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A Study of Aerosol Distribution over Indian Region based on Satellite Retrieved Data

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ABSTRACT

Atmospheric aerosols play a major role in climate change. However, aerosol measurements, particularly their vertical distribution, are sparse over Indian region. Data from Vertical distribution of aerosols obtained from space-borne Lidars such as CALIPSO (Cloud-Aerosol and Infrared Pathfinder Satellite Observation) has been used to study the properties of pollution aerosols, dust aerosols and biomass burning aerosols on randomly selected days over Indian region in the pre-monsoon and monsoon seasons of 2009

The first case study describes the presence of dust aerosols as retrieved by CALIPSO over central India on 18 March 2009. It is observed that thick layer of aerosols is present up to a height of 5km across India extending from south to north. It is also interesting to observe that the aerosols are being lifted along the slopes of Himalayas. In the second study on a monsoon day, the strong westerly winds with patches of upward and downward vertical winds give a good insight to understand the weather conditions on 22 June 2009.

A significant variation in the vertical distribution of aerosols is seen from day to night. During day maximum total attenuated backscatter is at 2-3 km and during night the maximum is at 4 km. Dust and polluted dust aerosols are dominating during both day and night. The year 2009 being a bad monsoon year, the presence of high aerosol levels up to a height of $\sim$ 4 km is clearly seen. MODIS derived Aerosol Optical Depth (AOD) also confirms high aerosol loading ranging from 0.4 to 1 μm.

INTRODUCTION

Atmospheric aerosols in the troposphere can affect the earth's climate directly by scattering and absorbing the solar and terrestrial radiation and, indirectly by altering cloud properties. The aerosols are the main source of uncertainty in both attribution of past climate change and in future climate projections (Forster et al 2007). This is due to their short lifetimes and numerous ways in which they interact with other elements of the climate system (Kaufman et al 2002). More precise evaluation of the direct and indirect effects of tropospheric aerosols on climate requires global information on aerosol properties such as optical thickness, size distribution, refractive index, phase and chemical composition. Such global information can only be acquired using satellite passive and /or active remote sensing (Karl 1995). Using CALIPSO satellite data, Kuhlmann and Quaas (2010) have studied the impact of aerosols above and around the Tibetan plateau on the Asian summer monsoon during pre-monsoon seasons March- April-May 2007, 2008 and 2009.

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) is a satellite developed by NASA-CNES for monitoring of cloud and aerosol properties. The prime objective of the CALIPSO mission is to provide vertically resolved information on aerosol distribution, extinction coefficient, hydration state, discrimination of large and small particles, and cloud masking, in order to enable climate models to estimate direct as well as indirect aerosol forcing and reduce the uncertainty. Another objective of CALIPSO is to provide comprehensive observations of cloud height, thickness and multi-layering, for more accurate computation of surface and atmospheric radiative fluxes in global climate models. The uniqueness

of CALIPSO is that it carries Lidar and gives aerosol vertical profiles whereas the other satellites provide columnar aerosol optical depths.

In the present paper, vertical distribution of aerosols data retrieved from CALIPSO has been used to study the distribution and properties of pollution aerosols, dust aerosols and biomass burning aerosols over the Indian region. The case studies pertain to randomly chosen dates during premonsoon and monsoon seasons of India focusing to understand aerosol and cloud distribution as observed by CALIPSO.

CALIPSO Satellite data and products

CALIPSO carries the cloud-Aerosol Lidar with orthogonal polarization (CALIOP), an active polarization sensitive lidar instrument which produces vertically resolved images of cloud and aerosol layers as well as their respective optical properties. Unlike earlier remote sensing instruments, CALIPSO can reliably detect aerosols over bright surfaces, like deserts and beneath thin clouds. It orbits the earth on a sun- synchronous 10 orbit at 705km altitude. The inclination i.e. the angle between the earth's equatorial plane and the satellite's orbital plane is 98.2. Each day, the satellite orbits the earth 15 times. Measurements are taken both in the day time and night time, with data availability for three years.

