SELECTION ALGORITHM FOR THE CALIPSO LIDAR AEROSOL EXTINCTION-TO-BACKSCATTER RATIO

Ali H. Omar[1], David M. Winker[1], Mark A. Vaughan[2]

[1]*NASA Langley Research Center, Atmospheric Sciences, MailStop 401 A, Hampton, VA 2368 ali.h.omar@nasa.gov*

[2]*Science Applications International Corporation (SAIC) NASA Langley Research Center, m.a.vaughan@larc.nasa.gov*

ABSTRACT

The extinction-to-backscatter ratio (S_a) is an important parameter used in the determination of the aerosol extinction and subsequently the optical depth from lidar backscatter measurements. We outline the algorithm used to determine S_a for the Cloud and Aerosol Lidar and Infrared Pathfinder Spaceborne Observations (CALIPSO) lidar. S_a for the CALIPSO lidar will either be selected from a look-up table or calculated using the lidar measurements depending on the characteristics of aerosol layer. Whenever suitable lofted layers are encountered, S_a is computed directly from the integrated backscatter and transmittance. In all other cases, the CALIPSO observables: the depolarization ratio, δ, the layer integrated attenuated backscatter, γ', and the mean layer total attenuated color ratio, χ, together with the surface type, are used to aid in aerosol typing. Once the type is identified, a look-up-table developed primarily from worldwide observations, is used to determine the S_a value. The CALIPSO aerosol models include desert dust, biomass burning, background, polluted continental, polluted dust, and marine aerosols.

1. INTRODUCTION

S_a is an intensive aerosol property, i.e., a property that does not depend on the number density of the aerosol but rather on such physical and chemical properties as size distribution, shape and composition. These properties are governed primarily by the source of the aerosol. The accuracy of the S_a value used in the lidar inversions is dependent in part, on the correct identification of the type of aerosol. The CALIPSO aerosol typing will utilize observation data (both climatological and field campaigns), knowledge of emission sources inferred from surfaces types, and CALIPSO aerosol measurements such as depolarization ratio and the ratio of the backscatter coefficients at 1064 nm and 532 nm, referred to as the color ratio to identify aerosol type.

2. LEVEL II EXTINCTION PRODUCTS

CALIPSO will produce two level II aerosol extinction products depending on the choice of the aerosol extinction-to-backscatter ratio: an approximate product and a CALIPSO extinction product. The approximate extinction product will be derived from a fixed S_a (35 and 30 sr at 532 and 1064 nm, respectively). This value is chosen because it corresponds to S_a of the clean rural or background aerosol. AERONET analyses described below show that clean background aerosol is a frequently encountered aerosol type in the atmosphere. In addition, experience with LITE measurements shows that this value is not likely to cause the failure of the extinction calculation. The CALIPSO extinction product is derived from S_a based on the best estimate developed using CALIPSO measurements and the most up-to-date field observations. This paper discusses methods of making this estimate and describes an algorithm to achieve this.

3. S_a FOR LOFTED AEROSOL LAYERS

The transmittance method requires clear air above and below the layer so that the transmittance through the layer can be determined. Fig. 1 is an example of an aerosol layer lofted above a clear air region at 1km. The transmittance method uses the following equation describing the relationship between optical depth and integrated attenuated backscatter:

$$\gamma' = \frac{2\pi}{\eta S_a}\left(1-\exp\left(-2\eta\tau\right)\right). \qquad (1)$$

Here γ' is the integrated (from layer top to base) attenuated backscatter defined by,

$$\gamma' = \int_{top}^{base} \beta_a(r) T_a^2(r) dr \qquad (2)$$

τ is optical depth, η is a multiple scattering parameter. The quantities γ', and τ describe characteristics of a feature, i.e., they are associated with the backscatter and/or extinction of particles only. Note that the effective two-way transmittance $T^2 = \exp(-2\eta\tau)$. If we define an effective S_a, $S^* = \eta S_a$, we can rewrite Eq. (1) as follows:

$$S^* = \frac{1-T^2}{2\gamma'} \qquad (3)$$

The effective two-way transmittance is typically obtained by fitting the return both above and below a feature to a reference profile [1].

