AN INITIAL ASSESSMENT OF THE CALIPSO AEROSOL SUBTYPING ALGORITHM

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ABSTRACT

The Cloud Aerosol Lidar Infrared Pathfinder Satellite Observations (CALIPSO, [1]) with its 3-channel lidar affords observations that can, with minimal processing, be exploited to identify aerosol types. Three months of CALIPSO Level II data are analyzed to assess the veracity of the CALIPSO aerosol type identification algorithm and generate distributions of aerosol types and their respective optical characteristics. The distributions show that the classification algorithm has no (1) surface type or (2) diurnal dependencies. For this initial assessment of algorithm performance, we analyze global distributions of the CALIPSO aerosol types, along with distributions of integrated attenuated backscatter, backscatter color ratio, and volume depolarization ratio for each type. The aerosol type distributions are further partitioned according to various geophysical discriminators (e.g., geographic region, land vs. ocean, and day vs. night). The algorithm generates the expected results in most scenes. Those cases of thin clouds misclassified as aerosols are subsequently typed as 'dust' or 'smoke'[2]. The total color ratio distributions show significant overlap between the aerosol types.

1. INTRODUCTION

Aerosol classification has several purposes: attribution of aerosol radiative forcing to natural or anthropogenic emissions requires the determination of the source of the aerosol; aerosol radiative properties vary significantly by type; and, most directly, determination of aerosol type allows an estimate of extinction-to-backscatter ratio (S_a). By 'type' we mean an aerosol mixture which is characteristic of a region or an air mass. The underlying paradigm is that the variety of emission sources and atmospheric processes will act to produce airmasses that can be characterized as consisting of a single, generic aerosol type. This is an idealization, but one that allows us to classify aerosols based on observations and location, and thus gain insight into the geographic distribution of aerosols and constrain the possible values of extinction-to-backscatter ratios for use in the CALIPSO aerosol extinction retrievals.

2. AEROSOL MODELS

The CALIPSO models define six aerosol types: desert dust, biomass burning, background, polluted continental, marine and polluted dust. These models were derived largely from a global cluster analysis of a multi-year AERONET database of aerosol properties [3]. The classes so derived are hereafter referred to as AERONET clusters. While this set does not cover all possible aerosol mixing scenarios, it accounts for a majority of mesoscale aerosol layers. In essence the algorithm trades off complex transient multi-component mixtures for relatively stable layers with large horizontal extent (10-1000 km).

3. METHODS

We investigate the distributions optical properties of the layers found at the highest resolution. To identify aerosol features at their finest resolution, the CALIPSO feature finding algorithm makes several passes through a specified scene, successively increasing the horizontal averaging distance from 5 km, to 20 km, to 80 km. After discriminating cloud and aerosol layers, the Scene Classification Algorithm (SCA) attempts to identify the type of aerosol in the layer. A look-up table is used to associate a lidar ratio and other properties with that layer based on the type determined by the subtyping algorithm. For this study, we analyze only the strongest aerosol layers, i.e., those found at 5 km. Using level II CALIPSO lidar data, we examine distributions of three key aerosol scattering properties: integrated attenuated backscatter, volume depolarization ratio, and total attenuated color ratio. The integrated attenuated backscatter ($\gamma'_{feature}$) is

$$\gamma'_{feature} = \int_{top}^{base} \beta_p(\mathrm{r}) \cdot T_p(\mathrm{r})\, d\mathrm{r} \quad (1)$$

where β_p and T_p are the aerosol backscatter and transmission, respectively. Though not always an indication of the optical depth, it is a good indicator of the amount (particle number concentration) of aerosol in the layer. The volume depolarization ratio (δ_{layer}) is defined as,

$$\delta_{layer} = \frac{\int_{top}^{base} \beta_{\perp}(\mathrm{r})\mathrm{r}}{\int_{top}^{base} \beta_{\parallel}(\mathrm{r})\mathrm{r}}, \qquad (2)$$

where the subscripts $\perp$ and $\parallel$, denote perpendicular and parallel components of the 532 nm backscatter. δ_{layer} is a good indicator of the relative proportion of non-spherical particles in the aerosol mixture.

