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Preliminary ground based measurements of Aerosol Optical thickness over Udaipur (Rajasthan), India

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ABSTRACT
We have carried out studies to understand the variability of Aerosol Optical Thickness (AOT) and precipitable water-vapour content (PWC) over Udaipur (24.58°N, 73.71°E), using hand-held microprocessor based MICROTOPS sun photometer-540 (1020 nm and 936 nm) from February, 2002 to March, 2004, excluding the rainy days (total of 156 days of clear-sky observations). We found that monthly AOT varied between 0.16 and 0.54 during the whole period and was higher in summer (mean value ~0.32) than the winter months (mean value ~0.19) with highest value in pre-monsoon month of June (0.54). The day-to-day variability of AOT is also higher in summer than winter months and is lowest during the post-monsoon months. We also found PWC to be maximum in monsoon month (July, ~3 cm) and minimum in December-February (~0.5 cm) winter months. A positive moderate correlation (0.45) between monthly AOT and PWC over the station during the study period is reported. This suggests that the production and loss of aerosol particles, which are hygroscopic in nature, are also associated with precipitable water-vapour content along with the other meterological factors.

Key words: Aerosol, Climate, precipitable water-vapour, atmosphere.

INTRODUCTION

Aerosols (tiny suspended particles in the atmosphere) are in the forefront of climate studies since last three decades, owing to the role they play in the Earth-Atmosphere system by absorbing or scattering the incoming solar radiation thus warming or cooling the atmosphere and hence playing an important role in the earth's radiation budget (Bellouin et al., 2005; Carlo et al., 2017). Atmospheric aerosols are contributed by natural as well as anthropogenic sources. Their natural source includes volcanoes, dust, forest, vegetation and sea-spray. Natural sources, such as volcanic activity, produce synoptic scale effects; while other sources, such as wind-blown dust, sea-spray, convective and general circulations produce regional-scale effects in modulating the background aerosols. Anthropogenic aerosols are short-lived and mostly produce negative radiative forcing. The major sources of anthropogenic aerosols are fossil fuel and biomass burning and these sources are also associated with degradation of the air quality and acid deposition. On a global scale, the natural sources of aerosols are more important than the anthropogenic aerosols but regionally, anthropogenic aerosols are considered more important (Kaufman et al., 1994 and Ramanathan et al., 2001). Moreover, aerosols influence the solar radiation both directly and indirectly through their various sizes and thus have different optical and physical properties. When aerosol particles are small, they act as cloud condensation nuclei and help in the formation of clouds and when sufficiently large in size, they scatter and absorb sun light (Rosenfeld, 2006). Although the dynamics change the aerosol size spectrum during their residence time, the particle population highly relies on the strength of their source and sinks mechanisms. As a result, concentrations of ambient aerosol differ to a great extent between urban and remote areas, and between industrialized and rural regions (Rao et al., 2001). The aerosols in the size 0.1-1 μm are considered most effective in attenuating the sunlight.

One of the important parameters related to the aerosol is the Aerosol Optical Depth (AOD) which is defined as a measure of extinction of solar radiation passing through the atmosphere due to absorption or scattering by the aerosols. There are several recent studies for the measurements of AOD over the whole globe (Engström and Ekman, 2010; Altaratz et al., 2013) and also over the Indian sub-continent (for e.g., Ranjan et al., 2007; Srivastava et al., 2008; Ramachandran et al., 2012). The seasonal and annual mean trends in AOD for a decade (2002-2012) have been derived using MODIS (Moderate Resolution Imaging Spectrometer) Level 2 data over different locations in India where AODs values were found to increase across India (Ramachandran et al., 2012). The AOD trends exhibited spatial, seasonal and annual mean variations. They found that both AODs and rainfall increases in that decade over most of the study locations like Delhi, Shimla, Dehradun, Jaipur, Hyderabad and Bengaluru.

