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Impact of Dashain Festival on Aerosol Optical Properties over an Urban Center of Eastern Nepal, Birtamode

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Abstract

An attempt has been made to investigate the changes in characteristics of aerosol optical properties induced during Dashain celebration 2018 over an urban city, Birtamode. Ground- based measurements of Aerosol Optical Depth (AOD) were carried out using a Microtops II sun-photometer during 13^{th} to 27^{th} Oct, 2018. AOD values on days before Dashain were in the range of 0.6 which increased above 1 attaining maximum value of 1.6 on 19^{th}. The AOD values started dropping below 1 on 24^{th}, attaining a daily average of 0.64. The peak values on respective days were validated through MODIS AOD retrievals. Similar days with peak values were identified during Dashain based on 5-year averaged MODIS AOD. The air mass trajectories show that the increase in the AOD values is of local origin.

Keywords

Aerosol optical depth, Microtops II Sun-photometer, MODIS, pollution

1. Introduction

Aerosols are suspended solid particulate materials and liquid droplets in the atmosphere. Having natural and anthropogenic origin, their size varies from 0.001μm to 100μm. They interact with incoming solar radiation and outgoing terrestrial long wave radiation by scattering and absorbing and produce radiative effect of cooling or warming the atmosphere. The climatic impact of aerosols has been confirmed by many researcher groups around the world. They take major role in enhancing poor air quality and pollution in the environment as well as harmful effect in human health[1]. Certain nature of aerosols cause negative radiative forcing indirectly through formation of clouds and thereby influence cloud properties and their lifetime[2]. Similarly, some aerosols such as black carbon and mineral dust cause positive radiative forcing (warming) by absorbing solar radiation[3][4]. The direct and indirect effects of atmospheric aerosols on radiative forcing and cloud microphysics are strongly dependent on their size characteristics and chemical composition[5]. Atmospheric aerosols exhibit very large spatial as well as temporal variability. Even though the natural aerosols play a very significant role on a global scale, aerosols of anthropogenic origin are very important on a regional scale[6][7]. Aerosol optical depth is a measure of attenuation of direct solar radiation by aerosols that is affected by the amount, type and size of aerosols.

Birtamode is one of the rapidly growing cities of eastern Nepal. It is a socio-economic hub of one of the five most populated districts of the country. Air above Birtamode is getting polluted by vehicular emissions, construction works, fumes from brick kilns, careless habit of burning waste, burning of agromass in the surrounding, etc. This study is the first of its kind in Birtamode and the objective of this paper is to identify the diurnal variation of Aerosol Optical Depth (AOD) and identify the changes caused during the national festival, Dashain.

2. Experimental Details

2.1 Study Area

A base station was selected in Birtamode region (26.65° N, 88° E, 137 m a.s.l.) for ground based measurement of AOD. Based on physiographical and climatic conditions, the region can be classified as a sub- tropical one with annual precipitation over 2000 mm per year. The major sources of air pollution in

Birtamode include industries (mainly brick kilns), biomass burning and vehicular emissions. Dashain is celebrated throughout Nepal and the people of Birtamode along with other parts of the country celebrated it from 16^{th} October to 20^{th} October 2018. The population of Birtamode and the surrounding increased temporarily during the festival.

2.2 Instrumentation

The ground- based spectral AOD measurements were carried out continuously from 13^{th} October to 27^{th} October at an interval of 30 minutes from 6:30 am to 4:30 pm. The instrument used was Microtops II Sunphotometer manufactured by Solar Light Company Inc., USA. It contains five different interference filters at 340-, 440-, 500-, 675-, and 870-nm wavelengths and provides columnar information about aerosols. The sun- photometer works on the principle of extinction of solar radiation intensity at a certain wavelength and has the bandwidth of 2 nm at a 340- nm channel and 10 nm for rest of channels [8][9]. The instrument has five accurately aligned optical collimators with 2.5° as a full field of view. More details about the Microtops II characteristics, its calibration, performance and accuracy of the retrievals are given in Morys et al.[10].

