Study of MPLNET-Derived Aerosol Climatology over Kanpur, India, and Validation of *CALIPSO* Level 2 Version 3 Backscatter and Extinction Products

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ABSTRACT

The level 2 aerosol backscatter and extinction profiles from the NASA Micropulse Lidar Network (MPLNET) at Kanpur, India, have been studied from May 2009 to September 2010. Monthly averaged extinction profiles from MPLNET shows high extinction values near the surface during October–March. Higher extinction values at altitudes of 2–4 km are observed from April to June, a period marked by frequent dust episodes. Version 3 level 2 Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP) aerosol profile products have been compared with corresponding data from MPLNET over Kanpur for the above-mentioned period. Out of the available backscatter profiles, the16 profiles used in this study have time differences less than 3 h and distances less than 130 km. Among these profiles, four cases show good comparison above 400 m with R^2 greater than 0.7. Comparison with AERONET data shows that the aerosol type is properly identified by the CALIOP algorithm. Cloud contamination is a possible source of error in the remaining cases of poor comparison. Another source of error is the improper backscatter-to-extinction ratio, which further affects the accuracy of extinction coefficient retrieval.

1. Introduction

Aerosols have an important role in the earth–atmosphere system with their effect on solar radiation, cloud microphysics, and climate. To account for their influences, it is necessary to have information about aerosol physical, chemical, and optical properties. However, aerosol concentration varies both in time and space. Because of different local meteorology and emission scenarios, aerosol content varies with geography. In addition, transport and stratosphere–troposphere exchange processes can result in change of vertical variation of aerosol content. Thus, it is necessary to have information about horizontal as well as vertical variation of aerosols. Knowledge of aerosol vertical profile is required in radiative transfer studies also, because height of the aerosol layer affects radiation at top of the atmosphere (Guan et al. 2010).

Further, the height of the aerosol layer and vertical profile is also of importance in having an accurate assessment of the radiative balance of the earth–atmosphere system. The total integrated aerosol optical depth (AOD) provides the information about the total aerosol content in the atmosphere, whereas the vertical profile tells the height at which the aerosols are present. Ganguly et al. (2009) demonstrate the usage of the vertical profile of aerosols to derive the composition and concentration of aerosol. Accurate information of these parameters has impact on the accuracy of radiative transfer calculations.

In situ and ground-based measurements of vertical profile of atmospheric species are obtained by ground-based lidar measurements, wherein an optical pulse is shot to the atmosphere and the backscattered signal is used to infer the atmospheric species and their altitude.

Ground-based lidar measurements can provide useful information on the temporal evolution of aerosol distribution and properties, but they have limitations because they are point measurements and cannot provide the spatial information. Such information is provided by satellite-based sensors that enable a global view of aerosols. However, the satellite-based measurements are based on several assumptions and theoretical

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computations that need to be verified based on comparison with ground-based data. Ground-based observations are normally free from such possible errors and provide the benchmark from which to validate the satellite data.

The National Aeronautics and Space Administration (NASA) Micropulse Lidar Network (MPLNET; Welton et al. 2001) is a worldwide network of lidars collocated with NASA Aerosol Robotic Network (AERONET; Holben et al. 1998) sun/sky photometers. Joint MPLNET and AERONET sites provide both columnar and vertically resolved aerosol properties and cloud height. AERONET retrievals of AOD are well documented and available periodically throughout the day at each site, with reported uncertainty of approximately ± 0.01 at 500 nm (Eck et al. 1999; Smirnov et al. 2000). AERONET products are produced at three quality levels: level 1 near-real-time (NRT) products are unscreened, level 1.5 are NRT but cloud screened, and level 2 products are quality assured but not NRT. MPLNET level 1 products include continuous day–night profiles of uncalibrated attenuated backscatter and associated uncertainties at 75-m vertical and 1-min temporal resolutions (Campbell et al. 2002; Welton and Campbell 2002). MPLNET uses the micropulse lidar (MPL; Spinhirne 1993), a commercially available single-wavelength elastic backscatter lidar, with wavelengths of 523, 527, or 532 nm, depending upon the lidar model. MPLNET level 1.5 (NRT, but not quality assured) profiles of aerosol extinction and backscatter are retrieved from 20-min cloud-cleared level 1 signal averages using the collocated AERONET AOD as a constraint (Welton et al. 2000). This process also retrieves a column-averaged extinction-to-backscatter ratio (or lidar ratio). Because of instrumental constraints, the lowest recoverable altitude is 400 m for newer MPL models, and the minimum aerosol backscatter retrieval limit is 1×10^{-5} (km sr)$^{-1}$. MPLNET data quality levels are identical to AERONET, with both level 1.5 and 2 (quality assured) aerosol products available. MPLNET level 2 extinction products have been validated numerous times, most recently by Schmid et al. (2006).