The seasonal and inter-annual variability in AOD and aerosol size distribution were investigated using sun photometer, sun/sky radiometer, MODIS and MSIR (M Radiometer) satellites over stations: Ahmedabad, Gurushikhar, Karachi, Kanpur and Gandhi College in Balliyan District of Uttar Pradesh in South Asia during 2006-2008 by Ramachandran (2013). They found that the AOD value was almost double over Karachi and Ahmedabad of the value observed at Gurushikhar, a high altitude remote site. Their study of ground-based and MODIS (Terra and Aqua) retrieved AODs showed that AODs do not change significantly in an hour. The comparative studies of column ozone content using MICROTOPS, TOMS and DOBSON unit over a low-latitude station, Udaipur is obtained by Pandey and Vyas (2004) and found a similar trend by three measurement techniques for column ozone during January 2001 respectively The correlative measurements of Ozone by MICROTOPS and TOMS was observed to be good (r=0.92) and MICROTOPS values were in 10% range of TOMS. Inspite of these observations, more studies on temporal and spatial distribution of AOD and their associated properties are needed to be accomplished regularly to understand the role of aerosols in the weather modification and climate change and related predictions. Hence, the aim of the present study is to investigate the variability of the AOD and precipitable water-vapour content (PWC) over Udaipur which is situated in desert area along with the lakes. This study shows the observations during 2002-2004 using MICROTOPS sunphotometer over Udaipur and hence may enhance the understanding of air-quality and the regional characteristics of the aerosols over a temperate city like Udaipur, which is considered as a pollution-free city. This may also serve as an investigation of background aerosols in a clean city which can be compared with the polluted cities. The AOD which acts as a proxy for the aerosol concentration also explains the variations in the cloud fraction atleast to some extent (Andreae, 2009).

Data Set

Udaipur city (24.58°N, 73.71°E) known as 'city of lakes' (~598 m above sea level), located among the lush green hills of Aravali range, lies in the western part of India under the tropical climate. The region experiences three main seasons viz. summer (mid-March to June), monsoon (July to September) and winter (October to March) respectively. Being located in the desert lands of Rajasthan, the climate and weather of Udaipur is usually hot during summer (25-40°C) and cool and dry during winter (10-28°C). Monsoons arrive in the month of July heralded by dust and thunderstorms. The city annually receives around 63.7 cm of mean rainfall. This scanty amount of rainfall makes Udaipur more humid. The humidity reaches to the extent of 90% during the months of Monsoon.

The Microtops II Sun photometer available in Mohanlal Sukhadia University, Udaipur is capable of measuring the atmospheric aerosol thickness (AOT≈AOD) which is a basic measure of aerosol in the atmosphere and is also an evaluation of decrease of solar radiation while passing through a column of atmosphere. Using Microtops II Sun photometer, we determined the AOT at a single wavelength, 1020 nm only. It is also used to measure the water vapor content at 936 nm wavelength. The complete details of the sun photometer and measuring technique have been described by Morys et al., (2001). The AOT measurements using this sun photometer are of limited use as the size distribution of aerosols cannot be attempted. We obtained the daily measurements of AOT at 1020 nm and precipitable water content (PWC) at 936 nm over Udaipur region. The AOD values are inversely proportional with the wavelength (Kohil et al., 2017). The wavelength 936 nm is water absorption band whereas 1020 nm is not.

Aerosols in Udaipur are unique of its kind in terms of its sources. There are marble, zinc and cement mining units in the city which are considered as potent source of loading of aerosols and hence cause environment pollution (Pandey and Vyas, 2004). We made the observations of AOT and PWC for about two years from February, 2002 to March, 2004, excluding the monsoon periods. Due to variable weather conditions and monsoon periods, observations were not regular and continuous and hence the data for such months are not available. The Figure 1 represents the total number of observations made in each month respectively. We found a total of 156 days of clear-sky observations during the study period. As the aerosols have a relatively weaker optical signal that often suffers from a low signal-to-noise ratio, it becomes even harder in the vicinity of clouds, as the separation between clouds and aerosols is not always clear (Koren et al., 2007) and hence the probability of cloud contamination (contribution of small and thin clouds to the aerosols signal) becomes higher (Zhang et al., 2005). In addition, clouds can illuminate the aerosols in their vicinity (Marshak et al., 2006) and such an illumination may falsely be interpreted as enhanced AOD, hence we have selected only the clear sky. The figure shows that more number of observations were made during April and October, 2003 than other months due to a restriction of clear-sky weather.

Since the sun-photometer can take the observations only when sun is available and therefore due to variability of weather conditions, the data sets are not taken continuously. Hence, the gap in the observational data is obvious. Number of observations in different months has been further affected by the cloud conditions and hence, the observations were avoided on such days.