The total color ratio (χ'), defined as

$$\chi' = \frac{\int_{top}^{base} \left(\beta_{m,1064}(r) + \beta_{P,1064}(r)\right) T_{P,1064}^{2}(r)\, dr}{\int_{top}^{base} \left(\beta_{m,532}(r) + \beta_{P,532}(r)\right) T_{P,532}^{2}(r)\, dr}, \qquad (3)$$

is a ratio of the integral of the 1064-nm backscatter to the integral of 532 nm backscatter within the layer. χ' is a rough indicator of the dominant particle sizes in the aerosol layer. All these variables are level II parameters calculated upstream of the extinction products in the algorithm flow. In Equation 3., the subscripts m and p denote molecular and particulate, respectively.

4. SUBTYPING ALGORITHM

The volume depolarization ratio (δ_v) is used to identify aerosol types that have a substantial mass fraction of non-spherical particles, e.g., a mixture of smoke and dust. The integrated attenuated backscatter (γ') is used to discern instances of transient high aerosol loading over surfaces where this is not usually expected, e.g., aerosols in polar regions. The algorithm takes into consideration the high aerosol loading due smoke or dust layers over land or the ocean. Lightly loaded aerosol layers found over snow/ice/tundra regions such as Antarctica and the clean Arctic are classified as clean continental determined by the magnitude of γ'. Arctic haze, by virtue of its high integrated backscatter value, is classified as polluted continental. Desert dust is identified by δ_v greater than 0.2. Aerosols with $0.075 < \delta_v < 0.2$ are classified as polluted dust. Aerosol layers found over land surfaces identified as urban areas are classified as polluted continental. To account for continental pollution advected off the coast and entrained in the marine boundary layer, we use the elevation above the ocean surface as an additional criterion. The land/water mask is based on the World Vector Shoreline (WVS) product and the surface types are from the International Geosphere Biosphere Programme (IGBP). A detailed description of the algorithm along with flow charts can be found at http://www-calipso.larc.nasa.gov/resources/pdfs/PC-SCI-202_Part3_v1.0.pdf

5. RESULTS

Figure 1 shows the distribution of aerosol types as the satellites passes over W. Russia, continental Europe, across the Mediterranean to the eastern Sahara desert. The sub-typing algorithm captures the evolution of the aerosol from smoke and polluted dust to pure dust in the Sahara. The dust layer stretches for about 4000 km and is mixed with smoke from Siberian fires at the leading edge. The horizontal extent, and the aerosol types shown (smoke, polluted dust, and dust) verify that the algorithm finds the expected types of aerosol.. Figure 2 is another example of the sub-typing result showing an aerosol layer that has been classified as predominantly smoke extending from land to the deep ocean. Note the aerosol type on the ocean surface is appropriately classified as marine aerosol. The algorithm correctly identifies this 3000 km layer of smoke found in south west Africa where biomass burning is prevalent in August. The image also illustrates that the algorithm is not dependent on surface type as the layer stretches from land to the Atlantic ocean.

Figure 3 shows the descriptive statistics of γ', δ_v, and χ' for three months (September, October, December of 2006). Both the means and standard deviations for all the three parameters show consistent patterns of the monthly distributions. The marine aerosol distributions of γ' show consistently higher than expected means for all the three months. It is not clear whether this is physical, an artifact of the subtyping or cloud aerosol discrimination algorithm.

Figure 4 shows the probability distribution functions (PDFs) of γ', δ_v, and χ' for one month (November 2006) for dust and polluted dust cases. We have superimposed the PDFs of the land surface layers and the ocean surface layers to examine any surface dependencies. The PDFs show that there are no dependencies on surface type. The color ratio distributions of these aerosol types are quite similar for dust and polluted dust. Since color ratios are intensive properties that could be used to identify aerosol types, the figure demonstrates that in the case of dust and polluted dust, the color ratio signatures are quite ambiguous.

