ENHANCEMENTS TO THE CALIOP AEROSOL SUBTYPING AND LIDAR RATIO SELECTION ALGORITHMS FOR LEVEL II VERSION 4

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1. ABSTRACT

Several enhancements have been implemented for the version 4 aerosol subtyping and lidar ratio selection algorithms of Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP). Version 4 eliminates the confusion between smoke and clean marine aerosols seen in version 3 by modifications to the elevated layer flag definitions used to identify smoke aerosols over the ocean. To differentiate between mixtures of dust and smoke, and dust and marine aerosols, a new aerosol type will be added in the version 4 data products. In the marine boundary layer, moderately depolarizing aerosols are no longer modeled as mixtures of dust and smoke (polluted dust) but rather as mixtures of dust and seasalt (dusty marine). Some lidar ratios have been updated in the version 4 algorithms. In particular, the dust lidar ratios have been adjusted to reflect the latest measurements and model studies.

2. INTRODUCTION

The version 4 aerosol subtyping algorithms are considerably improved over the earlier versions. They initially employ more accurately calibrated level 1 data and the MERRA-2 meteorological data. These discussed in detail in the data quality summaries (https://goo.gl/qVRmd8). The version 4 Level 2 aerosol subtyping algorithm is preceded by a much improved cloud aerosol discrimination algorithm and includes improvements in the tropospheric aerosol subtyping algorithm, and new schemes for stratospheric aerosol subtyping (c.f. [1]) and updated lidar ratios. Version 4 permits identification of all aerosol types over snow/tundra land surface types (Polar Regions) and therefore correctly accounts for transport of assorted aerosol types to polar regions, especially to the Arctic. Another significant improvement is that the version 4 algorithms account for the settling of dust plumes into the marine boundary layer which results in mixtures of dust and seasalt aerosols.

3. POLLUTED DUST AND DUSTY MARINE AEROSOL DEFINITION

Several comparisons of CALIOP's lidar ratios with High Spectral Resolution Lidar (HSRL) over

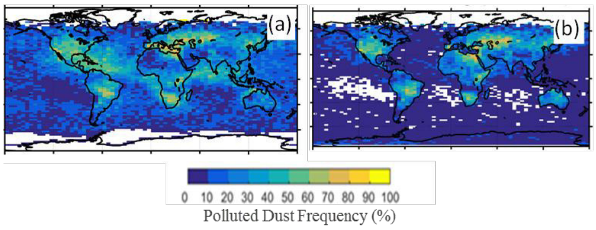

Figure 1. Polluted dust frequency for (a) version 3 and (b) version 4 for June-July-August 2008 nighttime layers.

the ocean show that the lidar ratio (S_a) estimates for dust and marine are in agreement. However, these same comparisons also show that the CALIOP lidar ratio assigned for polluted dust (55 sr) is typically much larger that the lidar ratio measured by the HSRL (~35 sr). [2]. Since S_a is a good proxy for aerosol type, this suggests that CALIOP's aerosol model is wrong for moderately depolarizing cases near the ocean surface and points to a need to define a more representative aerosol type. The version 4 aerosol subtyping algorithm now include a dusty marine (dust + marine) aerosol type, with a S_a value of 37 sr, for moderately depolarizing aerosols in and near the marine boundary layer (altitudes less than 2.5 km above the ocean surface). Figure 1 illustrates the improvement in the distributions of polluted dust over version 3. Though the distributions of polluted dust in version 4 are more reasonable, high frequencies in the northern Pacific and Indian Ocean persist. In version 3 smoke and polluted continental aerosol layers are occasionally misclassified as marine layers near continental outflows. The map in Figure 2(a) shows the altitude at which clean marine aerosols are most frequently found in version 3. There is a high frequency of elevated marine layers on the south west coast of Africa and the region stretching from the Kamchatka peninsula to the Sea of Japan. Figures 2 (b) – (c) show a case study of this misclassification arising from a number of bugs and incorrect elevated layer flag thresholds. Note the large number of elevated marine layers and attached polluted continental layers