The NASA *Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations* (*CALIPSO*) (Winker et al. 2009) was launched on 28 April 2006, in a polar orbit at altitude 705 km. The Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP) sensor on board *CALIPSO* provides global aerosol and cloud vertical distributions and properties. The retrieval of extinction from CALIOP is accomplished in three steps: Selective Iterated Boundary Locator (SIBYL), Scene Classification Algorithm (SCA), and Hybrid Extinction Retrieval Algorithm (HERA). SIBYL and SCA are related to the identification and classification of layers. SCA identifies the layer as cloud or aerosol and makes further classification of cloud or aerosol type. It also makes a selection of the values of the lidar ratio (S) and multiple scattering function (n) useful for optical depth and extinction retrievals. HERA makes the actual retrievals of optical depth, extinction, and backscatter coefficients (Mielonen et al. 2009). CALIOP extinction and backscatter profiles are reported at 532 nm, and 5-km horizontal and 60-m vertical resolution. In addition, profiles of backscatter at 1064 nm and depolarization are also provided.

Validation of CALIOP data have been reported in several papers. The CALIOP level 1 attenuated backscatter product has been validated with ground-based observations (Pappalardo et al. 2010; Mona et al. 2009; Mamouri et al. 2009). CALIOP version 2, level 2–derived backscatter products have also been validated against ground-based and aircraft observations (e.g., Kim et al. 2008; Kacenelenbogen et al. 2011). Version 3 *CALIPSO* data were released in 2010, and Rogers et al. (2011) show satisfactory performance of the CALIOP version 3 calibration algorithm. In this paper, the vertical profile of extinction and backscatter from the version 3, level 2 product of the CALIOP sensor is validated against the ground-based data from MPLNET (level 2) over Kanpur, India. The version 3 CALIOP product makes modifications related to uniformity of horizontal resolution of cloud and aerosol profile product, and the addition of several diagnostic and quality assurance parameters (*CALIPSO* quality statements: lidar level 2 Cloud and Aerosol Profile Products, version 3.01).

The difference between space- and ground-based lidar measurements can be due to large sensor-to-target distances, low signal-to-noise ratios (Vaughan et al. 2004), multiple scattering effects, rare collocation of satellite and ground lidar lines of view, horizontal inhomogeneities in aerosol conditions, and an inaccurate value of the lidar ratio (Ansmann 2006). Kacenelenbogen et al. (2011) mention calibration issues and problems with the cloud screening algorithm as additional sources of error in the CALIOP version 2 extinction product.

The study location is Kanpur in the Indo-Gangetic basin. It is a rapidly growing center of economic growth and is among the largest cities in the region. Based on meteorology, the year is divided into four seasons: winter, premonsoon, monsoon, and postmonsoon (Baxla et al. 2009). Rainfall is mainly concentrated in the June–September period. Because of higher wind speeds, the premonsoon and monsoon seasons are dominated by coarse-mode particles, whereas postmonsoon and winter are dominated by fine-mode particles. The premonsoon season is often characterized by heavy dust episodes and storms. Dey et al. (2004) and Dey and Di Girolamo

(2010) show that the winter-to-premonsoon season is accompanied by anthropogenic aerosols in addition to dust. During postmonsoon, resulting from the burning of agricultural farms to make them fit for next season, and the burning of leaves, etc., during winter, there is a large concentration of fine-mode particles in the air. Because of lower boundary layer height, these particles are not able to escape and are trapped in the atmosphere (Singh et al. 2004; Dey et al. 2005; Tripathi et al. 2005). Kanpur witnesses heavy dust storms during the premonsoon season, and fog during winter. In addition, the contribution from industrial pollution is present during all seasons. All of these features allow the examination of the CALIOP retrieval algorithm under different atmospheric conditions. The Kanpur MPLNET site was established in May 2009 using a model 4 MPL with a wavelength of 532 nm, and is located in the campus of Indian Institute of Technology, Kanpur, about 17 km from the city.

2. Methodology

Level 2 CALIOP extinction profiles are validated using level 2 MPLNET extinction profiles. Level 2 (quality assured and calibrated based on more strict screening criteria) data from MPLNET are available only during daytime because it uses the AERONET AOD product as a constraint in its algorithm. NRT level 1.5 aerosol extinction is available from MPLNET at night, but it is not available as quality-assured products. This reduces the number of profiles used in our validation because nighttime CALIOP retrievals are not included. Further, in the case of *CALIPSO*, noise is higher in daytime data as compared to nighttime data. Because of the very narrow swath of *CALIPSO* and the MPLNET observations being point measurements, it is very difficult to have coincident measurements. We have used the MPLNET measurement closest to the *CALIPSO* overpass, with the restriction that the absolute time difference between the two observations be less than 3 h. This is in order to have sufficient data for comparison without compromising on the quality of the same, that is, to avoid the differences resulting from change in atmospheric state. Details about the number of profiles along with their classification are provided in the results and discussion section.

It is necessary that the two instruments measure the same air parcel so that plausible conclusions can be derived regarding differences in profiles. Because the two observations seldom coincide in space and time, there could be a difference in the observed air parcel resulting from any change in wind speed and direction between the two observation times (Anderson et al. 2003). We have performed Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) 24-h backtrajectory analysis for all cases to ensure that the same air parcel is observed by both instruments (Draxler and Hess 2005). In most cases the HYSPLIT analysis is performed at 1, 2, and 3 km. However, in the case of missing data at these heights in the backscatter profiles, the analysis is performed at other heights.