4. S_a SELECTION FROM LOOK-UP-TABLES

One of the objectives of this algorithm is to estimate

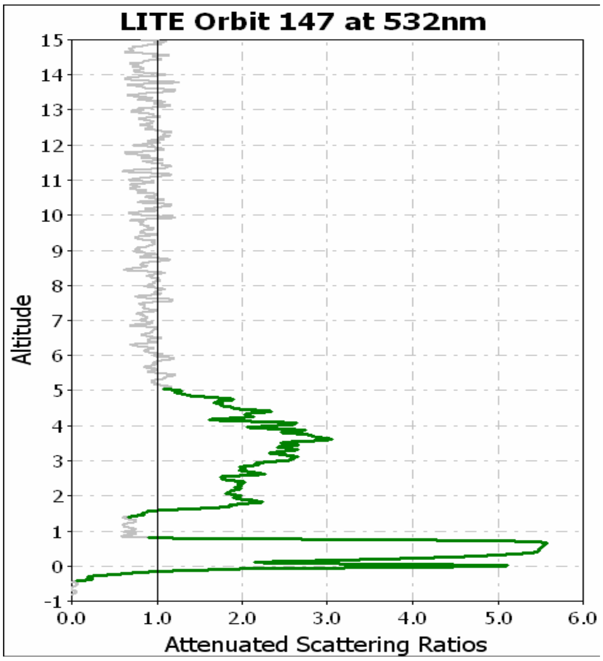

Fig. 1. The attenuated scattering ratios of a LITE return showing a case when the S_a value can be calculated directly using the transmittance method.

the appropriate value of S_a within 30% of the true value. The strategy is to identify aerosol type and then use a look-up table to select values of S_a and η appropriate for the layer. The selection scheme uses the observed backscatter strength and depolarization to identify aerosol type, to the extent possible, from among one of the six types. In most cases, the depolarization is directly related to the hydration state of the aerosol. The backscatter and depolarization are not sufficient to fully constrain the model selection, however. Therefore, additional data is used to narrow down the choices of aerosol types based on the lidar observables. The selection algorithm uses the lidar observables and the International Geosphere-Biosphere Programme (IGBP) surface types. The land/water mask is based on the World Vector Shoreline (WVS) product for coastal information, and the Digital Chart of the World (DCW) for inland water areas.

The input parameters - the magnitude of attenuated backscatter, altitude, location, surface type, depolarization ratio, and mean attenuated backscatter coefficient measurements - are used to identify the type following one of eleven pathways in Fig. 2. In Fig. 2, pathway 1 is a lightly loaded aerosol layer found over snow/ice/tundra regions such as Antarctica and the clean Artic. Arctic haze, by virtue of the high integrated backscatter value, will be classified as polluted continental following pathway 2. Desert dust (Pathway 4) is expected to have a volume depolarization ratio greater than 0.2 and should be the predominant selection pathway for layers with substantial fractions of non-spherical particles. Pathways 3 and 5 allow for mixing with biomass burning smoke which will depress the volume depolarization ratio to a value below 0.2. Pathway 6 is a clean non-desert land surface at which the aerosol loading is close to the background values. Pathway 7 is a highly polluted land surface such as would be found in urban areas. Pathway 8 accounts for continental pollution advected off the coast and entrained in the marine boundary layer. Pathway 9 is marine boundary layer aerosol usually found in the deep ocean and consisting primarily of seasalt. Pathways 10 and 11 are elevated aerosol layers over land and ocean, respectively, of biomass burning smoke. Note that elevated dust layers are found in Pathway 4.

Studies are underway to determine optimum threshold values of δ, β', and χ to be used in the typing scheme. The values shown in Fig. 2 are initial estimates based on LITE measurements and, in the case of depolarization, on a limited set of observations and models [2-6]. The goal is to base typing decisions on these observables as much as possible and avoid the use of geographic information. Therefore, the threshold values of δ, β', and χ will be implemented as runtime parameters that can be adjusted using a configuration script. When lofted layers are encountered under favorable conditions, S_a is computed directly from the integrated backscatter and transmission. We expect the algorithm will evolve significantly after the CALIPSO launch, when CALIPSO will provide a much larger set of δ, β', and χ, measurements than is currently available.