CALIPSO data is processed, archived and distributed from NASA's Langley Research Center's Atmospheric Sciences Data Center as the facility is responsible for NASA Earth science data in the areas of radiation budget, clouds, aerosols and tropospheric chemistry. Various levels of data products are made available to the public anywhere from 45days after the post launch check-out phase, to a 1-year validation period to ensure the release of high-quality data products. A CALIPSO data products catalog will provide an overview of the data products that are used or produced by the data management system -- production software that converts CALIPSO instrument data into scientific data products. More information about NASA's Langley Research Center's Atmospheric Sciences Data Center is available on its website, http://eosweb.larc.nasa.gov; from larc@eos.nasa.gov. Detailed information is available in the literature (Reagan et al 2002 and Winker et al 2003, 2004)

RESULTS AND DISCUSSION

Case Study 1:

The present case study describes the presence of dust aerosols as retrieved by CALIPSO over central India during March. On 18, March 2009, the CALIPSO crossed the Indian region around 08:29 UTC and 20:41UTC. Their tracks are shown in the Figure1 along with the meteorological conditions of NCEP derived wind speed, direction, vertical velocities and temperature (white contours) at 850 hpa. The figure shows west – northwesterly winds in the north and the persistence of vertical winds. This figure gives a good insight to understand the weather conditions of 18, March 2009 at 06:00 UTC. The region shaded with thick blue color is a region of strong updrafts and region shaded with light blue color is a region of downward motion. The wind vectors indicate the direction of the flow pattern during that day.

The Lidar level-1B data has been taken from the website http://eosweb.larc.nasa.gov/PRODOCS/calipso /table_calipso.html .The day and night images of total attenuated backscatter at 532nm have been shown in the Figures 2a & 2b. From these images it is observed that thick layer of aerosols is present up to a height of 5 km across India extending from south to north. The uplift of aerosols up to 5 km could be due to the existence of vertical winds as observed in Figure 1. The Figure 2(b) shows that these aerosols are persistent during night also. It is interesting to notice that the aerosols are being lifted up along the slopes of Himalayas. The aerosol vertical profiles in terms of total attenuated backscatter for the selected region (rectangle boxes indicated in Figure 2) are shown in Figure 3. Both day and night profiles coincide with each other. The aerosol layer extends from the surface to a maximum height of 5 km peaking at about 4 km. The vertical feature mask images shown in Figure 4 clearly indicate the presence of the aerosols during both day and night. The day image indicates the presence of small layered clouds, which might be due to local convective activities.

These aerosols can be considered as mostly dominated by dust particles as compared to anthropogenic aerosols. During pre-monsoon (March to May) season, dust aerosols are dominant due to frequent dust storms in the northern India. Meteorological parameters and conditions play a

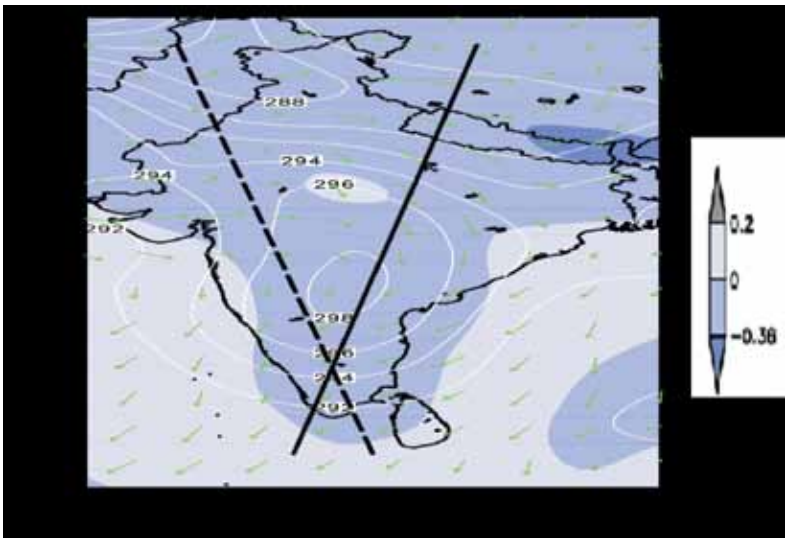

Figure 1. CALIPSO satellite tracks over India on 18 March 2009.Dashed line for day track and solid line for night track. The meteorological conditions are shown in the background with NCEP 850 hpa wind speed and direction. Vertical velocities in the shaded region-light blue is descending and thick blue is ascending. Temperatures as white contours