3. Results and discussion

MPLNET-derived monthly averaged profiles of extinction coefficients are shown in Fig. 1 for the period from May 2009 to September 2010. No level 2 MPLNET profiles were obtained for December 2009. The repetitive nature of the pattern in the extinction profile is seen in the data for May–September 2009 and May–September 2010. Higher extinction at 2–4 km is observed during the April–June period, resulting from elevated aerosols, which come down to 2 km during July–August. For October–March, most of the extinction is concentrated below 1 km. During November–January, extremely high values of extinction are observed near the surface. It is due to the burning of fields during October and also the burning of leaves, etc., to sustain against cold weather. High extinction and poor air quality is further deteriorated by the low planetary boundary layer height in winter that constrains the burning aerosols near the surface. Near-surface extinction during the remaining months is lower than 0.3 km^{-1}. The period from April to June is accompanied by large standard deviations. This large variation in the data is mainly due to the large number of dust episodes that are common in this region during these months (Dey et al. 2004; Chinnam et al. 2006).

A comparative study is made based on CALIOP and MPLNET backscatter and extinction data for the period from May 2009 to September 2010. One MPLNET profile (20-min average) is used to compare to one CALIOP backscatter profile. Only those profiles are chosen that have an absolute time difference of less than 3 h. The available profiles are sorted in order of increasing distance between MPLNET station and *CALIPSO* overpass. All of the cases having distances more than 130 km had poor comparison between the two datasets. Thus, 130 km is the optimum distance between the two observation points for comparing the data. The large distance between the observation points makes it inappropriate to make comparisons because of changes in meteorology.

Under these constraints, we have 16 comparison cases; among these, for 4 cases the datasets compare well at all heights above 400 m (R^2 greater than 0.7). The vertical range from 400 m to 6 km is divided into 100-m bins and the mean backscatter for a bin is taken as the backscatter

