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# Dust storms detection over the Indo-Gangetic basin using multi sensor data

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**Abstract**

Dust storms are common during the summer season over the Indo-Gangetic basin and are considered to be a major health hazard to millions of people living in the basin. In countries like India, there is no early warning made for dust outbreaks and as a result the day-to-day life is affected by these dust events. In this paper, efforts have been made to utilize multi sensor data to study the characteristics of dust storms. Moderate Resolution Imaging Spectroradiometer and Multiangle Imaging SpectroRadiometer images clearly show dust storm events over the Indo-Gangetic basin. The Total Ozone Mapping Spectroradiometer (TOMS) Aerosol Index and the Advanced Microwave Sounding Unit (AMSU) data over the western end of the Indo-Gangetic basin have been analyzed. These data show characteristic behavior of brightness temperature and Aerosol Index due to dust, which change significantly as dust migrates towards east over Kanpur. The TOMS Aerosol Index and the AMSU brightness temperature ($T_b$) show a characteristic anti-correlation, which confirms the presence of a dust storm over Indo-Gangetic basin.


*Keywords:* Indo-Gangetic basin; Dust storm; Remote sensing; Optical thickness

## 1. Introduction

Dust storms are very dynamic, as a result the particle size of aerosols and the concentrations vary significantly (MacKinnon and Chavez, 1993). Dust storms are generated by strong winds lifting particles of dust or sand into air from regions that are mainly deserts, dry lakebeds and semi-arid desert regions. However, Tegen and Fung (1995) have found that disturbed soil surface sources contribute up to 50% of the atmospheric dust load. Such dust events are considered anthropogenic in nature that play an important role in climatic conditions (Rosenfeld, 2001). Airborne particles from dust storms alter the local climatic conditions by intercepting sunlight and modify the energy budget through their behavior by cooling and heating the atmosphere (Liepert, 2002). The presence of an absorbing dust layer results in a substantial decrease in the incoming short wave solar radiation, resulting in a major change to the surface energy balance. Moreover, the atmospheric stabilization occurs when dust differentially warms a layer of the atmosphere at the expense of near-surface cooling. Generally, warming is found within the dust layer, whereas cooling occurs beneath the dust layer and near the surface (atmospheric heating rates can be 2 °C per day while the surface cooling rates can be 10–15 °C per day), with an overall cooling effect (Williams, 2001). El-Askary et al. (2003a) have utilized the difference in behavior between dust and haze in different regions of the electromagnetic spectrum to detect and track dust storms. During the pre-monsoon period, dust storms are experi-

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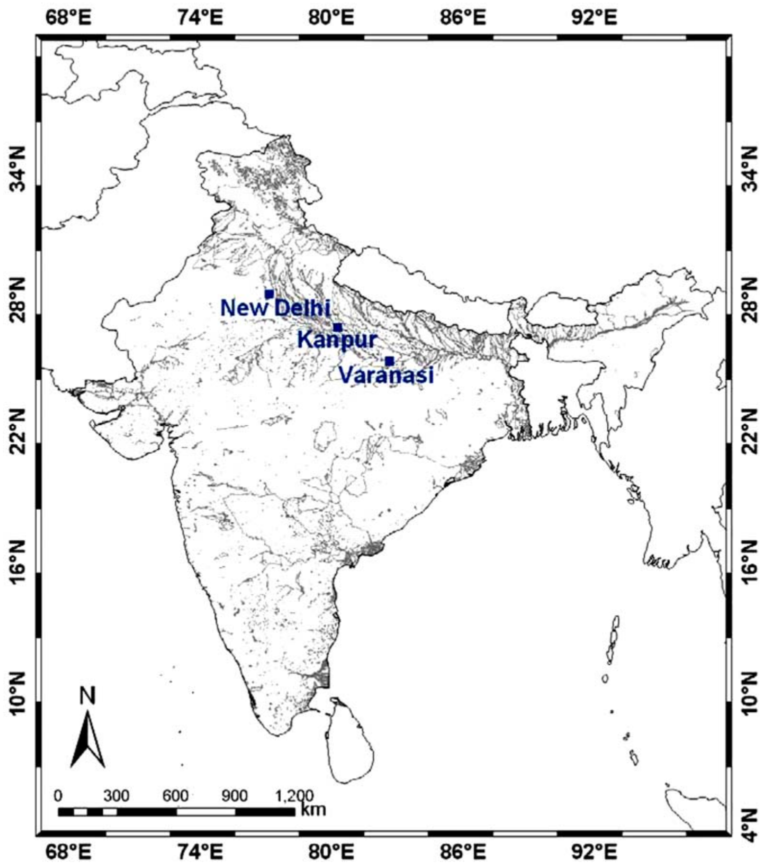


