Research Paper Physics

Role of Aerosol in Contrasting Change in Pre-Monsoon Rainfall Over Eastern And Western Region of Brahmaputra Valley in Assam

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ABSTRACT

The impact of aerosol on local pre-monsoon seasonal rainfall over the complex terrain of Brahmaputra valley is investigated using multiyear satellite based aerosol and rainfall products. The decadal (2001-2010) variation of aerosol optical depth, Black carbon aerosol, Ångström exponent (α), cloud fraction, cloud liquid water path, cloud drop effective radius and precipitation have been investigated using products derived from MODIS and TRMM sensor data and interpolated surface precipitation observations over the valley. The parameters have been studied over the eastern and western regions of the basin separately. It has been observed that the higher increase in total aerosols and absorbing aerosols with increase in α over the western Assam is negatively correlated with precipitation while a decrease in α, unchanged black carbon concentration, and moderate increase in aerosol aided with transport of un-precipitated moisture from western part of the valley is positively correlated with precipitation over the eastern Assam area.

KEYWORDS | Aerosol, rainfall, cloud, Brahmaputra valley

INTRODUCTION

Aerosols are one of the major drivers of climate change (IPCC AR5, 2014) and affect the climate system by changing cloud characteristics in many ways in addition to radiative forcing. Aerosols serve as cloud condensation nuclei (Warner and Twomey,1967), modifying cloud properties and affecting the climate system. The first indirect effector "Twomey effect" says that in a polluted environment, the intensification of aerosols will lead to an increase in available cloud condensation nuclei (CCN) for cloud formation (Twomey, 1977). Therefore, the presence of large amount of CCN in the atmosphere results in smaller cloud droplets. A decrease in droplet size has the additional effect of delaying the onset of collision and coalescence in warm clouds, reducing precipitation efficiency. As a result the cloud liquid waterpath increases along with the lifetime of the cloud (Albrecht,1989) which is termed as second indirect effect.

Enhanced input of aerosols into the atmosphere has been suggested to suppress precipitation (Ramanathan et al., 2001) by increasing CCN concentrations and reducing cloud droplet size and droplet coalescence (Twomey, 1977). Changes in precipitation can have significant, potentially even global consequences. Suppression of rainfall can potentially lead to a positive feedback through a drier land surface, stronger susceptibility to fires, and even greater aerosol-induced suppression of rainfall (Laurance and Williamson, 2001). Rosenfeld (1999), using satellite-based precipitation observations from the Tropical Rainfall Measuring Mission (TRMM), illustrated for a single day that aerosols from a biomass burning event in Indonesia shut down warm-rain processes. Kaufman and Fraser (1997), on the basis of satellite observations from the AVHRR sensor, have shown a reductionin the cloud droplet radius with aerosol loading from biomass burning in the Amazon but did not quantify the effect on precipitation. Andreae et al. (2004), analyzing aircraft observations in the Amazon, found reductions in cloud droplet sizes and delays in the onset of precipitation within smoky clouds. The lack of early warm-rain processes enabled updrafts to accelerate and reach higher altitudes and produce stronger storms.

Sekiguchi et al.(2003) investigated global-scale correlations between low-level cloud properties and aerosol concentrations measured by AVHRR sensor over the ocean.They reported increased cloud fraction with enhanced aerosol but no clear relationship with cloud top temperature.Rosenfeld and Woodley (2000) using aircraft data together with satellite data demonstrated that in a polluted environment there is indeeda suppression of rainfall due to the smaller size of cloud droplet.

Increasingly sophisticated and accurate remote sensing techniques have been introduced to understand aerosols and their effects. Especially for aerosols over land, the first operational global satellite dataset has been provided by the Moderate Imaging Spectrometer (MODIS). Since MODIS' launch aboard Terra (in late 1999) and aboard Aqua (in early 2002), the use of the MODIS aerosol products has grown exponentially. Since their launch, MODIS data and specifically aerosol data have been used for dozens of applications and in hundreds of publications.