Solar radiation traversing through the terrestrial atmosphere undergoes extinction due to three processes, namely Rayleigh scattering by air molecules, Mie scattering by aerosols, and molecular absorption. The instantaneous solar radiation intensity I reaching the ground is related to TOA radiation intensity I_0 through Bouger-Lambert-Beer law:

$$I = I_0 e^{-\tau(\lambda)m} \tag{1}$$

where $\tau(\lambda)$ is the aerosol optical depth, and m is the optical air mass, which is the mass of substances in a vertical cross section unit and is a function of solar zenith angle[11].

2.3 Angstrom's Coefficients α and β

The spectral AOD and the Angstrom exponent, α are the two main parameters for examining the columnar aerosol loading and properties. α contains information about the size of the particles or the volume fraction of the fine versus coarse- mode particles[12] and can be easily determined with Angstrom's power law[13]:

$$\tau(\lambda) = \beta\lambda^{-\alpha} \tag{2}$$

$$ln[\tau(\lambda)] = -\alpha ln(\lambda) + ln(\beta) \tag{3}$$

where $\tau(\lambda)$ is the estimated AOD at the wavelength λ, α is the Angstrom exponent and β is the turbidity coefficient which equals to AOD at $\lambda = 1\mu$m. In the present study, the values of α and β were computed in the wavelength interval 340- 870 nm, applying least square method to Eqn.3.

2.4 Error Analysis

The Microtops II sunphotometer was used for the first time in Birtamode and, so, special care was taken while making observations and also in the retrievals of spectral AODs and computation of Angstrom's parameters. To avoid any possible cloud contamination, measurements were only done on clear days, with few or no clouds covering the sky or clouds far from the sun disk. From the scans the values suspected to have been affected from undetected thin cirrus clouds have been removed. From the new dataset, the spectrums that calculated AODs beyond the daily mean $\pm 2\sigma$ were also excluded from the analysis.

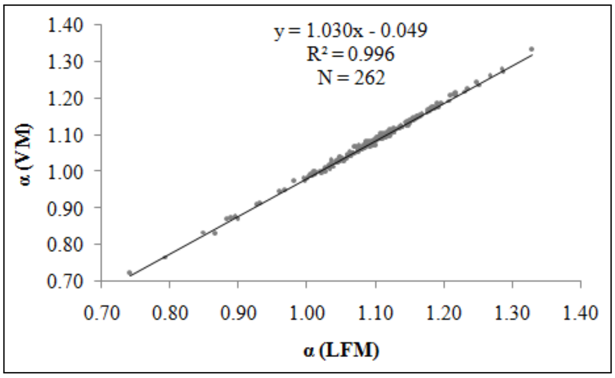

Figure 1: Correlation between values obtained with different techniques in the wavelength range 340-870 nm [LFM: Linear fit method; VM: Volz method]

Since spectral AOD presents a curvature in log-log coordinates due to inaccuracies in the fit of the Angstrom's formula the consistency in the retrievals of Angstrom exponent with different methods give credit to the accuracy of the spectral AOD retrievals and minimizes the curvature effect. So, α values obtained with the linear fit method (LFM, total use of five wavelengths) with those obtained with the Volz method (VM, use of two wavelengths) have been correlated (Fig. 1). The results show an excellent correlation (R^2= 0.99) between LFM and VM. The slope value close to 1 and negligible intercept indicate great accuracy in the retrievals of α and, therefore to the spectral AOD[14].

2.5 MODIS

MODIS instrument makes radiance observations in 36 spectral channels at spatial resolution ranging from 250m to 1km with a swath width of 2300km, allowing almost daily global coverage[15]. The MODIS sensor is onboard the polar orbiting NASA-EOS Terra and Aqua spacecrafts with equator crossing times of 10:30 and 13:30 local solar time (LST)[16], respectively. MODIS measures AOD with an estimated error of $\pm$ 0.05 $\pm$ 0.20τ[17] over the land. Daily AOD data (Level 2, Version C6.1) over Birtamode acquired with the MODIS instrument onboard the Aqua and Terra satellites were retrieved from the LAADS DAAC data platform(https://ladsweb.modaps.eosdis.nasa.gov/). The MODIS aerosol retrieval in this study(Deep_Blue_Aerosol_Optical_Depth_550_Land) was calculated on a 10km $\times$ 10km resolution (Level 2), which was retrieved from the higher resolution radiance measurements (Level 1B) with the use of Deep Blue (DB) algorithm. DB algorithm makes use of 0.412, 0.47 and 0.65 μm top of the atmosphere (TOA) reflectance for deriving AOD at 550 nm[18]. The data thus obtained was compared with the ground-based data obtained from the Microtops II sun-photometer. To maintain the consistency in data characteristics, Microtops AOD at 550nm was derived using the Angstrom's power law (Eqn. 2) where α and β were estimated from Microtops derived AODs in the spectra ranging from 340 to 870nm.