Fig. 1. Map showing the Indo-Gangetic basin drainage network and the three major cities lying within the basin.

enced in some parts of Asia. These storms contribute towards the aerosol loading in the troposphere and changes in local radiative forcing (Tegen et al., 1996).

Occasionally, Saharan dust storms travel all the way to Asia during summer seasons (Dey et al., 2004; El-Askary et al., 2004). Here, we are concentrating on the Indo-Gangetic basin that experiences dust storms, during the pre-monsoon period, that have a major threat to agricultural resources and also people living in this basin. Fig. 1 shows three main city locations (New Delhi, Kanpur and Varanasi) in the basin that suffer from dust events.

## 2. Dust screening using TOMS Aerosol Index

We have used TOMS Aerosol Index data with resolution $1° \times 1°$ to delineate dust and haze over the Indo-Gangetic basin and in particular the area over major cities in that basin. The TOMS product is derived from the ultraviolet spectral region and captures the response of smaller particles namely, aerosol to Rayleigh scattering, which is prominent at a relatively longer wavelength, compared to particle size (Herman et al., 1997; Cakmur et al., 2001). The TOMS instrument detects aerosol particles by measuring the amount of backscattered ultraviolet radiation. Fig. 2 shows the Aerosol Index variability over New Delhi and Varanasi during the month of June 2003. Aerosol Index shows maximum values due to the dust outbreak in the Indo-Gangetic basin on June 10 and 16, 2003 over New Delhi where two major dust events were recorded. The Aerosol Index data show some variability as the dust events enter different phases of deposition, origin and transportation. The corresponding values of Aerosol Index over Varanasi show a general major drop compared to those over New Delhi. These small values over Varanasi are due to the fact that the dust events took some time, days, before reaching from their origin in New Delhi. Therefore, on June 10 and 16, smaller Aerosol Index values are found, however, a few days later on June 14 and 21, higher values of the Aerosol Index are found which is due to the arrival of dust from New Delhi. Moreover, the Aerosol Index values observed on June 14 and 21 over Varanasi are lower as compared to the observed Aerosol Index values over Delhi on June 10 and 16. Such observations are due to the fact that the intensity of dust events weakens as the dust travels from one location to another with very fine aerosols dominating at subsequent locations. These Aerosol Index values reflect as well the existence of local dusts that originate within the Thar Desert, in addition to the major events

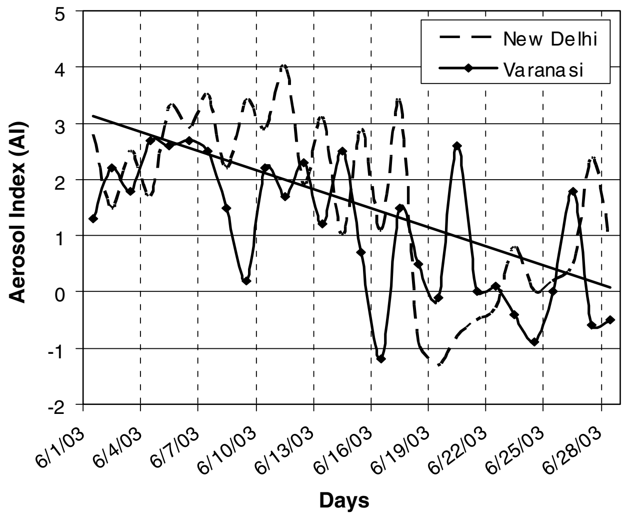


Fig. 2. Aerosol Index variability over New Delhi and Varanasi during June 2003, higher AI initially shows arrival of dust storm in Delhi. The higher AI over Varanasi shows transport of dust from New Delhi where AI decreased after the dust event was observed over New Delhi on June 9, 2003.