The Brahmaputra valley in North Eastern region (NER) of India with a unique terrain is among the highest rainfall receiving zones in India. Majority of the population in NER resides in the Brahmaputra valley spanning from east to west across the state of Assam. The valley is highly vulnerable to aerosols loading during winter owing to the fact that the valley has hills of altitude more than 1000m all around, except in the west. The wind over the region is primarily westerlies during the winter and pre-monsoon season that carries dust laden air from north-west and west Asian countries along with the contribution from Indo-Gangetic basin (Pathak et. al.,2014). The winter is also mostly dry with relative humidity remaining below 50% for most of the times. The aerosol within the atmospheric boundary layer therefore has the potential to get trapped over the area and cause sustained loading from post monsoon season to next pre-monsoon season through the winter season. The study has been taken up to investigate the impact of aerosol changes in the pre-monsoon seasonal (April-May) precipitation over the region.

STUDY REGION AND TIME

This study based on spatial variation of aerosol and its consequent impact on precipitation, was confined within the flood

plains of the Brahmaputra valley as shown in figure 1. For this purpose, the valley was divided into two distinct areas defined as eastern region (93.5°-96.5°E, 26.5°-28°N) and western region (89.75°-92.75°E, 25.75°-26.75°N), marked as rectangular boxes in figure 1. While the western region is densely populated with very less forest cover and large amount of agricultural fields, the eastern region is rather less populated and has large numbers of tea gardens and other forest. There are several oil fields and oil refineries present in the eastern region but only one oil refinery is present in the western region.

The sustained aerosol loading in the atmosphere over the NER of India primarily takes place during the winter (Nov-Feb months) and pre-monsoon (March-May) months. It is observed that pre-monsoon shower with thunders normally starts from end of March and peaks by the middle of April to Mid-May. By the end of May, good amount of rainfall takes place over the entire valley and aerosol is largely removed from the atmosphere. It is therefore expected that aerosol over the region shall have highest impact on the locally developed April and May month shower. The rainfalls for the months of April and May have therefore been considered for this study. The study has been done with data for the period of 10 years during 2001 to 2010.

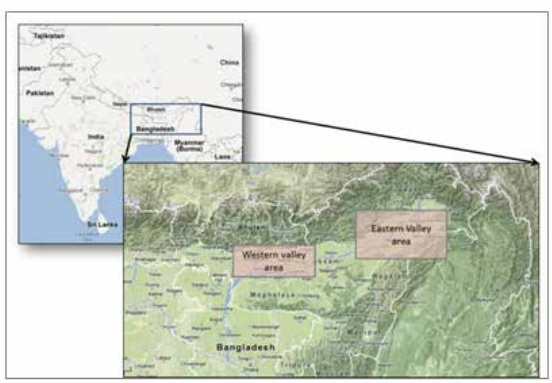

Figure 1: The study area. The study is conducted over two distinct regions in Brahmaputra valley marked with rectangular boxes

DATA DESCRIPTION

AEROSOL from MODIS

The collection 5, level 3 (spatial resolution 1° ×1°) monthly MODIS products on aerosol and cloud properties generated using data onboard Terra satellite with equatorial crossing time of 10:30 h local solar time (Levy etal., 2007) have been used over the selected locations. The data are obtained from the website http://giovanni.gsfc.nasa.gov. MODIS views the earth with a swath about 2330 km, thereby observing nearly the entire globe on a daily basis, and repeat orbits every 16 days. Each scan is 10 km along track. MODIS performs measurements in the solar to thermal infrared spectrum region from 0.41 to 14.235 μm (Salomonson et al., 1989). Detailed specifications and components can be found athttp://modis.gsfc.nasa.gov. The aerosol retrieval makes use of seven wavelength bands centred at 0.66, 0.86, 0.47, 0.55, 1.24, 1.64 and2.12 μm respectively,and a number of other bands to help with cloud and other screening procedures.

In order to apply MODIS aerosol retrievals in climate and air pollution applications, the products must meet certain expected accuracy (Kaufman et al. 1997). The aerosol optical depth (AOD) which gives the extinction of radiation due to aerosol scattering and absorption, at 550 nm was used for this study. The desired accuracy for AOD,specified by

$\Delta\tau = \pm 0.05 \pm 0.15\tau$ (where τ is AOD).