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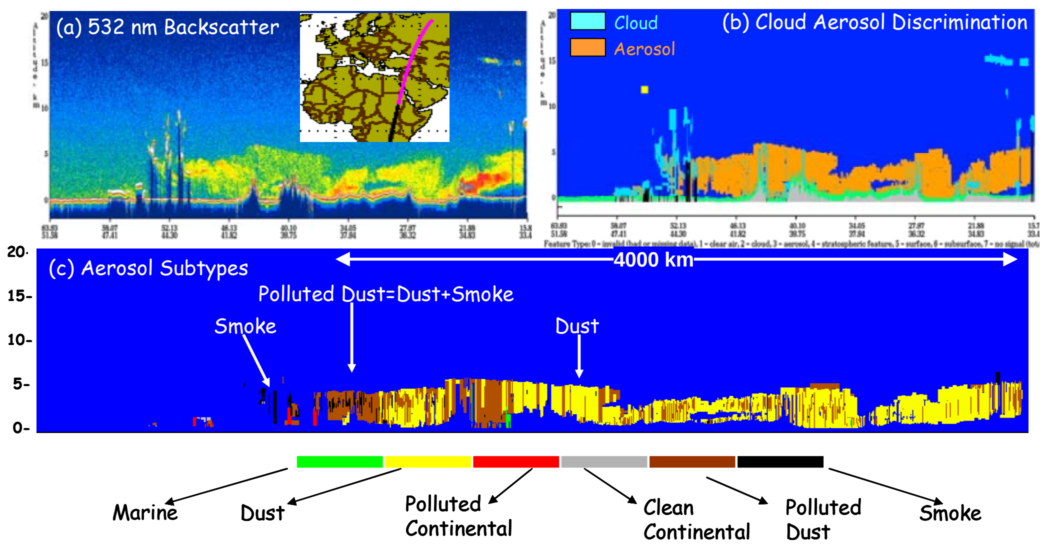

Figure 1. The evolution of aerosol types as the satellites passes over W. Russia, continental Europe, across the Mediterranean to the eastern Sahara desert from smoke to dust.

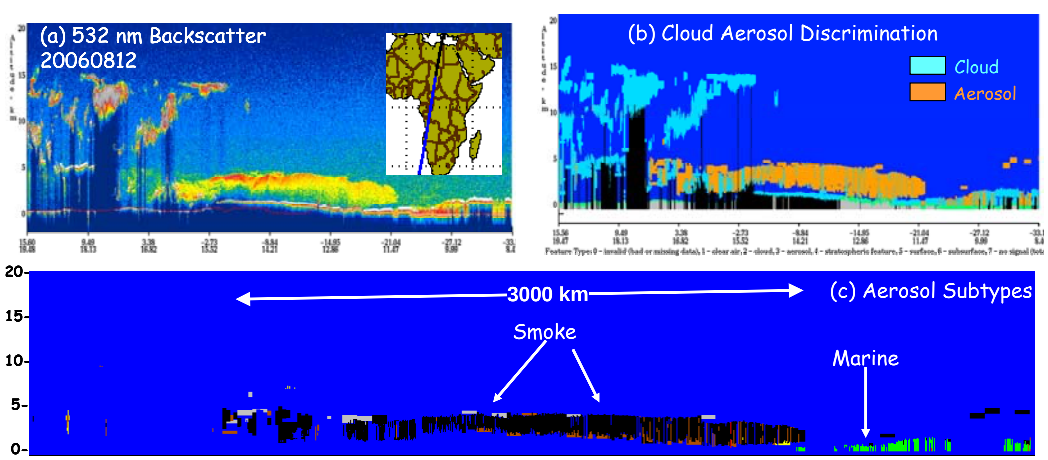

Figure 2. An aerosol layer identified by the sub-typing algorithm as smoke and polluted dust extending from Central Africa, the Congo basin, Angola to the S Atlantic Ocean (color key as in Fig 1)

