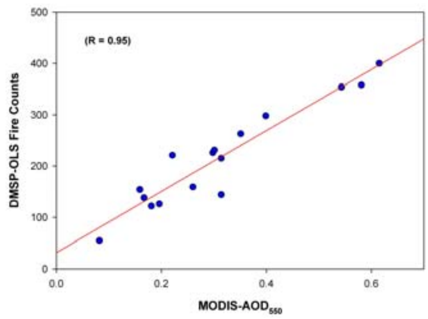

Figure 7: Scatter plot of DMSP-OLS fire counts v/s MODIS-AOD_{550}.

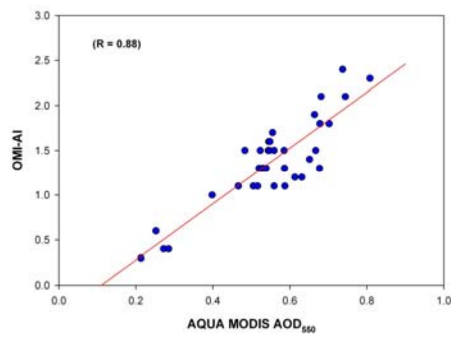

Figure 8: Scatter plot of OMI-AI v/s MODIS-AOD_{550}.

The scatter plot of DMSP-OLS derived nighttime forest fire events v/s MODIS aerosol optical depth (AOD) at 550 nm (Figure-7) showed good correlation (R = 0.95). The scatter plot of MODIS AOD at 550nm and TOMS-OMI AI (Figure-8) showed good correlation (R = 0.88) suggesting that multi-satellite observations over the region confirm the presence of absorbing aerosols due to biomass burning.

5. CONCLUSIONS

In the present study aerosol loading over the northeast region of India were analyzed using forest fire occurrences derived from DMSP-OLS nighttime satellite data, Aerosol Index (AI) from TOMS-OMI and AOD from TERRA-MODIS. Results of the study suggested that:

- Higher incidence of forest fires over the study areas due to slash and burn agriculture practices in March and April.
- Amongst various states, Mizoram showed to have higher incidence of forest fires.
- Analysis of OMI-AI and MODIS-AOD with fire events suggested good correlation in spatial patterns of aerosol concentration with fire locations.
- Results of the study suggest possible utilization of multi-satellite data sets in understanding differential aerosol loading over large regions. The information on extent and type of aerosol loading in atmosphere provides useful input for estimating their radiative impacts.

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