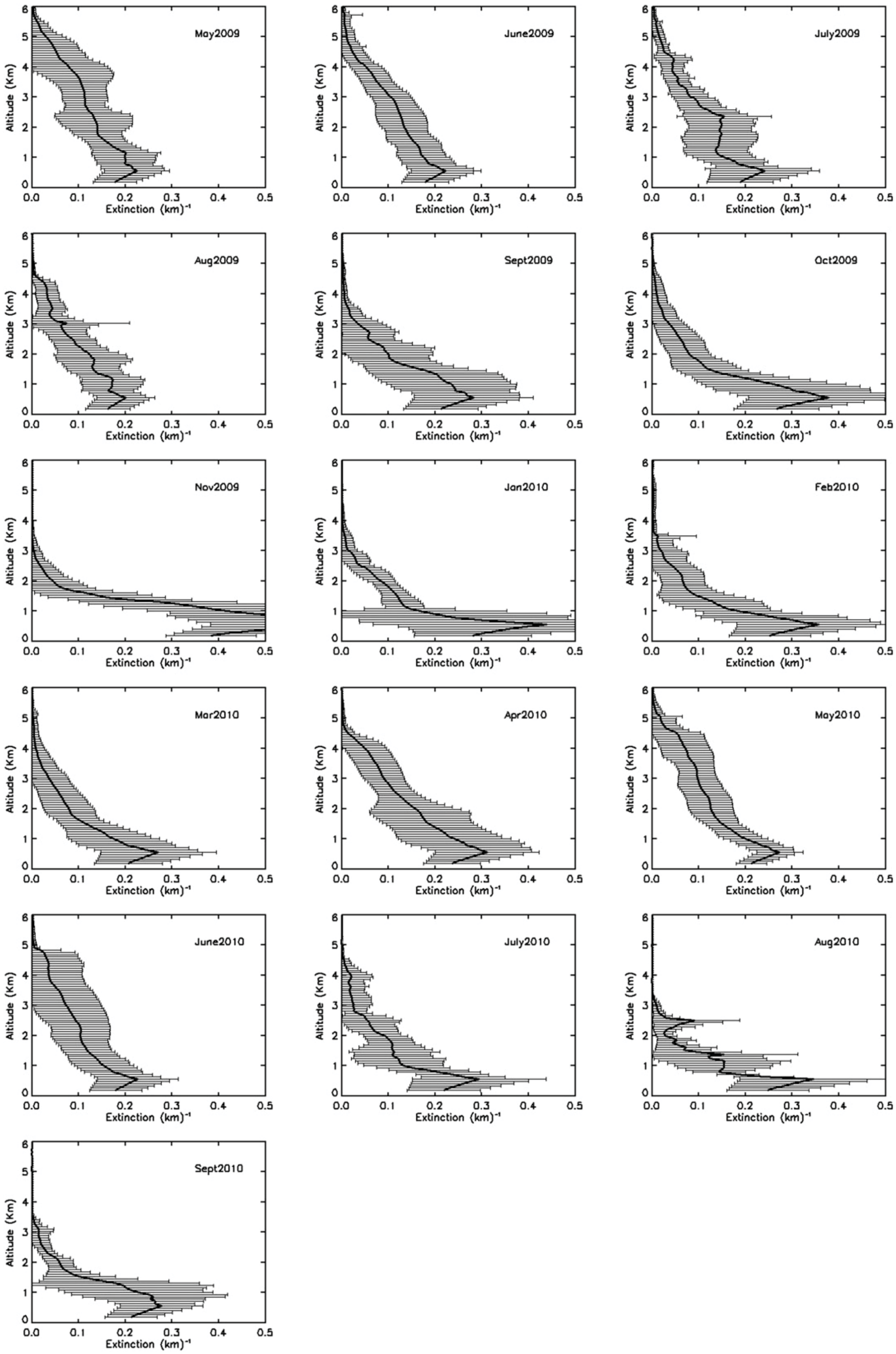

FIG. 1. Monthly averaged profiles of MPLNET-derived extinction coefficients for May 2009–September 2010. No level 2 MPLNET profiles were obtained for December 2009. Higher values of extinction are noticed at 2–4 km during April and May, a period marked by heavy dust episodes. October–March is accompanied by high values of extinction near the surface.

for that bin. The linear regression of CALIOP and MPLNET backscatter binned in this way is performed, and R^2 and slope are found. In addition, mean difference of CALIOP and MPLNET backscatter for the complete vertical range is calculated.

All of the cases are discussed below, with cases of good comparison being discussed first. The reason for poor comparison is explored with the help of vertical feature mask data from CALIOP that also provides information about the aerosol type (Omar et al. 2009), feature mask data from the MPLNET, lidar ratio from CALIOP and MPLNET, 5-day air backtrajectory analysis to identify the sources of aerosol measured, AERONET data especially the Ångström exponent, and aerosol size distribution. One case each of a good and a bad comparison is presented in Figs. 2 and 3, whereas the details of all the cases are given in Table 1.

a. *Discussion of good comparison cases*

For 21 September 2009, both profiles compare well at all heights above 1 km ($R^2 = 0.82$), whereas below 1 km, CALIOP-derived backscatter is underestimated reducing the slope of linear fit (0.53). CALIOP identifies the aerosol type as ''dust'' and ''polluted dust'' at different heights, whereas AERONET data at the overpass time show $\alpha = 1.09$, which is representative of smaller particles. AERONET-derived size distribution shows nearly equally prominent fine and coarse modes. In this case, backtrajectories show the air parcel to be traveling across the dust-dominated region in western India. Thus, the aerosol type assumed by CALIOP is appropriate. MPLNET lidar ratio for this case is 34.95 sr. The CALIOP lidar ratio is 40 sr between 0 and 2.85 and at 3.75 km, and 55 sr between 2.85 and 3.45, and 3.75 and 4.35 km.

On 16 October 2009 (Fig. 2) both the profiles compare well at all heights above 1.5 km ($R^2 = 0.85$). CALIOP underestimates below 1.5 km, leading to a lower value of slope of linear fit (0.55). October is the burning season when agricultural fields are prepared for the next season. AERONET data show AOD = 0.58 and $\alpha = 1.31$ at the *CALIPSO* overpass time, which is indicative of fine particles. AERONET-derived size distribution shows equally dominant fine and coarse modes. This information is well captured by CALIOP feature mask data that show dust below 2 km and polluted dust between 2 and 4 km. The 5-day backtrajectories at 1, 2, and 3 km are seen to come through the dust-dominated western Indian region. MPLNET lidar ratio for this case is 39.77 sr. CALIOP lidar ratio is 40 sr between altitudes of 0 and 1.95 km, and 55 sr between 1.95 and 4.35 km.

On 23 October 2009 the vertical extent and shape of aerosol presence is well reproduced by CALIOP ($R^2 = 0.80$, slope = 1.02). The inferred aerosol type is polluted dust with presence of ''smoke'' and a layer of dust at 2–2.5 km. The presence of smoke-like fine particles is indicated in AERONET data also where $\alpha = 1.23$. This is the burning season when agricultural fields are prepared for the next season. The 5-day backtrajectories are seen to be coming from the desert regions of Rajasthan. AERONET-derived size distribution shows equally dominant coarse and fine modes. The MPLNET lidar ratio for this case is 37.07 sr. The CALIOP lidar ratio is 55 sr between 0 and 1.65 km, and 40 sr between 1.65 and 2.55 km.