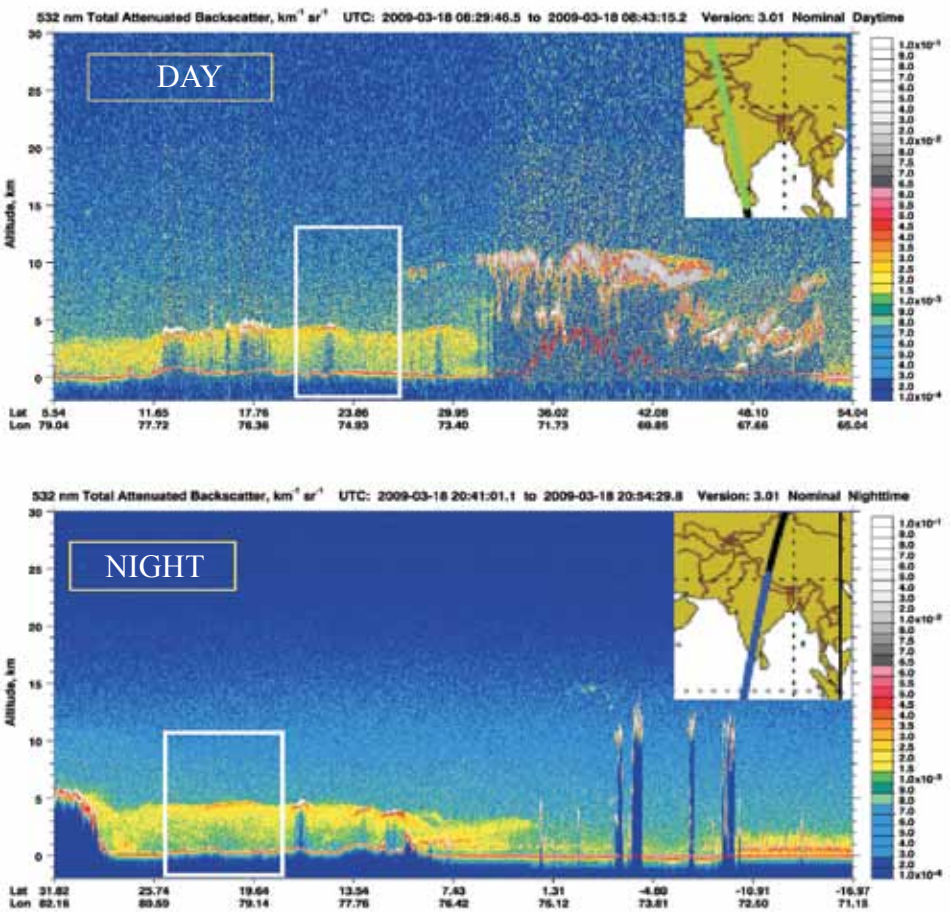

Figure 2. CALIPSO total attenuated backscatter at 532nm for the date 18 March 2009 during (a) day and (b) night. The white rectangle indicates the selected region for retrieving vertical profile.

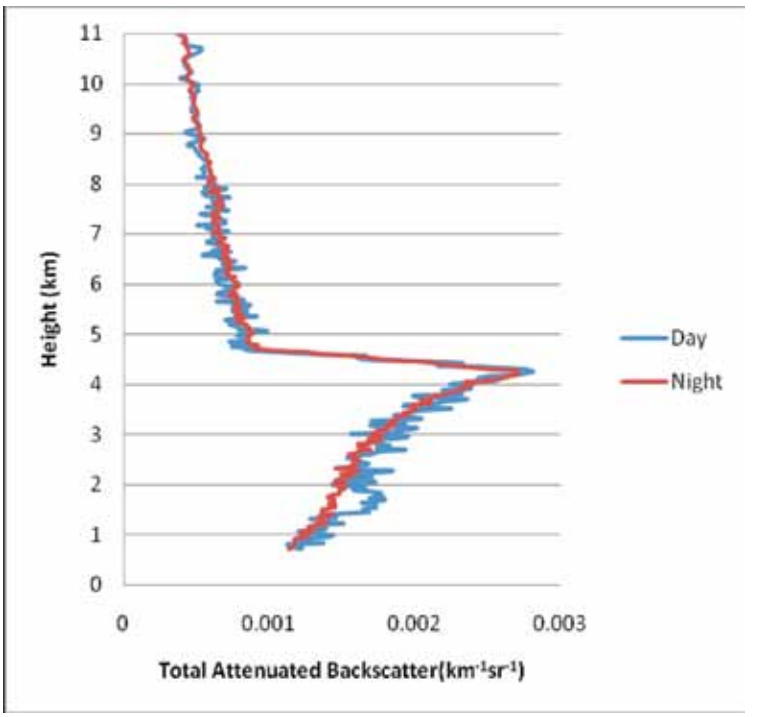

Figure 3. The CALIPSO retrieved attenuated backscatter as a function of height.

