Extinction-to-backscatter ratios of lofted aerosol layers observed during the first three months of CALIPSO measurements

A. Omar[1], M. Vaughan[2], Z. Liu[3], Y. Hu[1], J. Reagan[4], D. Winker[1]
[1]NASA Langley Research Center
Science Directorate
21 Langley Blvd, MS 401A
Hampton, VA 23681
Tel: 757-8645128 •Fax 757-8647790
email: ali.h.omar@nasa.gov

[2]Science Systems and Applications, Inc. (SSAI), NASA LaRC, Hampton, VA
[3]National Institute of Aerospace, NASA LaRC, Hampton, VA
[4]University of Arizona, Tucson, AZ.

Abstract
Case studies from the first three months of the Cloud and Aerosol Lidar and Infrared Pathfinder Spaceborne Observations (CALIPSO) measurements of lofted aerosol layers are analyzed using transmittance [*Young*, 1995] and two-wavelength algorithms [*Vaughan et al.*, 2004] to determine the aerosol extinction-to-backscatter ratios at 532 and 1064 nm. The transmittance method requires clear air below the layer so that the transmittance through the layer can be determined. Suitable scenes are selected from the browse images and clear air below features is identified by low 532 nm backscatter signal and confirmed by low depolarization and color ratios.
The transmittance and two-wavelength techniques are applied to a number of lofted layers and the extinction-to-backscatter ratios are compared with values obtained from the CALIPSO aerosol models [*Omar et al.*, 2004]. The results obtained from these studies are used to adjust the aerosol models and develop observations based extinction-to-backscatter ratio look-up tables and phase functions. Values obtained by these techniques are compared to S_a determinations using other independent methods with a goal of developing probability distribution functions of aerosol type-specific extinction to backscatter ratios.

Method
Given a solution of the particulate backscatter at 532 nm $\beta_{532,p}$, the two-wavelength method uses a least squares method to minimize the difference between the attenuated total backscatter measurement at 1064 nm, B_{1064} and the right hand side of eq. (1).

$$\begin{aligned} \mathrm{B}_{1064}(r) &= \left(\beta_{m,1064}(r) + \beta_{p,1064}\right)\cdot T^2_{p,1064}(r) \\ &= \left(\beta_{m,1064}(r) + \underline{\chi}\cdot\beta_{p,532}(r)\right)\cdot \exp\left(-2\cdot \underline{S_{1064}\cdot\chi}\cdot\gamma_{532}(r)\right) \end{aligned} \quad (1)$$

Note that the only unknowns (underlined) in eq.(1), the extinction to backscatter ratio at 1064 nm, S_{1064}, and the color ratio, χ (defined as $\beta_{1064,p}/\beta_{532,p}$), are both intensive properties defined by the layer composition, size distribution, and shape of its constituent particles. Since these characteristics do not vary substantially we make the assumption that S_{1064} and χ are constant within the layer. The method is applicable whenever there is a reliable S_{532} value such as in the CALIOP S_a selection algorithm for attached tropospheric aerosol layers.