3. Results and Discussions

3.1 Daily Variation of AOD

Figure 2 shows the variation of Microtops AOD for 15 days in October that includes Dashain (16th – 20th Oct). The trend of AOD increases towards the festive days which attain highest values on 17th, 18th, 19th and 20th October (i.e., day 5, 6, 7, and 8 out of 15 days). The AOD value rises as high as 1.6 whose value is nearly 0.6 before Dashian. The value remains above 1 for few more days finally decreasing to as low as 0.27 on 27th October (i.e., day 15). The highest value of AOD at day 5, 6, 7, and 8 is attributed to higher anthropogenic and biomass burning emissions due to temporarily increased population in order to celebrate Dashian at Birtamode and surroundings. The increased emission from petrol engines is validated through the demand of petrol at Charali depot of Nepal Oil Corporation. One of the highest demands of petrol is on Ashwin (October, 2018) in order to meet the requirements during festive season (Table 1). The increase in emission from biomass burning is explained in section 3.4. Similarly, the national capital, Kathmandu, which is inhabited by people from all around the country exhibits decrease in black carbon (BC) concentration during Dashain [19] which is attributed to temporarily decrease in population.

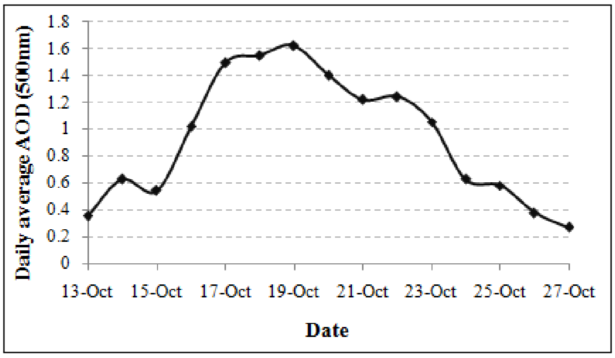

Figure 2: Variaiton of AOD (500 nm) before, during and after Dashain

Table 1: Import of petrol at Charali depot, Jhapa in 2018 (Source: Nepal Oil Corporation)

SN	Month	Petrol (kilo liters)
1	Shrawan	1997
2	Bhadra	1766
3	Ashwin	2466
4	Kartik	1898
5	Mangsir	1963
6	Poush	1919
7	Magh	1967
8	Falgun	2110
9	Chaitra	2332
10	Baishak	2166
11	Jestha	2197
12	Ashad	2190
	Total	24971

3.2 Validation of MODIS AOD

The MODIS AOD data obtained from Terra and Aqua satellite was compared with the Microtops data at $\pm$30 minutes of the respective satellite overpass. The MODIS AOD values show excellent correlation with the ground based observations made by Microtops. Figure 3 show the scatter plots between two values for 15 days (13^{th} October to 27^{th} October 2018). The R^2 value for Microtops AOD versus MODIS AOD at nearest pixel is high for both Terra (0.946) and Aqua (0.947). Similarly, the R^2 value corresponding to 3×3 grid for Terra is higher compared to 5×5 grid which is quite reasonable as the data coverage changes from $900km^2$ to $2500km^2$. However, for Aqua the R^2 value corresponding to 5×5 grid is higher compared to 3×3 grid which is contradictory to that obtained for Terra. Moreover, these values are much higher compared to that obtained in Lumbini i.e., 0.62 and 0.66 for Terra and Aqua respectively [20]. The higher R^2 value for Birtamode is attributed to comparison of instantaneous AODs at ±30 minutes of Terra and Aqua overpass compared to the daily averaged AODs taken in Lumbini. The R^2 values in Birtamode is much higher than that obtained at Ahmedabad (0.3 $\sim$0.69) where similar comparison procedure was applied[21]. This is due to the use of latest collection version C6.1 over C004 and C005.