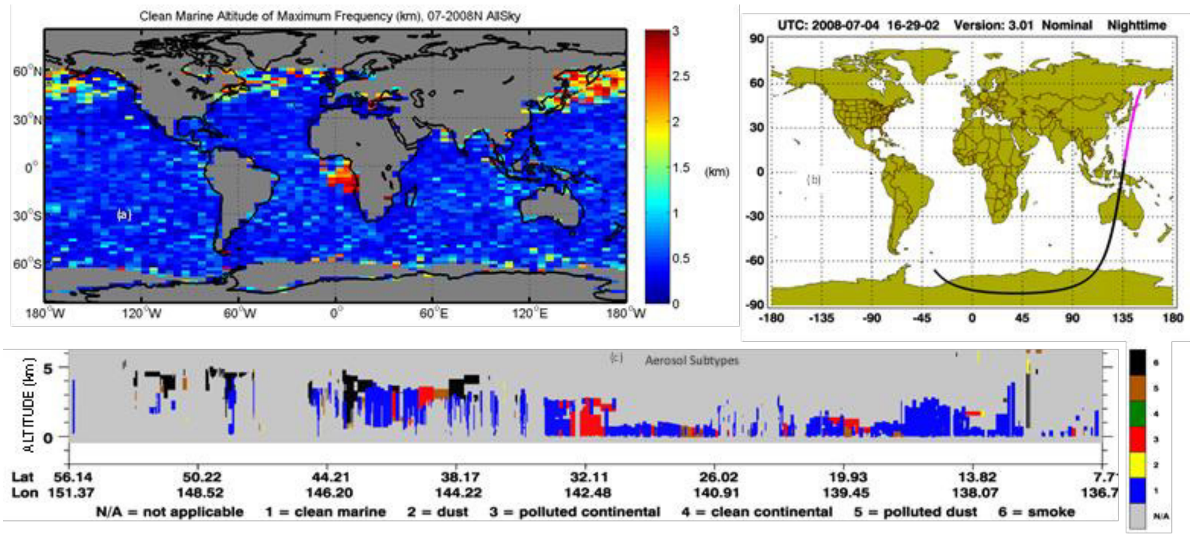

Figure 2. (a) The altitude of maximum frequency of marine layers in July 2007, (b) night time orbit and (c) the corresponding subtypes.

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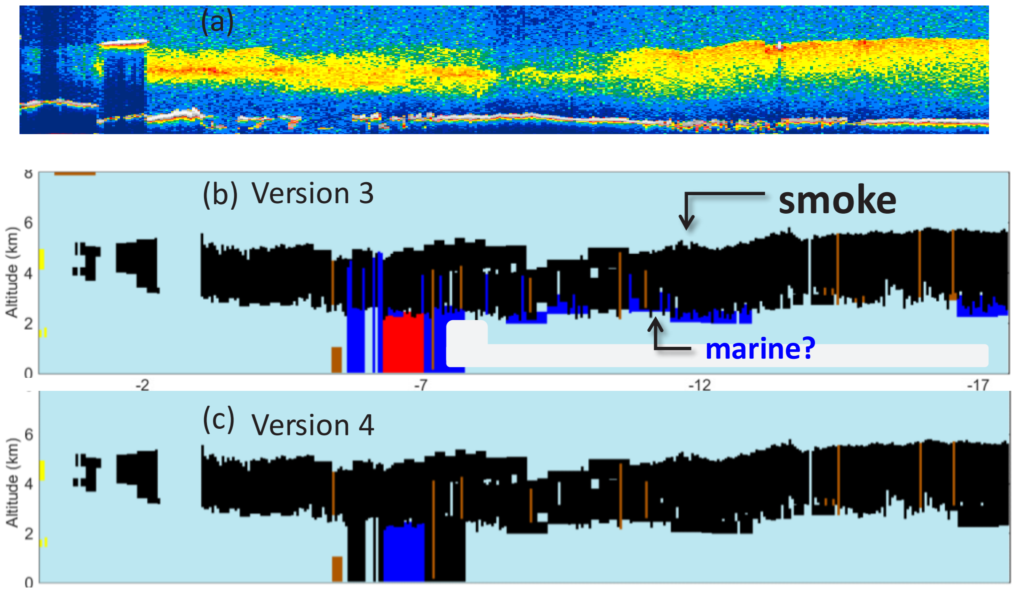

Figure 3(a) Browse image of an aerosol layer of the Gulf of Guinea, and (b) the version 3 and (c) version 4 classifications of the aerosol layer showing smoke in black, marine in blue and polluted dust in brown.

4. MARINE AND SMOKE TYPES

In version 3, smoke is a non-depolarizing and elevated aerosol. However, the definition also included 'elevated' included a threshold geometric thickness which resulted in spurious classifications and the large frequencies of smoke misclassified as marine shown in Figure 2 (a) above. Figure 3 shows a case study of a robust smoke layer (a) off the Gulf of Guinea and its version 3 classification (b). The version 4 algorithm, illustrated by Fig 3(c), identifies Smoke as non-depolarizing and elevated (i.e., layer top > 2.5 km) irrespective of the geometric thickness. In the version 4 subtyping products, fewer smoke layers are misclassified as marine and the ‘striping’ by marine layers in smoke plume is substantially reduced.