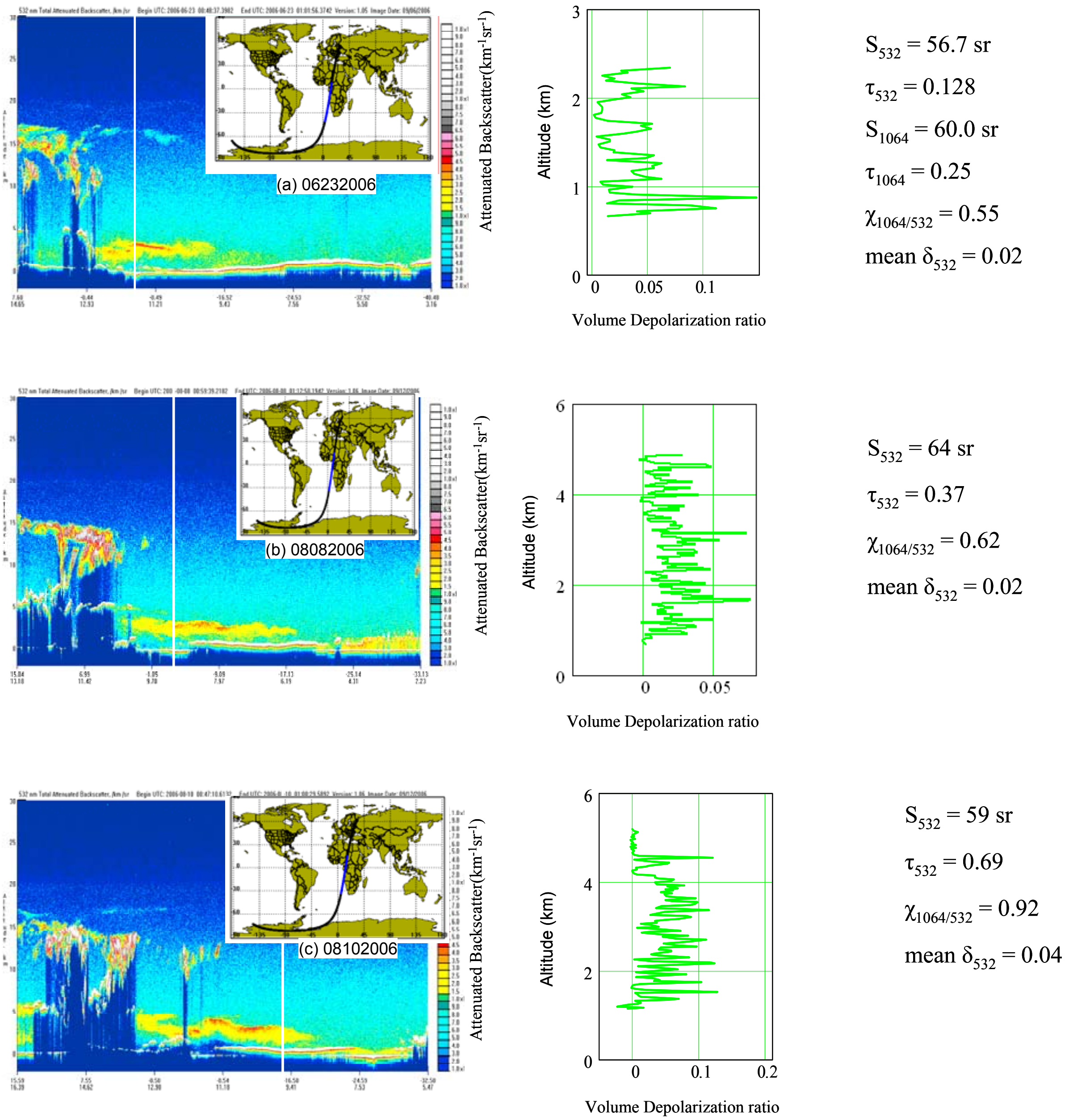

Figure 1. Elevated smoke layers observed of the west coast of Africa on (a) June 23, (b) August 8, and (c) August 10, 2006