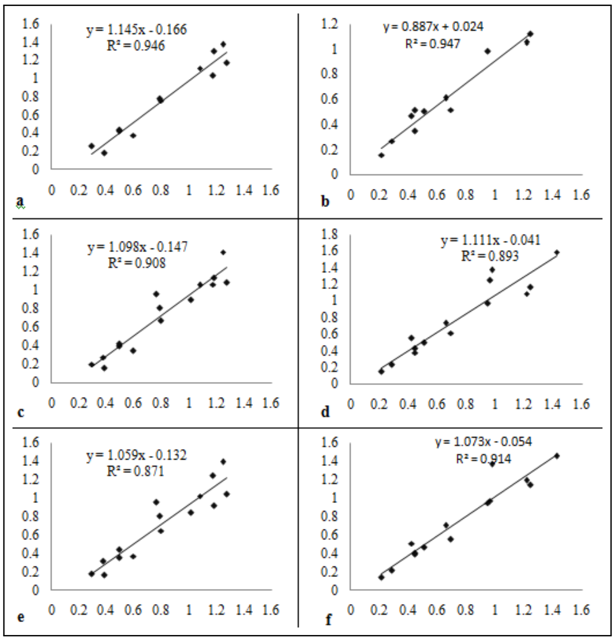

Figure 3: Scatter plot showing Microtops AOD and MODIS AOD (a,Terra) (b,Aqua) at nearest pixel (c,Terra) (d,Aqua) average value on 3×3 grid and (e,Terra) (f,Aqua) average value on 5×5 grid

3.3 Variation of MODIS AOD

The AOD values obtained from MODIS onboard Terra satellite show peak values around day 5, 6, 7 and 8 as obtained from the Microtops (Fig.4), which ensures higher anthropogenic emissions during Dashain. For the study of long term scenario the gridded average values (3×3 and 5×5) give better trend representation to the ground values as significant number of values at nearest pixel is missing.

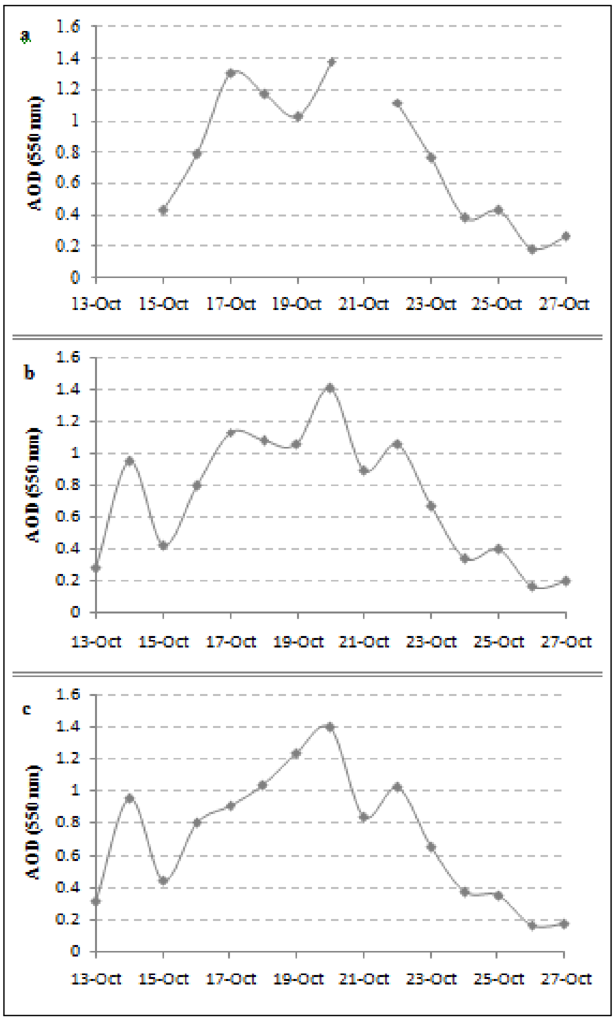

Figure 4: Variation of MODIS AOD (Terra) before, during and after Dashian, 2018 (a) at nearest pixel (b) avg. value at 3×3 grid (c) avg. value at 5×5 grid

To verify the peak values obtained during Dashian, 5-year (2013- 2017) averaged AOD values retrieved from MODIS have been plotted in Figure 5 and 6. It shows that the peak values lie around day 5, 6 and 7 which is quite similar to that obtained from ground based measurement in 2018, which illustrates that the higher values of AOD in Birtamode and surrounding during Dashian is a normal phenomenon.