Most of the validation studies have shown that although MODIS generally derives AOD within the expected error, it tends to over-estimate for small AOD and under-estimate the same for high AOD (Chu et al, 2002; Levy et al. 2005). For MODIS collection 5 products, the MODIS to AERONET τ regression equation (levy et al., 2006) is expressed as:

$$\tau_{MODIS} = 0.03 + 1.01\ \tau_{AERONET}$$

Another parameter often used for characterizing aerosol features is Ångström exponent (α). This parameter is often used as a measure of the spectral dependence of AOD that provides qualitative information of aerosol size distribution. $\alpha$for the aerosols over land based on 470 and 660 nm optical depths were used for the study. The α values can be obtained by Angstrom (1964) formula

$$\text{or} \ln\tau(\lambda) = \ln\beta - \alpha\ln\lambda$$

The high value of α indicates dominance of anthropogenic fine mode aerosols from coarse mode aerosols (Bellouin etal., 2008; Jones and Christopher, 2007). Anthropogenic aerosols such as sulphates and carbonates (blackcarbon and organic carbon) are considered as fine mode aerosols and they produce high α values, whereas natural aerosols consisting of mechanically produced dust and sea salt aerosols are coarse mode and they result in lower α values (Kaufman et al., 2005).

MODIS CLOUD

The MODIS Cloud Product combines infrared and visible techniques to determine both physical and radiative cloud properties. The cloud fraction is produced by the 1 km X 1km footprint MODIS cloud mask (MOD35_L3, collection 5) algorithm, which makes use of as many as 14 of the 36 MODIS spectral bands to identify clouds (Ackerman et al.,1998, 2002). The cloud microphysical properties like cloud droplet effective radius (Re) and liquid water path (LWP) are at1km X 1km footprint.

The LWP is defined as the column amount of liquid water in the cloud. It has a significant role in the transport of latent heat in the earth-atmosphere system. The CER is an area-weighted mean radius of the cloud droplets and is determined as;

$$r_e = \frac{\int_0^{\alpha} r^3\, n(r)dr}{\int_0^{\alpha} r^2\, n(r)dr}$$

Where, r = particle radius; n(r) = particle size distribution (number of particles per cm^2 with radius in the range r and r+dr microns). The MODIS algorithm uses near-infrared to mid-infrared measurements to retrieve CER that are then converted to LWP. Uncertainty analysis reveals that for thick clouds the error on CER is less than 0.1μ, but for thin clouds the error on CER is around 0.3μ (Tripathi et al., 2007). The errors involved in the retrieval of aerosol and cloud products from MODIS are a limitation of this study.

The rainfall data are obtained from India Meteorological Department (IMD) gridded 1° X 1° data (Rajeevan et.al, 2005) and TRMM 3B42 V7 derived product.

RESULTS AND DISCUSSION

Aerosol and Rainfall characteristics

The AOD has shown a consistent increasing trend (during the study period) over both the region with higher AOD over the western region of the valley. On a regional scale, the AOD over the eastern Assam increased from 0.396 to 0.481, while the same over the western Assam increased from 0.415 to 0.665 (figure 2 and 3). The α values increased at the rate of 0.008 per year over the western region while the same over the eastern region decreased at the rate of 0.003 per year. The precipitation has decreased at the rate of 12 mm/year during the study period over the western region while the same has increased at the rate of 15 mm/year over the eastern region. Jeoung et al. (2013) have shown that decrease in

fine mode aerosol (indicative of decrease in α) is generally associated with increase in precipitation. The significant decrease and increase in rainfall over western and eastern region of the valley respectively, is associated with high increase in AOD and α and moderate increase in AOD and decrease in α over the western and eastern region of the valley respectively. Table 1 shows changes per year for major aerosol and cloud properties over the regions during the 2000-2010 periods.