On 16 March 2010 $R^2 = 0.78$, though the slope of the linear fit is comparatively low (0.40), mainly resulting from underestimation by CALIOP below 2 km. The backtrajectories show the aerosol to be of desert origin, and this is also captured by CALIOP, which shows the aerosol type as dust above 500 m, and polluted dust below 500 m. AERONET measured $\alpha = 0.92$, and the aerosol size distribution shows a dominant coarse mode and a smaller fine mode. The MPLNET lidar ratio for this case is 46.51 sr and the CALIOP lidar ratio is 55 sr between 0 and 0.45 km, and 40 sr between 0.45 and 3.45 km.

b. *Cases of poor comparison*

On 16 May 2009 aerosol types assumed are dust from the surface to 3 km and polluted dust from 3 to 3.5 km. It is consistent with season and supported by backtrajectories at 2 and 3 km. However, the trajectory at 1 km indicates a continental origin of aerosol present at this altitude. The CALIOP feature mask shows the presence of clouds, indicating the possibility of cloud contamination in the profile chosen for comparison. AERONET-derived size distribution shows a dominant coarse mode and a small fine mode. The MPLNET lidar ratio in this case is 34.32 sr. The CALIOP lidar ratio is 40 sr between 0 and 2.55 km, and 55 sr between 2.55 and 3.45 km.

On 25 May 2009 the aerosol type identified by CALIOP is polluted dust, which is reasonable for the premonsoon season. AERONET-derived size distribution shows coarse and fine modes. The backtrajectories at 2 and 3 km further support this inference. However, the trajectory at 1 km indicates a continental origin. This case is of special interest because it falls in the period of 23–26 May 2009 when Cyclone Aila was active in the Bay of Bengal. The 5-day backtrajectory at 1-km altitude starts in the Bay of Bengal, implying a high probability of cloud presence. The AERONET data have gaps at the time of the *CALIPSO* overpass. However, MPLNET data showed as being ''blocked'' at this time, so that cloud presence could not be confirmed. The

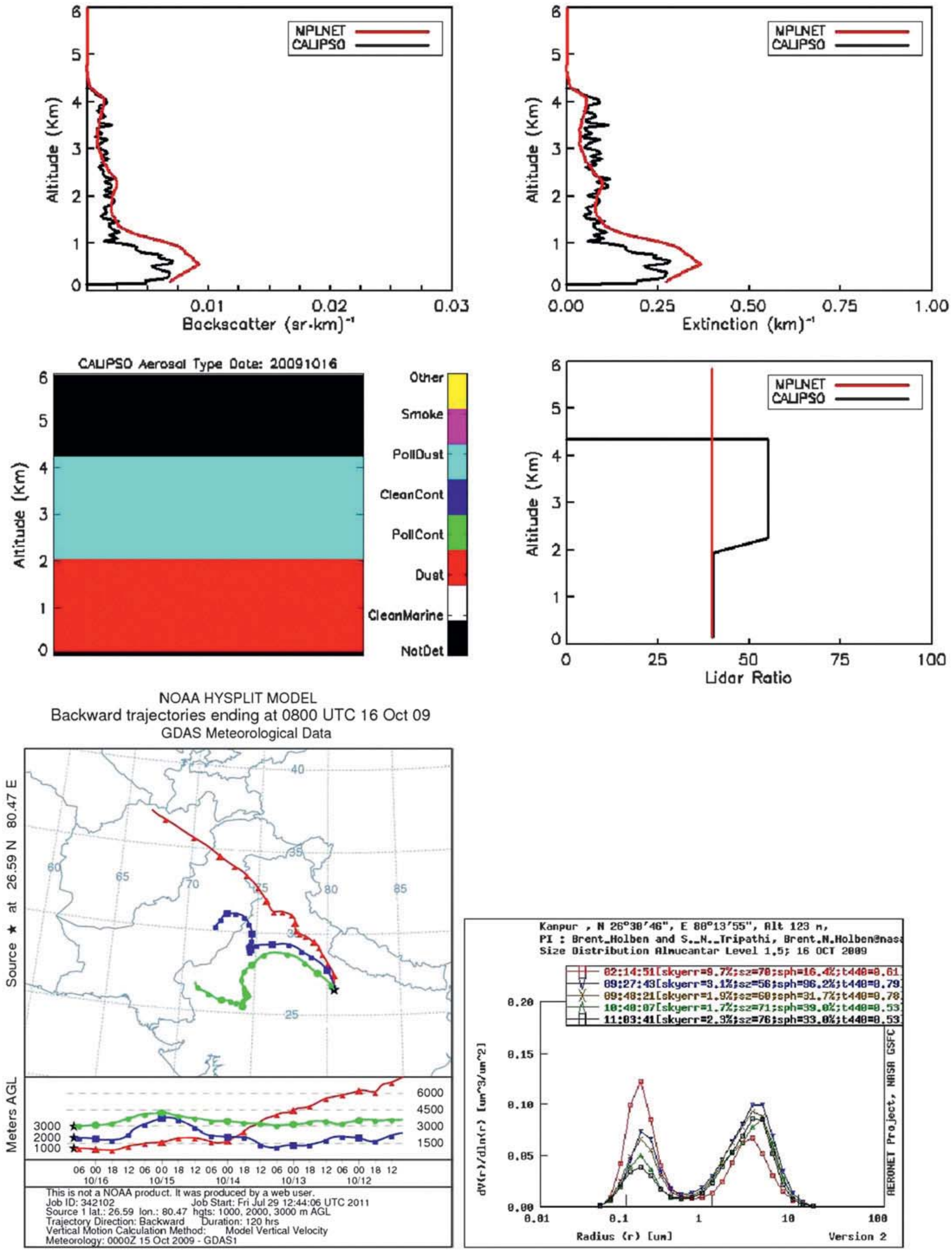

FIG. 2. Comparison of CALIOP and MPLNET backscatter and extinction profiles, aerosol type inferred by CALIOP, lidar ratio taken by the CALIOP algorithm for the retrieval process, 5-day backtrajectory ending at the CALIOP overpass location, and AERONET-derived aerosol size distribution for the 16 Oct 2009 case. MPLNET observation time is 8.7 h.