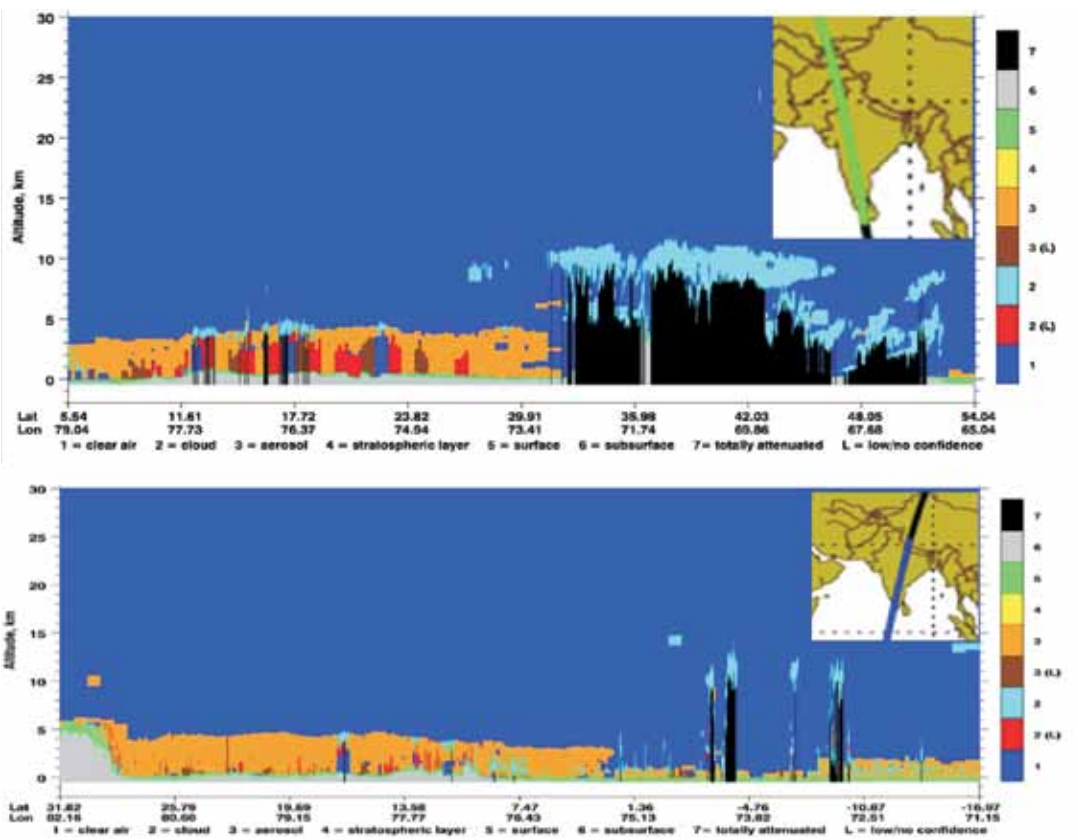

Figure 4. CALIPSO vertical feature mask for 18 March 2009 for (a) day and (b) night