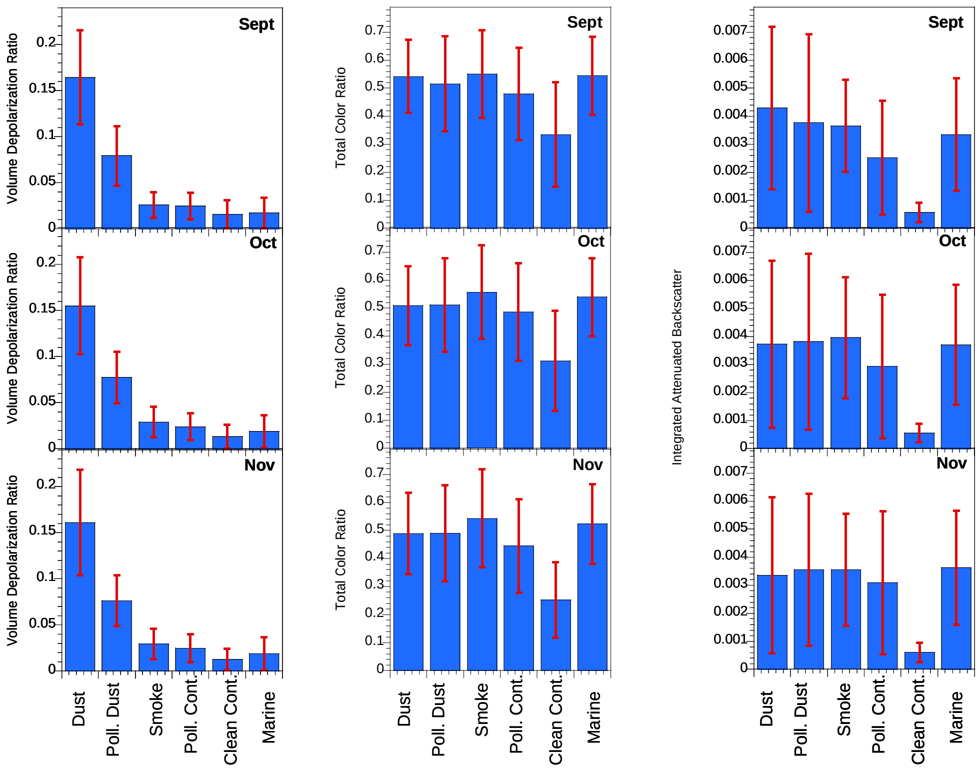

Figure 3. Means (blue bar) and Standard Deviations (Red line)of γ', δ_v, and χ' for September, October, December of 2006

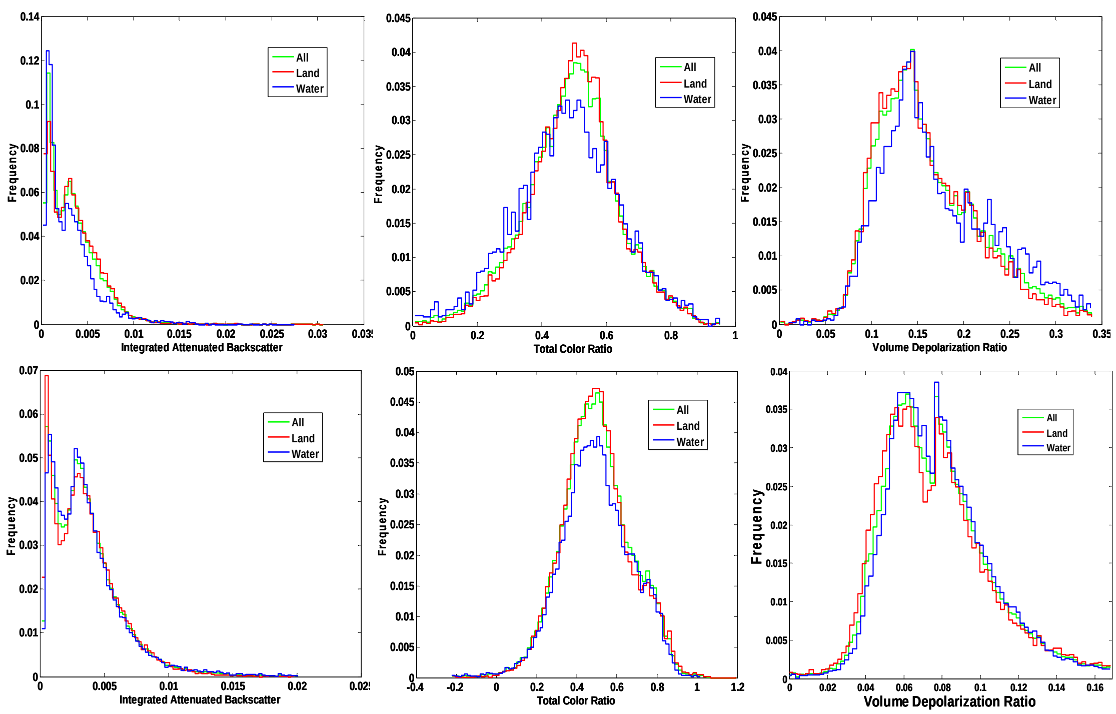

Figure 4. The probability distribution functions (PDFs) of γ', δ_v, and χ' for one month (November 2006) for dust and polluted dust cases. The different colors denote layers found over land (red), water (blue) and both (green).