MPLNET lidar ratio in this case is 73.45 sr and the CALIOP lidar ratio is 52.3 sr between 0 and 2.55, and 3.45 and 4.05 km; 53.8 sr between 2.55 and 2.85 km; and 55 sr between 2.85 and 3.45 km.

For 10 June 2009 (Fig. 3), the aerosol type inferred by CALIOP is dust, which is reasonable with prevailing climatology during this season. The AERONET data show $\alpha = 0.28$ and a single coarse-mode size distribution,

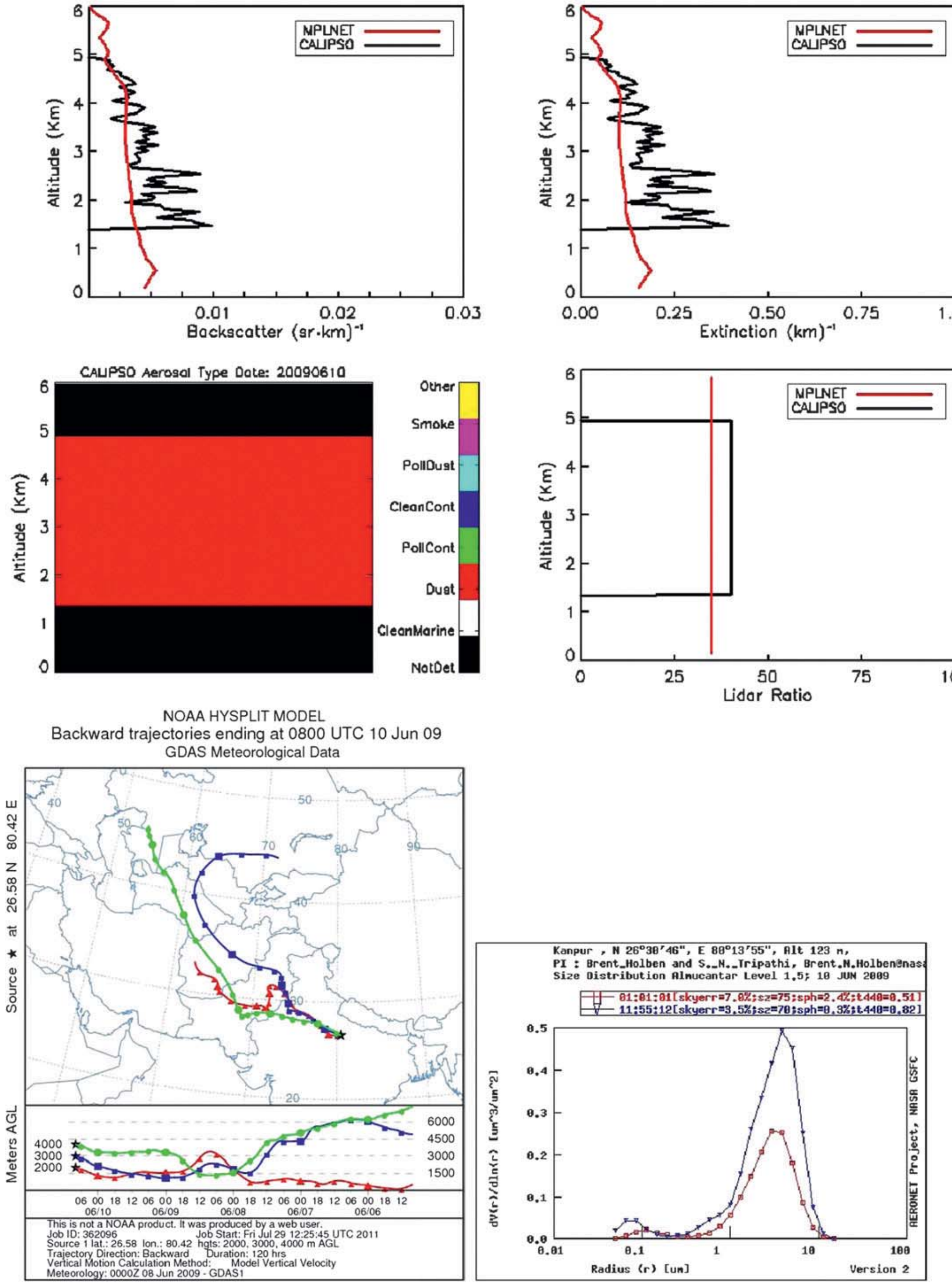

FIG. 3. Comparison of CALIOP and MPLNET backscatter and extinction profiles, aerosol type inferred by CALIOP, lidar ratio taken by the CALIOP algorithm for the retrieval process, 5-day backtrajectory ending at the CALIOP overpass location and AERONET-derived aerosol size distribution for 10 Jun 2009 case. MPLNET observation time is 10.6 h.