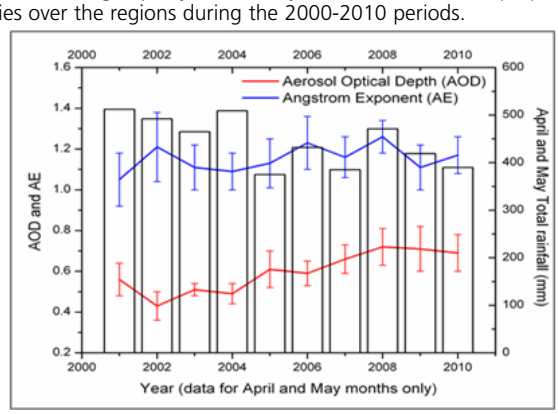

Figure 2: 10 year (2001-2010) variation of AOD, Ångström exponent and rainfall over western region of Brahmaputra valley

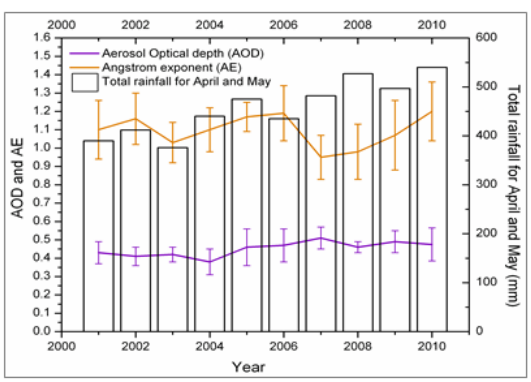

Figure 3: 10 year (2001-2010) variation of AOD, Ångström-exponent and rainfall over eastern region of Brahmaputra valley

TABLE 1
Change per year for mean (April and May) aerosol and cloud properties for eastern and western region of Brahmaputra valley

Name of parameter	Western Assam (change/ yr)	Eastern Assam (change/ yr)
AOD	+0.025	+0.0085
BC AOD	+0.001	+0.00032
AE	+0.008	-0.003
Cloud Fraction	+0.0023	- 0.0031
Cloud LWP (gmm^{-3})	- 3.30	+ 2.0
r_e(μm)	- 0.26	- 0.085
Rainfall (mm)	-12.0	+15.0

AEROSOL AND CLOUD PROPERTIES

The Twomey effect (1977) says that with increase in aerosol and particularly the fine mode aerosol, the number of CCN shall increase in the atmosphere. Both the regions considered here, have experienced a drastic reduction in cloud drop effective radius (r_e) with increase in AOD (figure 4). The r_e values have reduced at a much faster rate over the western region (-0.26 μm per year) than over the eastern region (-0.085 μm per year). The reduction in r_e most likely to be associated with increase in number concentration of cloud drops, however, using satellite based estimates it is not possible to examine the changes in aerosol number concentration. The cloud drop effective radius has a correlation coefficient of 0.78 and 0.58 with AOD for western and eastern region respectively.

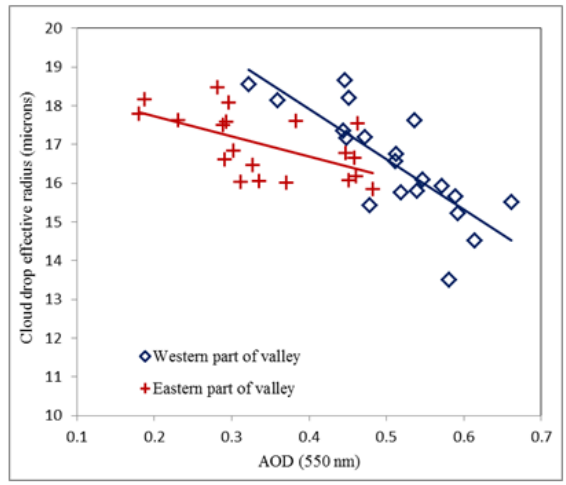

Figure 4: Changes in cloud drop effective radius against AOD

The cloud fraction has shown a contrasting change with increase in aerosol as shown in figure 5. The increase in cloud fraction but resulting in reduced precipitation over the western region confirms the reduction of deep convective cloud. On the other hand, reduced cloud fraction and more rainfall over eastern region could be possible because of increase in deep convective cloud. It will be worth to study the daily rainfall intensity that could further confirm the changes in frequency of deep convective cloud.