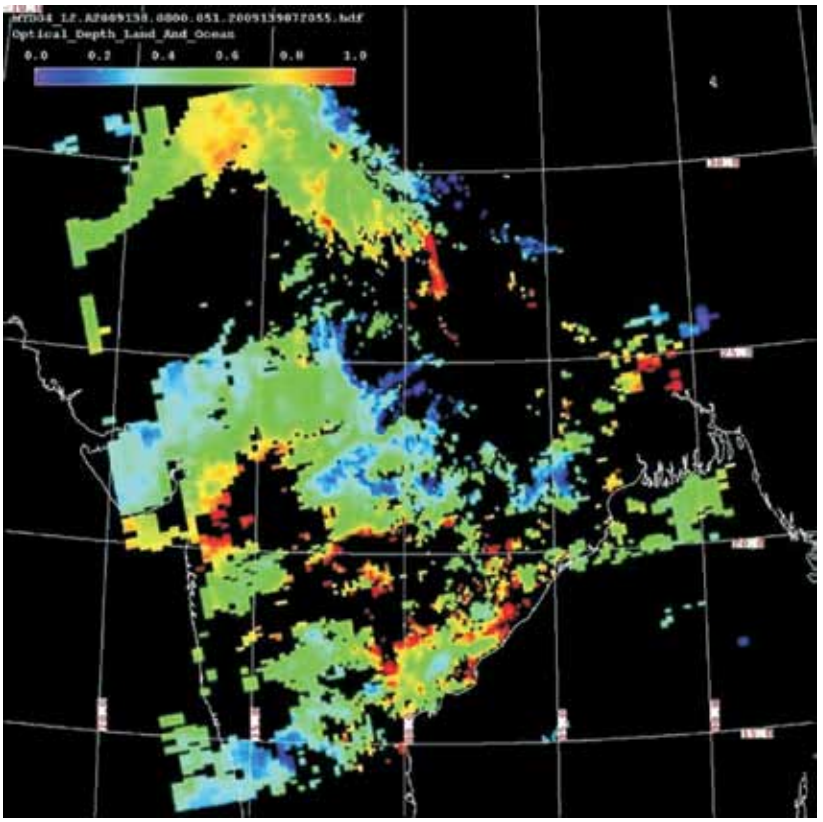

Figure 5. MODIS (AQUA) Aerosol Optical Depth at 08:00UTC on 18 March 2009

dominant role in the transport of dust aerosols. Dust is being considered as one of the major sources of tropospheric aerosol loading, and constitutes an important key parameter in climate aerosol forcing studies. The ability of the satellite data to detect dust plume is limited by several factors, such as radiative properties of the dust and the underlying land or ocean surface, the cloud presence, the density of the dust plumes and the algorithms used in the aerosol retrievals. The transport of dust plays an important role in the regional and global radiative balance both at the surface and the top of the atmosphere. Therefore dust monitoring is better achieved by the combined use of the remote sensing and surface meteorological observations.

MODIS has been acquiring nearly daily or global coverage Level 2 data that are produced at the high spatial resolution of a 10x10 km (at nadir)-pixel array. Figure5 shows the AQUA-MODIS AOD (Aerosol Optical Depth) obtained at 8:00UTC on 18, March 2009. MODIS derived AOD also shows high aerosol loading ranging from 0.4 to 1μm.

Case Study 2:

In this study one day is randomly selected during monsoon season to understand aerosol and cloud distribution during monsoon, as observed by CALIPSO. This study is based on the data obtained on 22, June 2009. On this day the CALIPSO crossed the Indian region around 08:23 UTC and 20:47UTC. Their tracks are shown in the Figure 6 along with the meteorological conditions of NCEP derived wind speed, direction, vertical velocities and temperature (white contours) at 850 hpa. The figure shows strong westerly winds with patches of upward and downward vertical winds. This figure gives a good insight to understand the weather conditions on 22, June 2009 at 06:00 UTC. The region shaded with thick blue color is a region of strong updrafts and region shaded with light blue color is a region of downward motion. The wind vectors indicate the direction of the flow pattern during that day.

The day and night images of total attenuated backscatter at 532nm are shown in the Figure 7(a,b). These figures show the presence of clouds as well

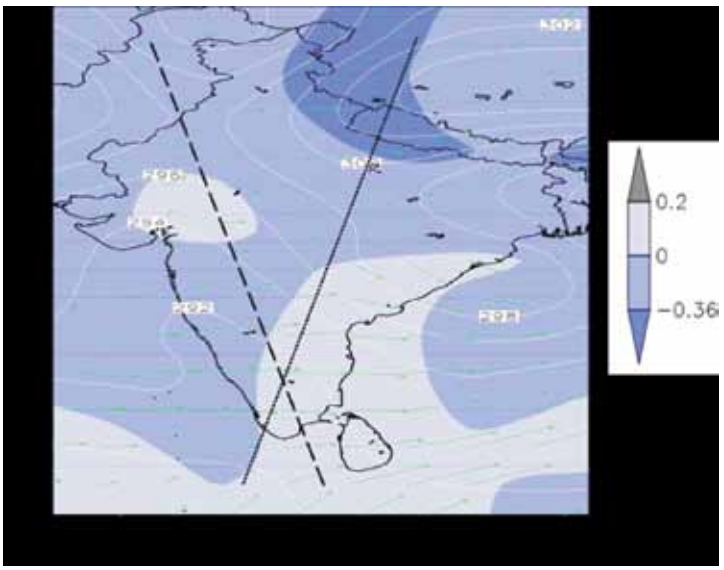

Figure 6. CALIPSO satellite tracks overINDIA for 22 June 2009 (dashed line for day track and solid line for night track). The meteorological conditions are also shown in the background with NCEP 850 hpa wind speed, direction, vertical velocities (shaded regions-light blue is descending and thick blue is ascending) and temperature (white contours).