4.1. Aerosol types from AERONET

Aerosol type is highly variable on time scales as short as a few hours [7]. Aerosol optical measurements must therefore be made at short time scales (about 30 minutes) to develop a large data base which can be used to derive statistically significant correlations and from which type-specific characteristics can be deduced. The AERONET measurements are likely to provide such a data base albeit for total column rather than vertically-resolved measurements. Cluster analysis was used for grouping multi-year AERONET data set based on several optical and physical characteristics of the aerosol [8]. Some of the CALIPSO aerosol models were derived from these groups. Fig. 3 (a)-(f) show the physical and chemical properties of the CALIPSO aerosol models and the corresponding S_a values at 532 nm (green) and 1064 nm (red). The AERONET cluster analysis yielded six distinct types of aerosol. Only three of these clusters (desert dust, biomass burning, polluted continental, Fig. 2a, b, and d, respectively) were used to characterize the CALIPSO aerosol models. The CALIPSO model of background and marine aerosols are not derived from the AERONET measurements.

The AERONET records of the background cluster had low mean optical depths (< 0.05 at 673 nm).

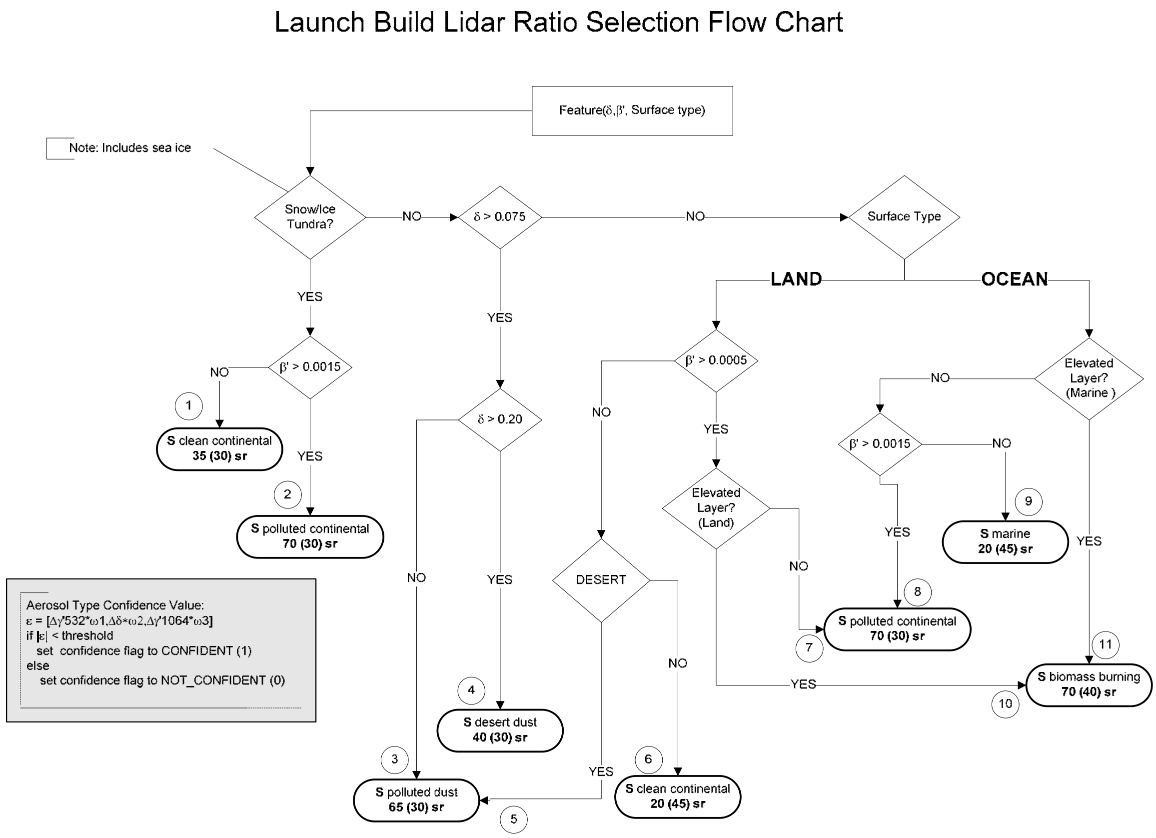

Fig. 2. Flowchart of the CALIPSO S_a selection scheme for tropospheric aerosols.