For the validation of MICROTOPS sunphotometer measurements, we compared the AODs and PWC as measured by MICROTOPS and MODIS (Moderate Resolution Imaging Spectrometer)-Aqua measurements. This data validation covers the period since the MODIS instrument data is available (July 2002) to the March 2004 respectively. MODIS measures the Earth leaving radiances in 36 high resolution bands from 0.4 to 14.0 microns with

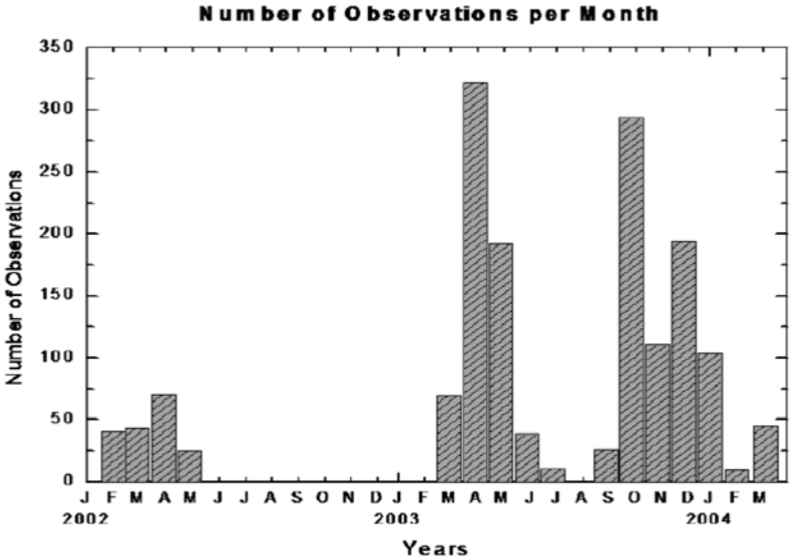

Figure 1. Representation of the number of observations in each month during February, 2002 to March, 2004.

a spatial resolution of 250 m, 500 m and 1 km depending on the wavelength. Its large swath of 2330 km allows the nearly global coverage within 1 or 2 days. We obtained the dataset belonging to the Collection 6 MODIS level 3 monthly mean AODs at 550 nm (variable name "Deep_Blue_Aerosol_Optical_Depth_550_Land") and Atmospheric water vapour (variable name "Atmospheric_Water_Vapor_Mean") within a 1 × 1 degree grid cell respectively, which are produced from higher order level 2 data (Patrick et al., 2015).The averaged monthly AOD and Atmospheric water vapour (AWV, equivalent to Precipitable water vapour content, PWC in atmosphere) is obtained over 73.5°-74.5°E and 24.5°-25.5° N respectively.

RESULTS AND DISCUSSION

Aerosol optical thickness at 1020 nm

The daily values of aerosol optical thickness (AOT) at 1020 nm in each month were measured for the period from February 2002 to March 2004. The monthly mean values of AOT at 1020 nm and AOD at 550 nm with their standard deviation values for each month is represented in Figure 2. The monthly AOT values varied between 0.16 and 0.54 for the whole period. The length of the bar for each point indicates its variability in particular month which is higher in summer months This represents that the mean value of AOT at 1020 nm increases from winter (mean ~0.19) to summer months (mean ~0.32), peaks just prior to monsoon (~0.54) and falls suddenly after the monsoon respectively. The highest AOT was recorded in June month. Here, the loading of aerosols during the pre-monsoon months and washing out during the monsoon months are clearly indicated. A similar trend using different wavelength filter has also been reported earlier by Narasimhamurthy et al., (1998); Niranjan et al., (1998) and Ranjan et al., (2007) over other Indian stations: Mysore, Visakhapatnam and Rajkot respectively. The MODIS-AODs at 550 nm also exhibits similar seasonal trend but the values are lower in winter months but matches well in summer and monsoon months. The day-to-day variability of MODIS-AODs as observed by standard deviations is also higher in summer months than winter months, which is in agreement to the MICROTOPS observations. The correlation is found to be moderate (0.50) between the AODs at 1020 nm by MICROTOPS-II and the AOD at 550 nm by MODIS. Misra et al., (2008) also compared the MODIS derived AODs with the ground based Microtops sunphotometer over Indian station, Ahmedabad (72.5°E, 23.03°N) and found the best correlation in pre-monsoon (April-May) and the least during dry season (December-March) respectively. Jethva et al., (2005) found a systematic overestimation by MODIS during summer and an underestimation during winter respectively.

Precipitable water-vapour content (PWC) at 936 nm

The monthly variation of precipitable water vapour content (PWC) at 936 nm and the atmospheric water vapour (AWV) measurements at infra-red with their standard deviations showing the daily variabilities for each month is shown in Figure 3. The distribution of water vapour content in the atmosphere is considered a good indicator of the dynamics of the circulation systems in the atmosphere (Raj et al., 2004). The hygroscopic growth of aerosols gets controlled by the relative humidity (RH) of the atmosphere which changes the physical and optical properties of the aerosols.