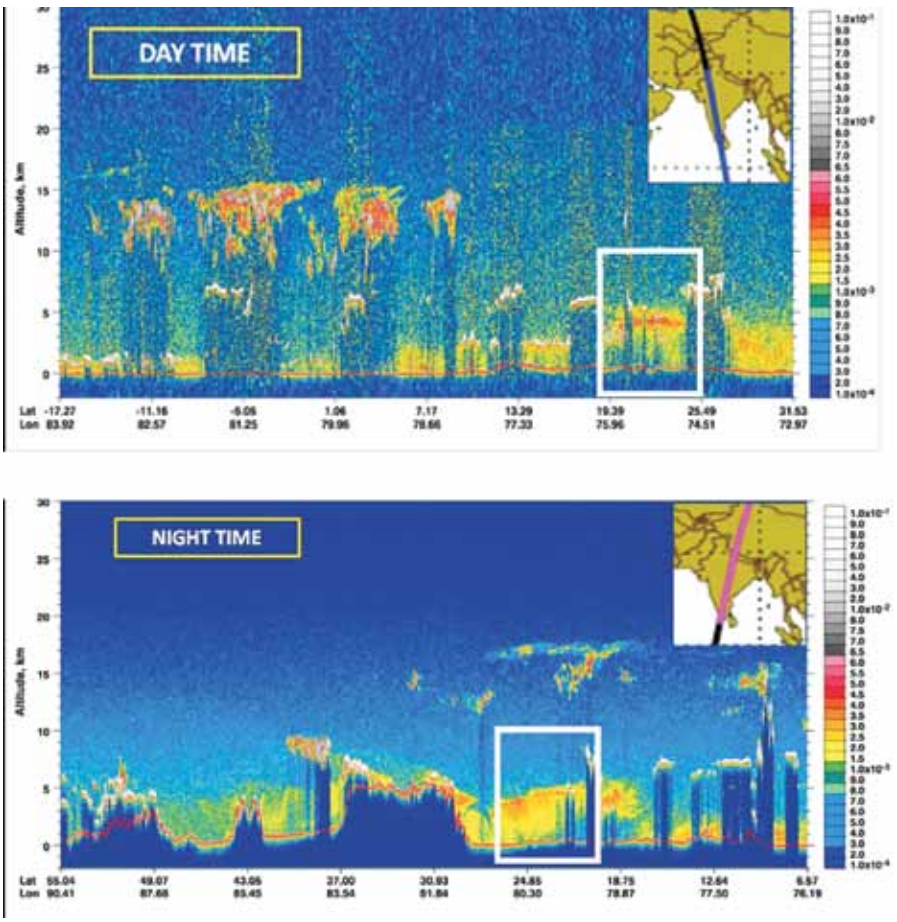

Figure 7. CALIPSO total attenuated backscatter at 532nm obtained on 22 June 2009 during (a) day and (b) night. The white rectangle indicates the selected region.

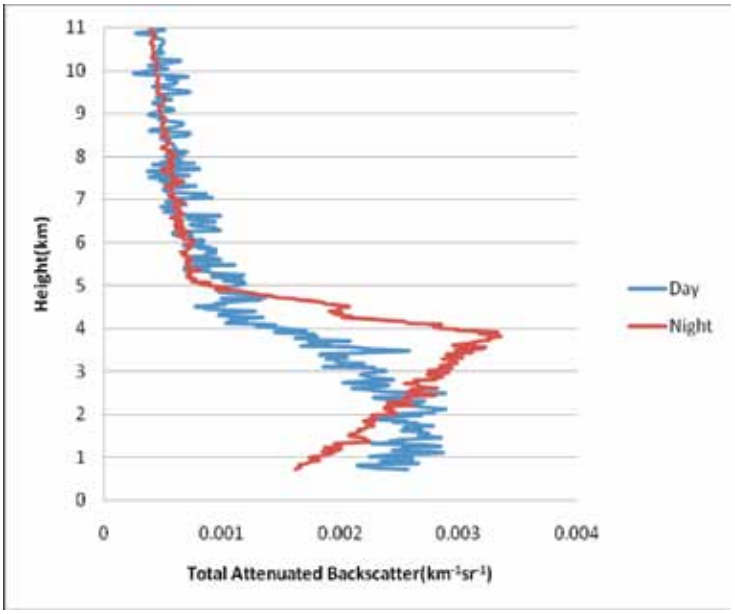

Figure 8. The CALIPSO attenuated backscatter at 532 nm as a function of height on 22 June 2009 for the area shown in rectangle in Figure 7.