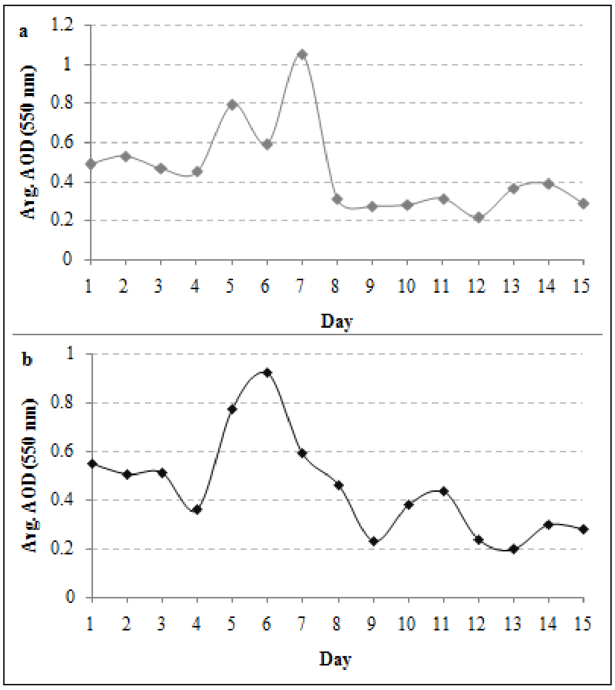

Figure 5: Variation of averaged MODIS AOD (a) Terra and (b) Aqua at 3×3 grid before(1-3), during(4-8) and after(9-15) Dashian, 2013-2017

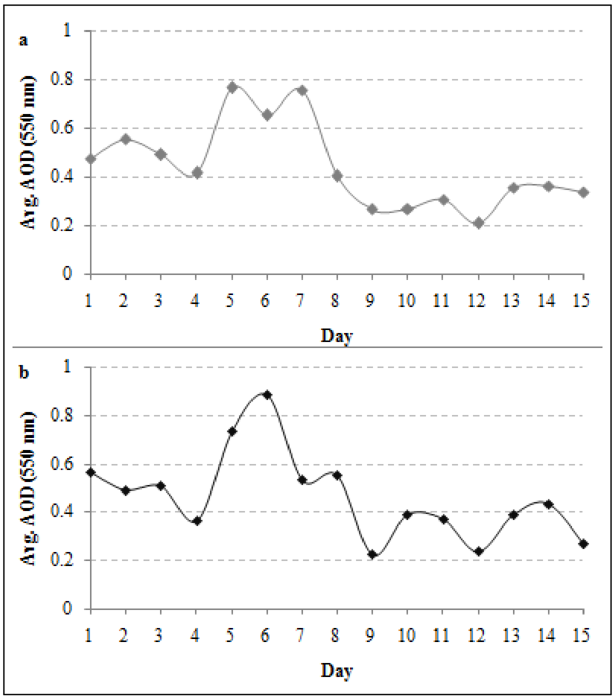

Figure 6: Variation of averaged MODIS AOD (a) Terra and (b) Aqua at 5×5 grid before(1-3), during(4-8) and after(9-15) Dashian, 2013-2017

3.4 Classification of Aerosol

One of the methods of aerosol classification is correlating AOD and α. Thus scatter plot (Fig. 7) between AOD and α is used to classify different aerosol types over Birtamode. Based on threshold values for AOD and α from literature[9], five dominant aerosol types are identified, viz., clean background condition (CBC), mostly dust (MD), anthropogenic aerosol (AA; mainly coming from urban/industrial regions around the measuring site and, as well as from vehicular emissions), biomass burning (BB), and mixed type (MT) aerosol. Table 2 represents the threshold values used for classification of aerosol in this study [9].