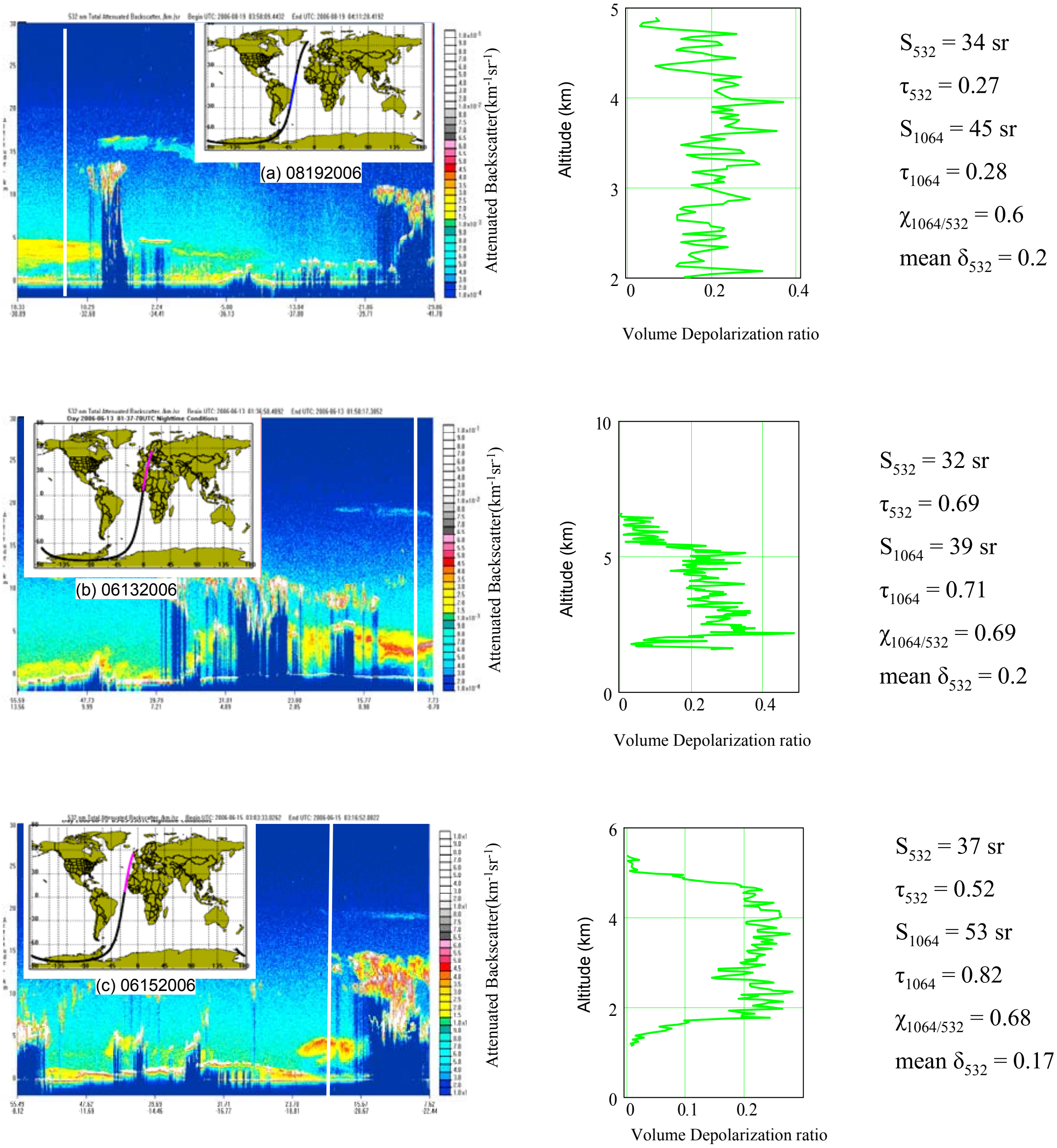

Figure 1. Elevated dust layers observed on (a) August 19, (b) June 13, and (c) June 15, 2006

Fig. 1 and 2 show attenuated backscatter measurements on the left plotted in a color scheme that uses deep blue to indicate clear sky, white to indicate clouds and warm colors (green, yellow, orange and red) to indicate aerosols. The white line in the figures denotes the center of the 40-80 profiles averaged for the calculations. Fig. 1 plots indicate smoke layers observed in south west Africa and off the coast of Namibia on June 23, 2006 during the third week of CALIPSO measurements. The layers are identified by the low volume depolarization ratios (less than 5%) for all three layers. The smoke layer is near the surface at an altitude of 0.8 km (layer base) and 2.5 km (layer top). The small region of clear air below the layer allows the use of the transmittance method to calculate the extinction to backscatter ratio (S_a) at 532 nm of 57 sr. The two wavelength algorithm described in Eq. 1 is used to calculate S_a at 1064 nm of 60 sr. Figures 1(b) and (c) are smoke layers observed in the same region within the same 48 hour period on August 8 and August 10, 2006. The layers are located at 2 km (layer base), 4 km (layer top) are more elevated than the June 23 layer. The layer in Figure 1(b) yielded an extinction to backscatter ratio of 64 sr. The 1064 nm dual wavelength calculation failed to converge for both layers. The August 10 layer (Fig. 1 (c)) has a slightly higher depolarization ratio and color ratio indicating aging of the smoke layer and subsequent aerosol growth and contamination by larger non spherical particles likely from the nearby Kalahari desert.

Fig. 2 shows similar plots to Fig. 1 but for the dust aerosol cases. Fig. 2(a) shows a dust layer from the Sahara observed over the Atlantic ocean near South America. The dust layer is located at 2 km (layer base), 4 km (layer top) with an extinction to backscatter ratios of 34 sr and 45 sr respectively at 532 nm and 1064 nm. The layer mean volume depolarization ratio is 0.2. Fig 2(b) and (c) is a dust layer observed over the Sahara desert on June 13 and 15, 2006, respectively. The extinction to backscatter ratios of these layers for June 13 and June 15 layers are 34 sr (39 sr) and 37 sr (53 sr), at 532 nm (1064 nm), respectively.

Conclusion

Case studies of six episodes of smoke and dust have been analyzed to determine the extinction to backscatter ratios using the transmittance method to obtain the S_a values at 532 nm. A two wavelength approach has been used to determine the 1064 nm S_a. The average extinction to backscatter ratio for smoke observed in South West Africa is 60±2.9 sr at 532 nm. The average extinction to backscatter ratio for Sahara dust is 34.3±2.1 sr at 532 nm, and 45.7±5.7 sr at 1064 nm. The CALIPSO algorithm values at 532 nm (70 sr for smoke and 40 sr for dust) are about 17% higher for both of these types. The 1064 nm dust S_a values from this study (45 sr) are 50% higher than CALIPSO algorithm estimates of 30 sr determined primarily from theoretical models. Additional studies are underway to revise the 1064 nm S_a estimates for the CALIPSO algorithms.

References

Omar, A.H., D.M. Winker, and J.-G. Won, Aerosol Models for the CALIPSO Lidar Inversion Algorithms, in *SPIE*, edited by C. Werner, pp. 104-115, Deutsches Zentrum fuer Luft-und Raumfahrt e.V. (Germany), Barcelona, Spain, 2004.

Vaughan, M.A., Z. Liu, and A.H. Omar, Multi-wavelength analysis of a lofted aerosol layer measured by LITE, in *22nd International Laser Radar Conference*, edited by G. Pappalardo, and A. Amodeo, pp. 495-499, European Space Agency, Matera, Italy, 2004.

Young, S.A., Analysis of lidar backscatter profiles in optically thin clouds, *Applied Optics*, *34* (30), 7019-7031, 1995