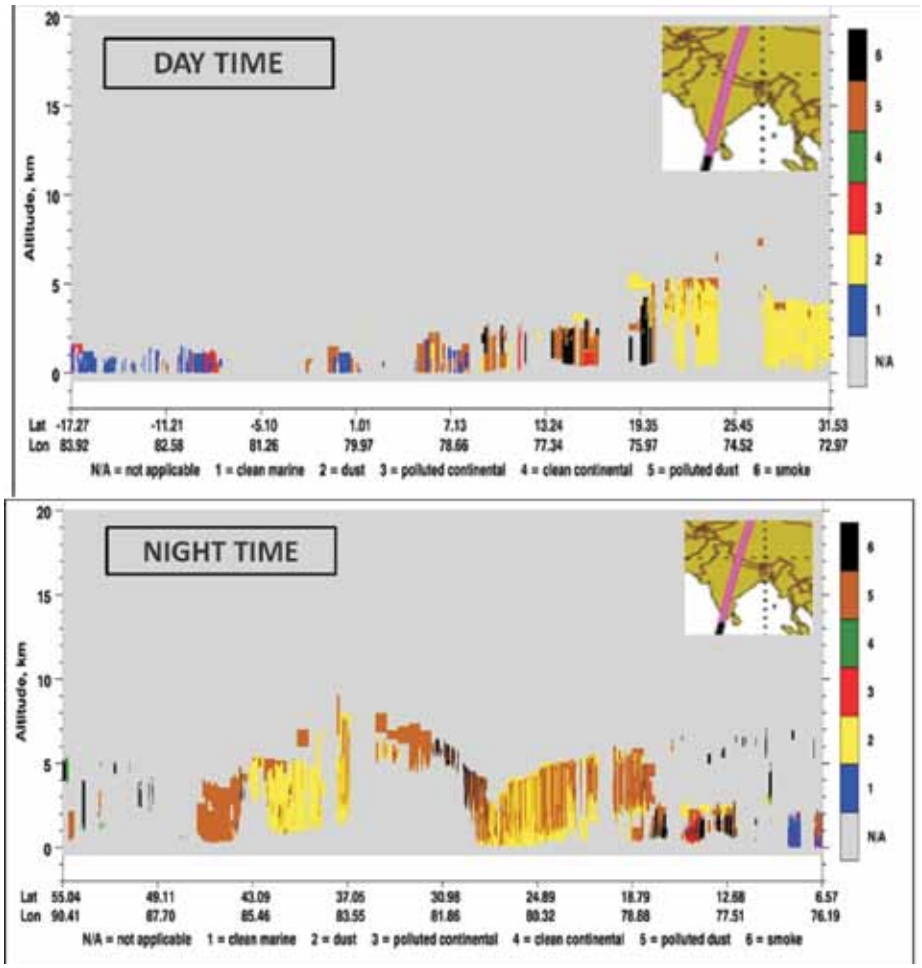

Figure 9. CALIPSO Aerosol subtype for 22 June 2009 for both day and night respectively.