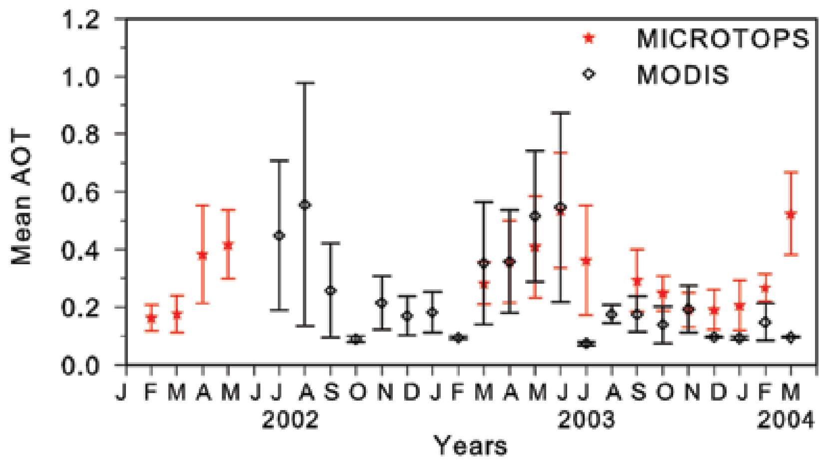

Figure 2. Monthly mean aerosol optical thickness at 1020 nm by MICROTOPS-II and at 550 nm by MODIS with their standard deviations during the study period.

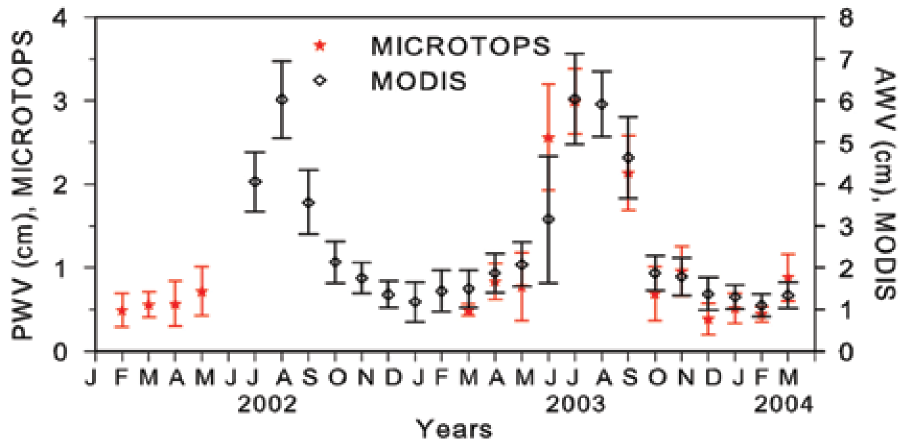

Figure 3. Monthly mean precipitable water content at 936 nm by MICROTOPS and atmospheric waver vapour content at Infra-red by MODIS with their standard deviations during the study period.

The monthly PWC varied between 0.3 and 3 cm during the whole period. The variability in PWC is found to be higher during the months of June, July and September and monthly mean value is highest (~3 cm) in the month of July and minimum in December-February i.e. winter months (~0.5 cm). This is expected as these are the normal monsoon months (July-September) for Udaipur. The lower values of PWC are observed for the months of October to May. Similar variability is observed by the MODIS-AWV, but the values are higher than that of MICROTOPS and highest values are observed in monsoon (~6 cm). The AWV varies between 1 and 6 cm during the whole period with highest variability in monsoon months. The correlation between the PWC as obtained by MICROTOPS-II and the AWV at infra-red by MODIS is found to be very strong (0.92).

Relation between AOT and PWC

As both observed AOT and water-vapour content by MICROTOPS exhibits similar trend and may be related, we plotted them together in figure 4 to find if any relation exists. We considered the PWC as a variable as in high humidity regions, aerosols may take up water vapor which increases the AOT. A high relative humidity is also important for cloud formation and thus AOT and cloud fraction could be correlated as a result of variations in the relative humidity (Engstrom and Ekman, 2010).