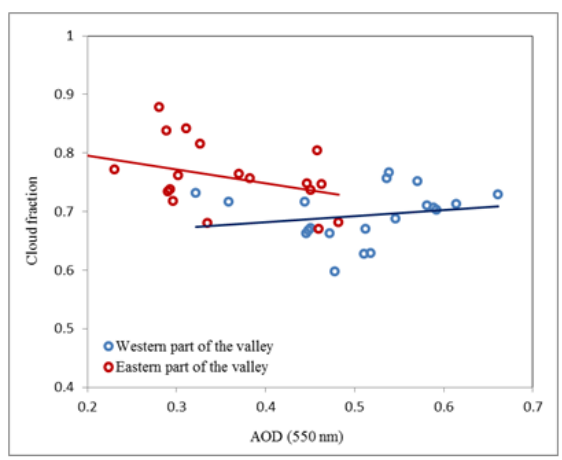

Figure 5: Monthly mean changes in cloud mode fraction against AOD for April month

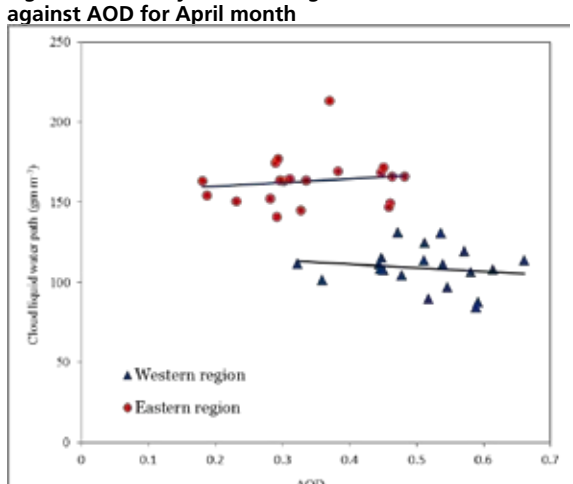

Figure 6: Variation of cloud LWP against AOD

The increase in α over the same region and reduction in r_e is expected to reduce the precipitation efficiency of the clouds over the western region leading to reduction in overall rainfall. On the other hand, the cloud fraction has reduced with increase in AOD, signifying improved precipitation efficiency of cloud over the eastern region of the valley. The cloud LWP has also shown a decreasing trend with increasing AOD over the western region while the same over the eastern region has shown a moderate increasing trend as shown in figure 6. The westerlies wind could drive the un-precipitated moisture from the western region of the valley towards the eastern region, thereby increasing the precipitation further over the region.

CONCLUSION

The Brahmaputra valley in Assam is vulnerable to aerosol loading during post monsoon season to next pre-monsoon season.The AOD and BC AOD has been showing an increasing trend over the valley; however the rate of change varies across the valley. A study over two distinct regions in eastern and western part of the valley show contrasting impact of aerosol changes over rainfall. Moderate increase in aerosols over the eastern region of the valley with little decrease in fine mode aerosol enhances precipitation from convective clouds. The increase in total aerosol associated with increase in fine mode aerosol reduces cloud precipitation efficiency and hence reduced rainfall over the western part of the valley. There is significant decrease in cloud drop effective radius over both regions with increasing AOD indicating strong Twomey effect over both the region. The westerlies could transport additional moisture that might remain in the atmosphere from western part of the valley to the easternmost part allowing more rainfall over the eastern region. The observations need to be taken on a daily basis to identify individual convective systems to confirm the synoptic observations made.

ACKNOWLEDGEMENT:

Analyses and visualizations used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISCMODIS, NASA. We would like to express our gratitude to the NASA terra and TRMM projects for providing the MODIS and TRMM products. The authors are also thankful to the ARFI project management of Space physics Laboratory (SPL) of ISRO.

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