The values shown are the extinction-to-backscatter ratios at 532 nm and 1064 nm in parentheses. Note that the mean attenuated backscatter coefficient $\overline{\beta'} = \gamma' / z$ where z is the layer thickness

The microphysical properties derived from these are likely to have large uncertainties [9]. The CALIPSO background aerosol model (Fig. 2c) was derived by fitting size distributions and refractive indices to measurements of S_a of long-range continental transport [10]. Note that the S_a values for this aerosol type are used to generate the approximate extinction product described in section 2 above. The AERONET marine aerosol cluster is comprised of a small number of records (< 4% of the total). The CALIPSO marine aerosol model (Fig. 2f) is derived from the parameters measured during the SEAS experiment[11]. The CALIPSO polluted dust is a mixture of the AERONET desert dust and biomass burning clusters (Fig 3e).

5. CONCLUSION

An algorithm for determining aerosol type from knowledge of emission sources inferred from surfaces types, and CALIPSO aerosol measurements (such as depolarization ratio and the mean attenuated backscatter coefficients at 532 nm) has been developed. These aerosol types are characterized using observation data from both climatological and field campaigns. The strategy identifies aerosol type and uses a look-up-table to assign an extinction-to-backscatter ratio to the aerosol layer.

A global data set, AERONET, has been used to identify main clusters of aerosol types and to determine microphysical properties of aerosol groups. This characterization is augmented by measurements where the uncertainty in the AERONET retrievals is high. The above algorithm will evolve with new measurements and, upon launch the CALIPSO data will significantly enhance the available data base of δ, $\overline{\beta'}$, and χ. Such data sets will be used to further refine the probability distribution functions and threshold values of δ, $\overline{\beta'}$, and χ used in the algorithms. The flowchart in Fig. 2 is therefore a preliminary selection scheme. This approach will ensure that the science mission requirements for optical depth accuracy of 40% error assuming a 30% uncertainty in the extinction-to-backscatter ratio will be realized.