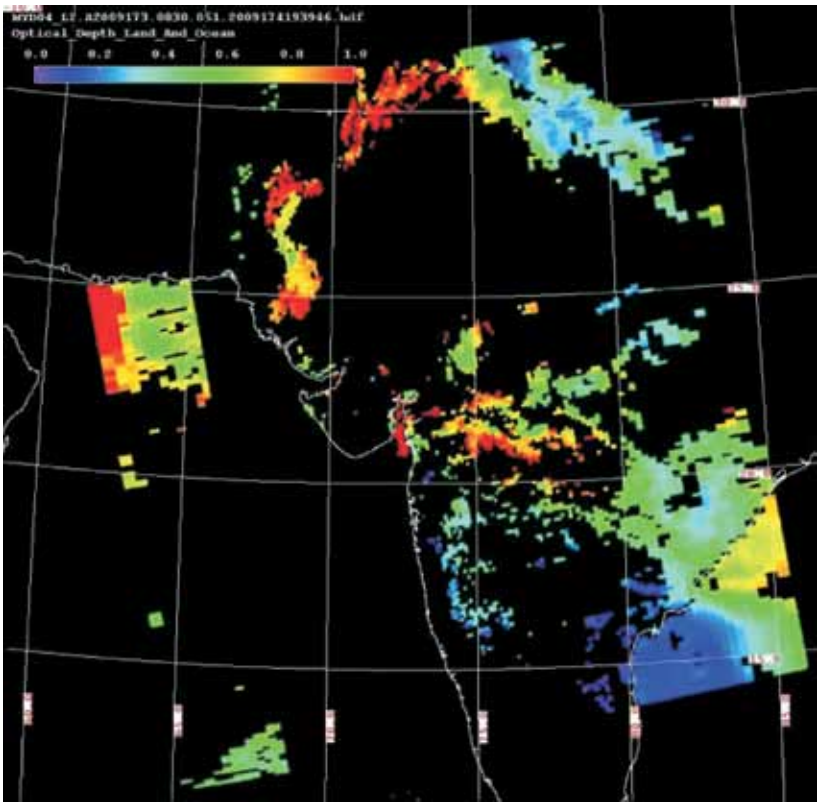

Figure 10. MODIS (AQUA) Aerosol Optical Depth at 08:30UTC on 22 June 2009.

as aerosols. As CALIPSO is a space-borne Lidar, it can observe the aerosol characteristics, but cannot penetrate the thick clouds. The identification method used in CALIPSO is only limited to thin clouds. Hence, clouds are seen where aerosols are not observed. In the absence of cloud, thick layer of aerosol is seen. From the day image it is noticed that clouds are formed at higher altitudes over ocean, whereas over land clouds are at lower altitudes. However, during night, clouds are observed at higher altitudes over land. Figure 8 describes the day and night vertical profiles of the total attenuated backscatter (screened for clouds). There is a significant variation in the distribution of aerosols in vertical from day to night. During day maximum total attenuated backscatter is at 2-3 km and during night the maximum is at 4km. The presence of sub type of aerosols is shown in Figure 9. They clearly indicate that dust and polluted dust aerosols are dominating during both day and night. The year 2009 being a bad monsoon year, the presence of high aerosol levels up to a height of ~ 4km is clearly seen. These aerosols might be mostly anthropogenic in nature apart from dust and other pollutants from long range transport.

Figure 10 shows the AQUA-MODIS AOD (Aerosol Optical Depth) retrieved at 8:00UTC on 22 June 2009. MODIS derived AOD also shows high aerosol loading ranging from 0.4 to 1μm.

CONCLUSIONS

In the present study the spatial distribution of aerosols over India has been studied and the vertical profiles have been retrieved to see the peak aerosol layers. Two case studies have been considered by randomly selecting one day during pre-monsoon (18 March 2009) and the other day during monsoon (22 June 2009) season to understand how the aerosols are distributed. The day and night profiles of Total Attenuated Backscatter at 532 nm have been drawn for both the dates. The synoptic situation during these two days is also considered for better understanding.

On 18, March 2009, thick layer of aerosols is present up to a height of 5 km across India extending from south to north. The uplift of aerosols up to 5 km could be due to the existence of vertical winds on this day. These aerosols are found to persist

during night also. Both day and night profiles are very much similar with each other with aerosol layer extending from the surface to a maximum height of 5 km peaking at about 4 km. It is also interesting to observe that the aerosols are being lifted up along the slopes of Himalayas. Aqua-MODIS also showed high AODs on this day.

On 22, June 2009, the presence of clouds as well as aerosols is observed. As CALIPSO is a space-borne Lidar, it can observe the aerosol characteristics, but cannot penetrate the thick clouds. Hence, clouds are seen, where aerosols are not observed. And in the absence of clouds, thick layer of aerosols is seen. A significant variation in the vertical distribution of aerosols is seen from day to night. During day maximum total attenuated backscatter is at 2-3 km and during night the maximum is at 4km. Dust and polluted dust aerosols are dominating during both day and night. The year 2009 being a bad monsoon year, the presence of high aerosol levels up to a height of ~ 4km is clearly seen. Information retrieved from Aqua-MODIS also indicated high AODs on this day.

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