Table 2: Threshold values of AOD and α for aerosol classification

Aerosol Type	AOD	α
Clean Background Condition (CBC)	<0.3	<0.9
Mostly Dust (MD)	>0.7	<0.6
Anthropogenic Aerosol (AA)	0.3 - 1.0	>0.9
Biomass Burning (BB)	>1.0	>1.0
Mixed Type (MT)		

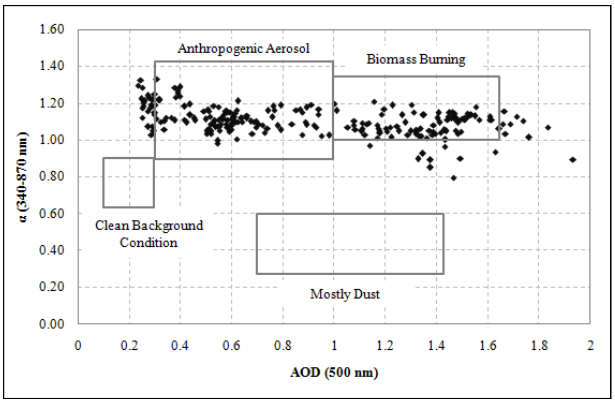

Figure 7: Scatter plot between AOD(500nm) and α(340-870nm) during Dashain

The AA type has maximum contribution (~86.5%) before Dashain which is replaced by BB (~82%) during Dashain. The drastic change in the aerosol contribution by BB is attributed to the celebration induced emission which basically includes the emission from fire woods. The BB aerosol type is more frequent during post- monsoon due to extensive agro-residue burning in the Indo Gangetic Plain. The CBC and MD type has no contribution during the study period.

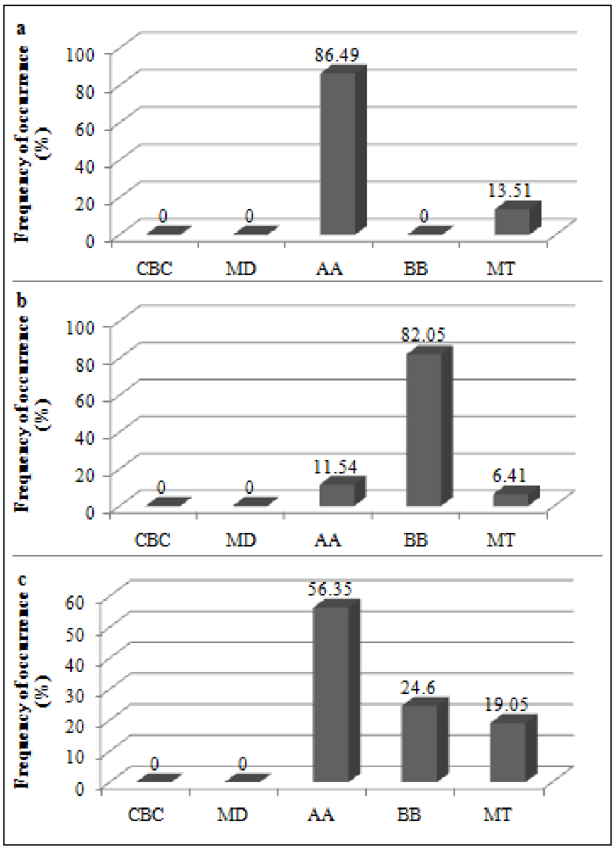

Figure 8: Frequency of occurence of each aerosol type (a) before Dashain (b) during Dashain (c) after Dashain

4. Conclusions

The ground- based observations of Microtops II sun-photometer were analyzed at an urban station of Birtamode, during Dashian festival period and compared with satellite retrievals. The results of the analysis suggest that:

- The observed AOD values are higher during Dashain festival period.
- The MODIS AOD values shows good correlation with ground-based sun-photometer.
- MODIS AOD variation shows similar trend during Dashain festival based on 2018 data and 5- year (2013- 2017) averaged data.
- Results of the study suggest possible utilization of MODIS data sets in understanding the long term trend of aerosol characteristics in Birtamode.

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