The value of the correlation coefficient between monthly AOT and PWC for the whole study period was found to be 0.45 implying that the annual variation of PWC followed that of AOT but moderately. The moderate correlation occurs due to the monsoon period and the November 2003 month when both AOT and PWC does not show a clear relation. The AOT was highest in the June month of year 2003 (~0.54), whereas water vapour was higher (~3 cm) in the July month of the same year. This indicates that higher AOT in the summer months (pre-monsoon period) gets washed away by the rains in the monsoon period (July-September) due to this reason, and

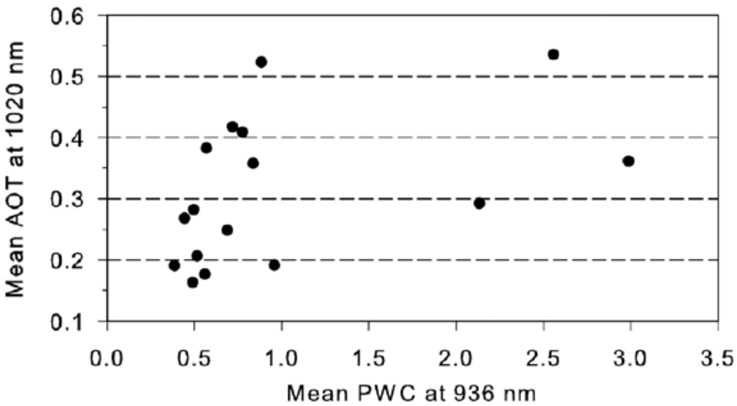

Figure 4. Plot showing the variability of monthly precipitable water vapour content and aerosol optical thickness.

hence the AOT value decreases to ~0.35 in the July month. In other winter and summer months, both AOT and PWC exhibits a stronger correlation (~0.78), as both are either lower/higher in winter/summer months respectively. The moderate positive correlation observed between AOT and PWC also suggested that the growth of aerosols, which are hygroscopic in nature is seldom associated with higher PWC and are also associated occasionally with other meterological factors like temperature, pressure, humidity and/or wind speed and direction. By examining the covariation of AOD and cloud fraction with different meteorological variables, Engstrom and Ekman (2010) found that the 10-meter wind speed correlates significantly with both AOD and cloud fraction. Similar short term trends of AOT and PWC have also been reported by Pandey and Vyas (2004) at Udaipur using tropospheric ozone content over same station. The similar trends were also observed in our observations for AOT and PWC in the months of April and May, 2002 where the column water increased, following AOT just before monsoon in June, 2002. Both AOT and water column content attained lower levels during winter months of November, December and January. Our results are in the qualitative agreement with the results reported by other investigators at other Indian stations (Narasimhamurthy et al., 1998, Moorthy et al., 1993, 1998).

CONCLUSIONS

The aerosol size distribution depends on their production mechanism. Some particles are small in size as they are formed by gas-to-particle conversion. Some particles are large in size as they are formed by mechanical actions such as wind lifting of dust, wave-breaking, etc. In general, the anthropogenic aerosols are smaller in size and the naturally produced particles are of bigger size. Generally the AOT at higher wavelength (1020 nm) is because of aerosols of coarse size. Hence, AOD measurements made in our study are aerosols of bigger size which are naturally produced.

These preliminary observations of aerosol optical thickness (AOT) and Precipitable water-vapour content (PWC) has helped us in knowing the air-quality and understanding the existence and behaviour of the aerosols and water-vapour content present over Udaipur (24.58°N, 73.71°E) during February, 2002 to March, 2004 respectively. The monthly AOT values at 1020 nm varied between 0.16 and 0.54, whereas PWC at 936 nm varied between 0.3 and 3 cm respectively as obtained by the ground-based MICROTOPS II sunphotometer. The AOT measurements exhibited seasonal variability of aerosol where AOT increased gradually from winter (~0.19) to summer (~0.32) months and was highest in pre-monsoon (~0.54) which reduces drastically for the post-monsoon months. The variability in PWC is found to be higher in June, July and September with highest value in July (~3 cm) and minimum in December-February winter months (~0.5 cm). The MODIS-AODs at 550 nm and Atmospheric water vapour content (AWC) also exhibited trends similar to MICROTOPS measurements but AWC measurements were higher by MODIS. The correlation is found moderate (0.50) for AOD measurements and very strong (0.90) for PWC between the MICROTOPS-II and MODIS measurements. The correlation coefficient between observed monthly AOT and PWC was found to be positive and moderate (0.45) implying that the annual variation of PWC followed that of AOT but moderately and also dependant on other meterological factors like rainfall, temperature, humidity, wind speed and direction respectively.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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