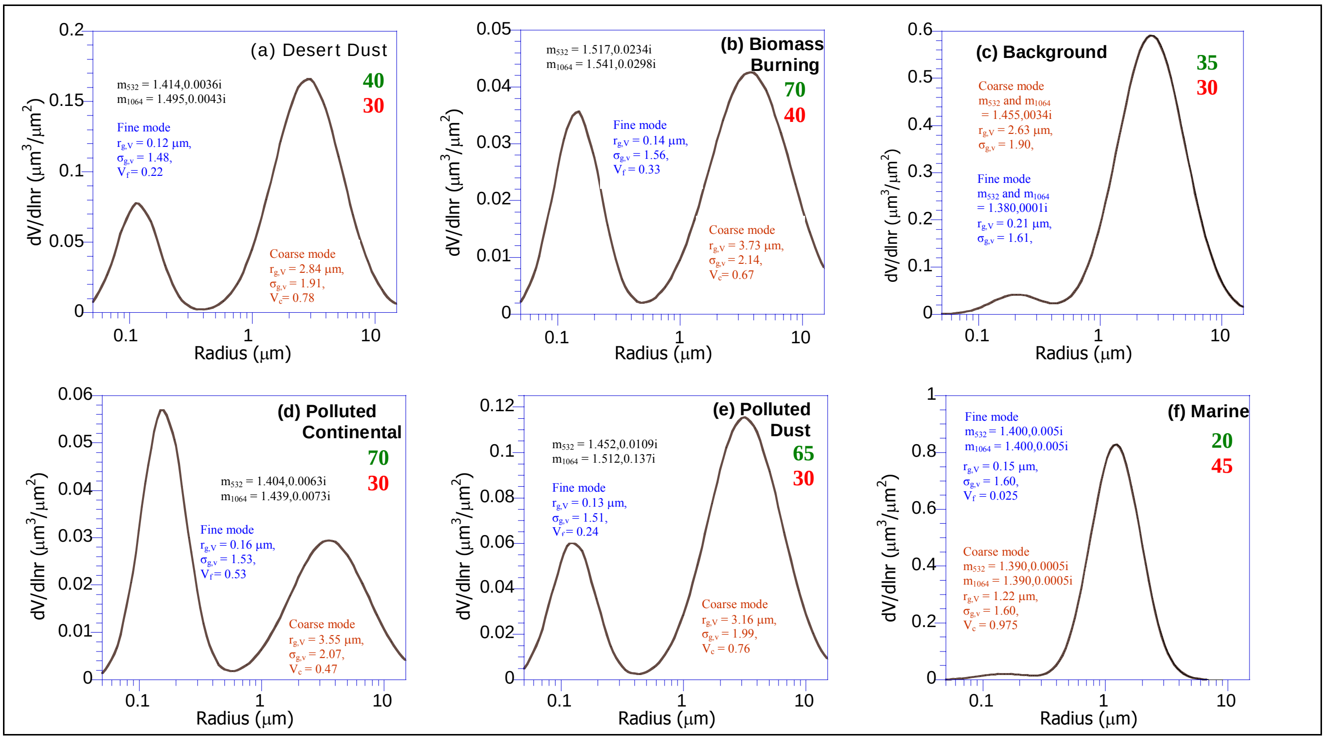

Fig. 3. The size distributions, and microphysical properties of the CALIPSO aerosol models. For each model, the S_a (in sr) at 532 nm and 1064 nm, is shown in green and red numbers, respectively. $r_{g,v}$ and $\sigma_{g,v}$ are the geometric mean radii and standard deviations of the distribution respectively. m_i is the complex refractive index at wavelength i.

6. REFERENCES

1. S. A. Young, Analysis of Lidar Backscatter Profiles in Optically Thin Clouds, *Applied Optics*, vol. 34, pp. 7019-7031, 1995.

2. G. P. Gobbi, et al., Altitude-Resolved Properties of a Saharan Dust Event over the Mediterranean, *Atmospheric Environment*, vol. 34, pp. 5119-5127, 2000.

3. T. Murayama, et al., Application of Lidar Depolarization Measurement in the Atmospheric Boundary Layer: Effects of Dust and Sea-Salt Particles, *J. Geophys. Res.*, vol. 104, pp. 31781-31792, 1999.

4. J. A. Reagan, et al., Lidar Aerosol Ratio: Measurements and Models, presented at International Geosciences and Remote Sensing Symposium (IGARSS), Sidney, Australia, 2001.

5. T. Sakai, et al., Raman Lidar and Aircraft Measurements of Tropospheric Aerosol Particles During the Asian Dust Event over Central Japan: Case Study on 23 April 1996, *J. Geophys. Res.*, vol. 108, pp. 4349, 2003.

6. M. J. McGill, et al., Airborne Lidar Measurements of Aerosol Optical Properties During Safari-2000, J. Geophys. Res., vol. 108, 2003.

7. P. J. Sheridan, et al., Four Years of Continuous Surface Aerosol Measurements from the Department of Energy's Atmospheric Radiation Measurement Program Southern Great Plains Cloud and Radiation Testbed Site, J. Geophys. Res., vol. 106, pp. 20735-20747, 2001.

8. A. H. Omar, et al., Development of Global Aerosol Models Using Cluster Analysis of Aerosol Robotic Network (Aeronet) Measurements, J. Geophys. Res., vol. 110, 2005.

9. O. Dubovik, et al., Variability of Absorption and Optical Properties of Key Aerosol Types Observed in Worldwide Locations, Journal of Atmospheric Sciences, vol. 59, pp. 590-608, 2002.

10. T. L. Anderson, et al., In Situ Measurements of the Aerosol Extinction-to-Backscatter Ratio at a Polluted Continental Site, J. Geophys. Res., vol. 105, pp. 26907-26915, 2000.

11. S. J. Masonis, et al., A Study of the Extinction-to-Backscatter Ratio of Marine Aerosol During the Shoreline Environmental Aerosol Study, Journal of Atmospheric and Oceanic Technology, vol. 20, pp. 1388–1402, 2002.