which is indicative of dust aerosols. However, there is large gap in AERONET data and blocks in MPLNET data, implying possible cloud presence during the period. For 10 June 2009, the MPLNET lidar ratio is 34.80 sr, while the CALIOP lidar ratio is 40 sr between 1.35 and 4.95 km.

For the 17 June 2009 case, the backscatter from MPLNET and CALIOP compares well above 1 km.

TABLE 1. MPLNET observation time (decimal hours); time difference between *CALIPSO* overpass and MPLNET observation (decimal hours); distance (km) between *CALIPSO* overpass and MPLNET location; AOD (500 nm), Ångström exponent, Reff, and single-scattering albedo (SSA) (675 nm) from AERONET at closest observation time to MPLNET; mean and standard deviation of difference between CALIOP and MPLNET-derived backscatter [(sr km)$^{-1}$]; R^2; and slope of the correlation between MPLNET- and CALIOP-derived backscatter from 400-m to 6-km altitude. The vertical range is divided into 100-m bins.

Date	MPLNET observation time	Time diff	Distance	AOD	α	Reff	SSA	Mean backscatter diff	R^2	Slope
21 Sep 2009	9.5	1.3	126.1	0.73	1.09	0.42	0.85	−0.001 (0.002)	0.82	0.53
16 Oct 2009	8.7	0.5	25.3	0.58	1.31	0.41	0.85	−0.0008 (0.001)	0.85	0.55
23 Oct 2009	8.9	0.7	123.8	0.39	1.23	0.32	0.88	0.002 (0.002)	0.80	1.02
16 Mar 2010	8.3	0.1	121.5	0.62	0.92	0.48	0.86	−0.001 (0.002)	0.78	0.40
16 May 2009	8.8	0.6	129.4	0.58	0.70	0.61	0.91	0.0004 (0.002)	0.11	0.72
25 May 2009	9.4	1.2	20.0	0.44	1.04	0.79	0.91	0.005 (0.005)	0.65	6.85
10 Jun 2009	10.6	2.4	19.8	0.61	0.28	0.94	0.95	0.001 (0.002)	0.52	2.48
17 Jun 2009	9.4	1.1	130.2	0.33	0.43	0.62	0.87	−0.0001 (0.001)	0.52	0.70
14 Sep 2009	9.6	1.4	24.9	0.76	1.43	0.41	0.96	0.0009 (0.005)	0.53	1.12
28 Feb 2010	8.4	0.1	121.8	0.28	0.69	0.63	0.90	−0.001 (0.002)	0.01	−0.04
9 Mar 2010	8.1	0.1	28.5	0.17	0.80	0.55	0.86	−0.001 (0.0006)	0.23	0.32
17 Apr 2010	7.8	0.4	120.0	0.69	0.30	0.90	0.78	−0.002 (0.002)	0.54	0.40
19 May 2010	11.0	2.7	120.9	0.72	0.64	0.74	0.89	−0.004 (0.001)	0.03	−0.10
4 Jun 2010	9.1	0.9	120.9	0.56	0.09	0.84	0.92	0.023 (0.046)	0.58	21.23
13 Jun 2010	9.4	1.3	30.5	0.48	0.69	0.72	0.71	0.003 (0.004)	0.60	2.14
20 Jun 2010	5.7	2.6	118.4	0.77	0.95	0.48	0.65	−0.0006 (0.002)	0.37	−0.39

However, large overestimation by CALIOP below 500 m results in a lower value of R^2 (0.52). AERONET data for this case show $\alpha = 0.43$ and the aerosol size distribution shows a dominant coarse mode and a noticeable, but small, fine mode. The aerosol type inferred by CALIOP is dust above 500 m and "polluted continental" below 500 m. This is reasonable for this season and consistent with AERONET data and backtrajectories. The MPLNET lidar ratio for this case is 30.51 sr. The CALIOP lidar ratio is 70 sr between 0 and 0.45 km, and 40 sr between 0.45 and 4.95 km.

On 14 September 2009, comparison between CALIOP- and MPLNET-derived backscatter is good from about 1.75 to 4 km. However, between 1 and 1.75 km, CALIOP-derived backscatter is lower, whereas below 1 km, there is a large overestimation by CALIOP. The poor comparison at lower heights results in a low value of R^2 (0.53). AERONET data during this day have intermittent gaps, indicating cloud presence at *CALIPSO* overpass. However, this could not be confirmed from MPLNET data because they were blocked at the *CALIPSO* overpass time. The profiles show good comparisons between 1 and 4 km. The aerosol type inferred by CALIOP is polluted dust between 2.5 and 4 km, and polluted continental below 2.5 km. This is reasonable considering the AERONET-derived aerosol size distribution, which shows a dominant fine mode in addition to a coarse mode. The MPLNET lidar ratio in this case is 46.48 sr. The CALIOP lidar ratio is 70 sr between 0.45 and 2.55 km, and 55 sr between 2.55 and 4.05 km.