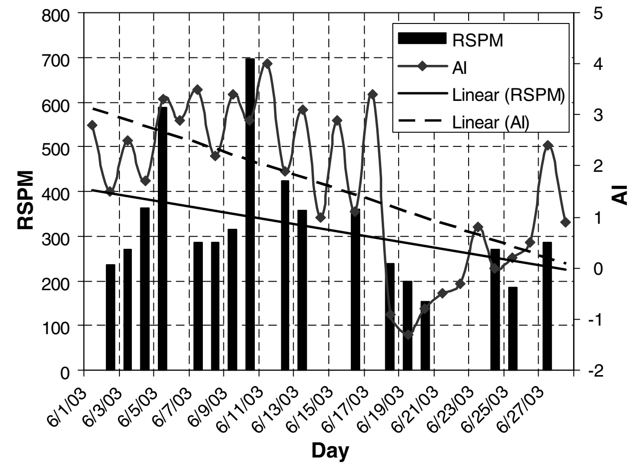


Fig. 3. Variability of AI and RSPM (μg $m^{-3}$) over New Delhi during June 2003, higher RSPM is clearly observed after the increase of AI due to dust.

originating from the Sahara desert. The general trend as seen over both cities verifies the transport of dust from New Delhi to Varanasi as well as reduction in its strength as dust deposition occurs during the event propagation.

Aerosol Index values can be very helpful in determining the occurrences of aerosol anomalies beyond the normal thresholds, however further investigation and detailed data analysis are still required to verify the dust occurrence (El-Askary et al., 2003b). This is attributed to the fact that with TOMS data, it is difficult to distinguish between different types of aerosol particles which cover large areas of the Earth, based on their size (dust tends to have larger particles size than smoke) and absorbing properties in the ultraviolet spectrum.

After the observation of aerosol anomaly over New Delhi, further analysis was carried out to study the relation between Aerosol Index and ground based Respiratory Suspended Particulate Matter (RSPM).[1] The RSPM data show a significant increase of particulate matter concentration in atmosphere during the month of June, thus confirming the presence of dust particles. Fig. 3 shows the relation between Aerosol Index and RSPM over New Delhi. On the day of the dust outbreak (June 10, 2003), high Aerosol Index values are found to match the RSPM values. The trend lines of both the Aerosol Index and RSPM show a general decline after June 10, as dust propagated away from New Delhi towards Kanpur and Varanasi. The decreasing trend of both parameters indicates departure of the dust storm towards the east direction across the Indo-Gangetic basin.

[1] http://envfor.nic.in/cpcb/.

## 3. Visible sensing of dust storms

A dust storm over India was detected from MODIS measurements on June 9, 2003 where a large dust plume is clearly seen. Fig. 4 shows the occurrence of a strong desert dust outbreak (which takes some days to reach India from its origin in the Saharan region) detected by MODIS on June 9, 2003. Large extension of the dust plume is clearly observed; its extent reaches New Delhi, Kanpur and Varanasi several days after due to the dynamic circulation patterns of the dust plume. Although the extraction of physical aerosol parameters from the images is more difficult (Stowe et al., 1997; Tanré et al., 1997; Torres et al., 1998), methods are being developed by our team in aerosol studies. Remote sensing must be validated and complemented by ground-based measurements (Singh et al., 2004).