5. LIDAR RATIOS

[3] developed a technique that takes advantage of the relatively small variability of the lidar ratio for water clouds and uses opaque water clouds as a reference to determine the optical depth of overlying transparent aerosol or cirrus layers. [4] applied this technique to CALIOP level 1 measurements in dust region off the coast of W. Africa to retrieve, unambiguously, distributions of dust and smoke lidar ratios.

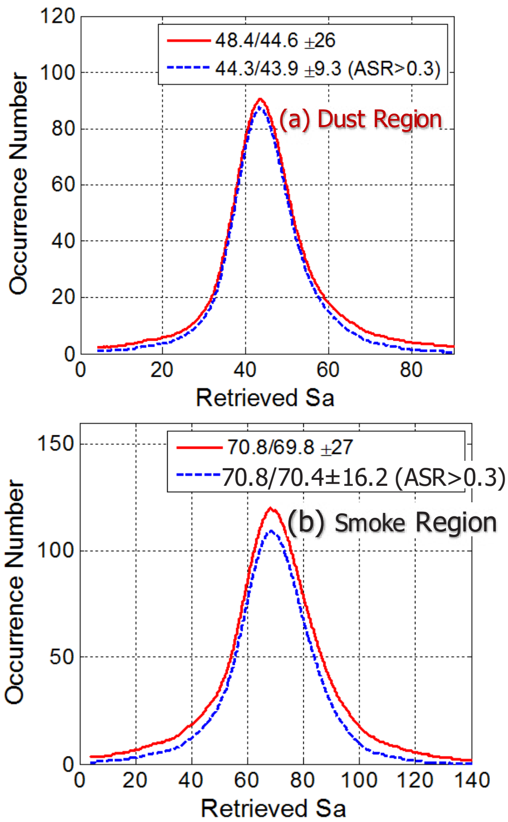

Figure 4. Multiyear retrieval of dust and smoke lidar ratios (Liu et al. 2015). Lidar ratios of dust and smoke are well constrained around 44 sr and 70 sr, respectively. The blue dotted lines are for aerosol scattering ratios (ASR) > 0.3.

These are shown in Figure 4 and are used to inform the adjustment of the dust S_a (44 sr) for version 4 products. While the smoke S_a remains unchanged from version 3, the uncertainty is reduced. The lidar ratios and uncertainties used for all version 4 aerosol subtypes are listed in Table 1. Version 4 assumes the 532-nm and 1064-nm lidar ratios are the same.

Table 1. 532 nm Lidar Ratios of Versions 3 and 4

Layer Type	532 nm Lidar Ratios (sr)	
	version 3	version 4
Dust	40 ± 20	44 ± 9 [A,B]
Smoke	70 ± 28	70 ± 16 [A]
Clean Continental	35 ± 16	53 ± 11 [C]
Polluted Continental	70 ± 25	70 ± 25
Polluted Dust	55 ± 22	55 ± 22 [D]
Clean Marine	20 ± 6	23 ± 5 [E]
Dusty Marine		37 ± 15 [F]

S_a and uncertainty based on CALIPSO constrained retrievals by Liu et al. (2015)

[B] Based HSRL measurements of transported Saharan dust. No λ dependence based on [5]

[C] S_a measured by HSRL for layers classified as clean continental by CALIPSO [6]

[D] Based on the microphysical measurements made during NAMMA. S_a values in agreement with [7] and [8]

[E] S_a measured by HSRL in multiple field campaigns, [8] No λ dependence based on [9]), [10] , [7]

[F] S_a based on mixture of dust and marine aerosol (65/35 by surface area). Uncertainty is larger than either dust or marine alone.

SUMMARY

The aerosol subtyping algorithm in version 4 includes a number of improvements. Specifically, polluted dust is identified in more realistic regions compared to version 3 which showed widespread misclassification. A new dusty marine aerosol type is added to account for dust settling into the marine boundary layer. Smoke layers are no longer misclassified as clean marine aerosol, improving aerosol optical depth estimates for smoke layers in oceanic smoke outflow regions. Aerosol lidar ratios have also been updated in version 4 to reflect current understanding by independent instruments. In addition to the improvements discussed here, stratospheric aerosol types are now identified (volcanic ash, sulfate, smoke, PSC aerosol). Descriptions of aerosol subtyping improvements for version 4 are available on the CALIPSO Data Users Guide [https://www-calipso.larc.nasa.gov/resources/calipso_users_guide/qs/cal_lid_l2_all_v4-10.php].

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