For 28 February 2010, the backtrajectories are seen to travel across the semiarid region of Gujarat in western India, and support the dust and polluted dust aerosol types assumed by the CALIOP algorithm. However, the aerosol type assumed near the surface, namely, "clean continental," is not consistent with the backtrajectory. AERONET size distribution shows a dominant coarse mode and a smaller fine mode. However, conclusive remarks cannot be made in this regard because of the problem in retrieval near the surface by MPLNET. For this case, the MPLNET lidar ratio is 37.18 sr. The CALIOP lidar ratio is 35 sr between 0 and 0.45 km, 40 sr between 1.05 and 1.35 km, and 55 sr between 1.35 and 1.95 km.

On 9 March 2010 the extinction profile is limited to 0–2 km and is similarly retrieved by the two instruments. The aerosol type inferred by CALIOP for this case is dust, which is reasonable during this month because it is a transition period between winter and premonsoon. The AERONET $\alpha = 0.80$ at the time of CALIOP overpass. This is also reflected in the backtrajectories, which are seen to be coming through dust-dominated regions. However, the AERONET-derived size distribution shows a fine mode in addition to a dominant coarse mode. Thus, polluted dust is more appropriate to describe this case. The MPLNET lidar ratio in this case is 36.35 sr. The CALIOP lidar ratio is 40 sr between 0 and 1.65 km.

The aerosol type chosen for the 17 April 2010 case is dust, which is consistent with the AERONET-observed value of $\alpha = 0.30$. This is corroborated by the backtrajectories that are seen to come across the desert region in western India. The size distribution derived by AERONET shows a single mode attributed to coarse particles. The MPLNET lidar ratio in this case is 30.50 sr. The CALIOP lidar ratio is 40 sr between 0 and 4.05 km.

For 19 May 2010, the MPLNET lidar ratio is 46.23 sr. The CALIOP lidar ratio is 40 sr between 0 and 2.85 km, and 55 sr between 4.05 and 4.35 km. The AERONET-derived size distribution for this case shows a dominant coarse mode with a very small concentration of particles in the fine mode.

On 4 June 2010, AERONET $\alpha = 0.09$, which is consistent with the dust aerosol type assumed by CALIOP. AERONET-derived size distribution shows a single coarse mode, representative of dust aerosols. The backtrajectories are seen to travel across the dust-dominated regions of Rajasthan and Gujarat in western India. The CALIOP feature mask shows cloud presence between 2- and 4-km altitude; thus, the profile chosen for comparison could be contaminated by cloud presence. The CALIOP lidar ratio is 25.24 sr (the value for clouds) between 0.75 and 1.35 km, 40 sr (the value for dust) between 1.35 and 2.85 km, and again 25.24 sr between 2.85 and 4.05 km. The MPLNET lidar ratio for this case is 28.24 sr.

On 13 June 2010 the aerosol type assumed by CALIOP is polluted dust, which is supported by backtrajectories at 2 and 3 km, though not at 1 km, which is of a continental nature starting in the Bay of Bengal 5 days earlier. There is further inconsistency in the lidar ratio and aerosol type. Although the aerosol type is identified as polluted dust, the lidar ratio used for retrieval by CALIOP is 55 sr (the value for polluted dust) between 1.65 and 3.75 km, and 40.47 sr (the value for dust) from the surface to 1.65-km altitude. The MPLNET lidar ratio in this case is 36.37 sr. However, the AERONET-derived size distribution showing a dominant coarse mode and a very small fine mode supports the polluted dust aerosol type inferred by CALIOP.

For 20 June 2010, the MPLNET lidar ratio is 74.64 sr. The CALIOP lidar ratio for this case is 55 sr between 0 and 1.05 km, and 40 sr between 2.85 and 3.45 km. The AERONET-derived size distribution for this case shows equally dominant fine and coarse modes.

4. Conclusions

Backscatter and extinction from version 3 of CALIOP level 2 aerosol profile product is compared with corresponding data from MPLNET for May 2009–September 2010. Among 16 available profiles having time differences of less than 3 h and distances of less than 130 km, 4 profiles show a good comparison between the two sets of data above 400 m. Cases of poor comparison hint at possible confusion between heavy aerosol and cloud by CALIOP. Extinction profiles usually follow the same pattern as backscatter. However, there are differences attributed to the different backscatter-to-extinction ratios used in the algorithms. This is the subject of ongoing research and will be addressed in a future communication. The aerosol type is properly identified by CALIOP, as seen on comparison with the Ångström exponent and aerosol size distribution data from AERONET. The present study analyzed the performance of the latest CALIOP aerosol profile algorithm, thus providing useful input for future improvements in the retrieval process.

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