Fig. 5 shows MISR images which clearly show the detection of large dust storms like the present one over the northwestern part of India. MISR is characterized by its ability to observe at different viewing angles and hence identification of dust storms is greatly improved (El-Askary et al., 2003b). This is attributed to the fact that dust storm events are difficult to be detected in the nadir-viewing angle, while easily detected in the off-nadir angle views due to the thicker depth of atmosphere. MISR has the potential to enhance the detection of small dust storms, thus it might be helpful in early detection of dust storms (El-Askary et al., 2003b). In addition, combining the information from different views could be useful in discriminating between dust clouds and regular clouds. Moreover, different view-angles of MISR make it possible to set limits on particle shape, size and composition, as well as aerosol amount. It also helps in distinguishing between various types of aerosols such as dust, soot, sulfates, etc. Therefore,

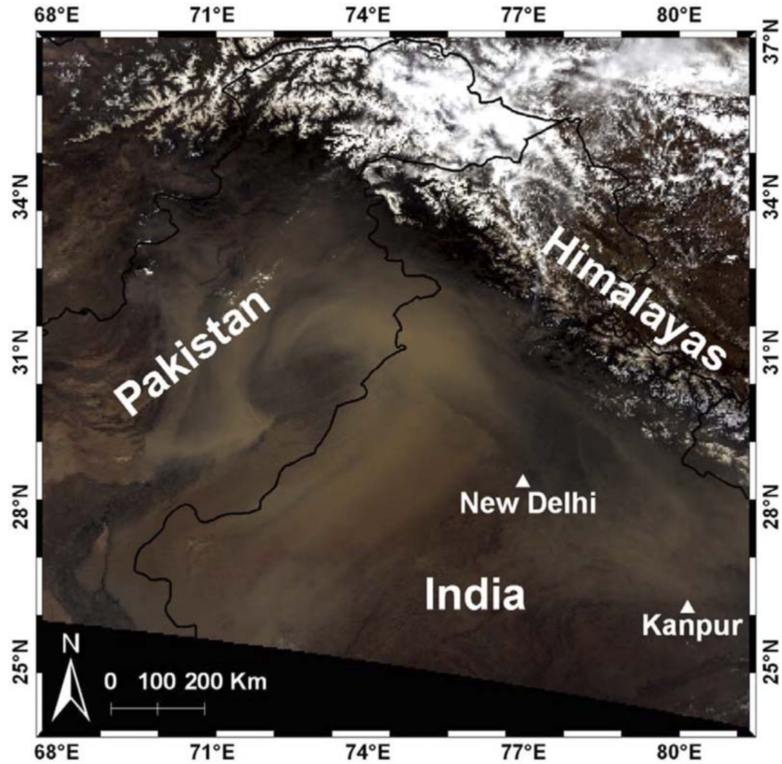


Fig. 4. MODIS true color image showing dust outbreak in Northern India on June 9, 2003.

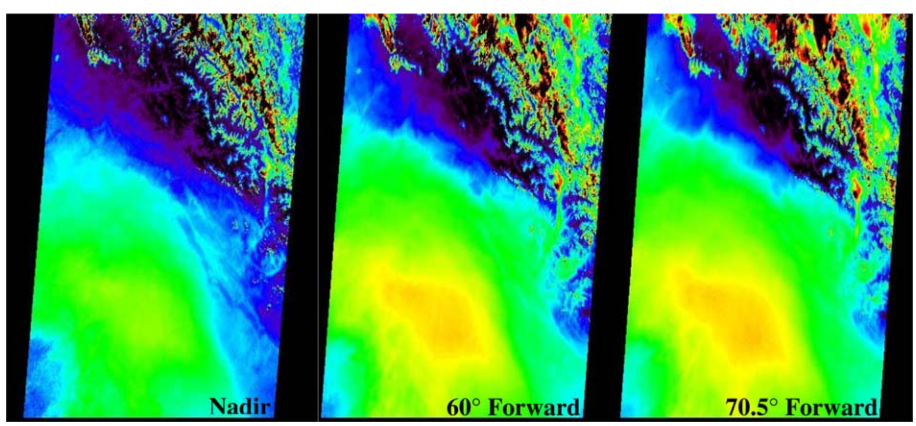


Fig. 5. Different angle views of a large dust plume on June 9, 2003 over the northwestern part of India.

MISR could be useful in decreasing the background effects for desert regions by selecting suitable viewing angles as well.

## 4. Dust microphysics using microwave remote sensing data

Dust particles vary in size distribution and contribute towards a major portion of the aerosol concentration in any dust outbreak event. However, dust particles are generally found to be greater in size than other aerosol particles. Therefore, they are not amenable to proper monitoring by optical sensors. Wentworth (1922) has estimated that the sand grain size (diameter) ranges from 2 to 1/16 mm, whereas the silt size is from 1/16 to 1/32 mm, and the clay size can be from 1/32 to 1/264 mm. Therefore, the expected grain size of dust particles settled to higher levels of the atmosphere ranges from fine sand to clay. Recently, Dey et al. (2004) have found that dust over Indo-Gangetic basin is transported from the Thar Desert and also from the Arabian region.

The presence of dust storms over the Indo-Gangetic basin has been corroborated through the use of passive microwave data (El-Askary et al., 2003a). AMSU on-board the Aqua satellite is primarily a temperature sounder operating in 15 frequency channels ranging from 23.8 to 89 GHz and has 40 km horizontal spatial resolution at Nadir. The first two channels, 23.8 and 31.4 GHz, provide surface and moisture information. In the present study, we have used the 23.8 GHz frequency channel (vertically polarized), which measures brightness temperature at near surface level. The microwave region of electromagnetic spectrum has longer wavelengths compared to the visible and ultraviolet regions. Therefore, Mie scattering is dominant when sand particles are about the same size as the radiation wavelength. This type of scattering takes place in the lower atmosphere less than 4.5 km, where larger particles are more abundant, dominates when cloud conditions are overcast and can affect longer wavelength radiation. Smoke, dust particles, pollen and water vapor are the dominant sources of Mie scattering in the lower atmosphere, affecting the longer wavelengths. Thus, microwave sensing provides another potential way to distinguish and detect dust in the atmosphere due to the similarity in size of dust particles and wavelength. This means that as the incident radiation is of longer wavelength in the microwave range, scattering due to particles is greater and hence brightness temperature is lower. Dust storms produce large scattering of the incoming solar radiation.

Using microwave data, we have found that $T_b$ is negatively correlated with Aerosol Index due to high scattering in the atmosphere in the presence of a dust storm (June 9). While in dust free atmosphere, $T_b$ is found to be positively correlated with Aerosol Index. The daily variations of $T_b$ obtained from AMSU were plotted against Aerosol Index from TOMS, over New Delhi. Low brightness temperature corresponds to greater scattering produced by dust particles indicating the presence of dust. A clear negative correspondence between $T_b$ and Aerosol Index is observed during the different phases of the dust storm (Fig. 6).

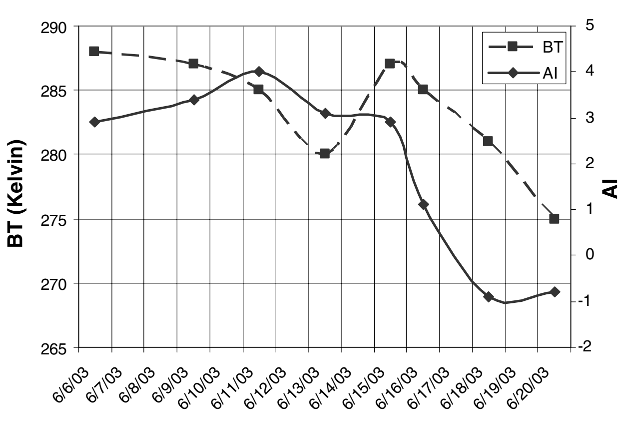


Fig. 6. Daily variations of brightness temperature and Aerosol Index over New Delhi, during June 2003.

## 5. Conclusions

Dust particles form a major composition of the aerosol concentration in any dust outbreak; detection of their presence, distribution and transport has been carried out using remote sensing data over different regions of the electromagnetic spectrum. The dust event of June 10, 2003, has been studied and Aerosol Index values have been observed over the Indo-Gangetic basin. As a result higher RSPM is noticed. The anomalous increase of RSPM is harmful and causes respiratory problems. Negative correlation between brightness temperature from AMSU and Aerosol Index from TOMS shows that dust particles scatter most of the radiation leading to decrease in brightness temperature. The present results show that multi sensor data will be very useful in monitoring the transport and characterization of dust events.

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