GLOBAL SCALE LIDAR RATIO RETRIEVAL OVER THE OCEAN

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ABSTRACT

In this paper we discuss global scale lidar ratio retrieval over the ocean as derived by the Synergized Optical Depth of Aerosols (SODA) algorithm (based on CALIPSO/CloudSat ocean surface echo) and comparisons with CALIOP V3 lidar ratio for marine aerosols, dusts and cirrus clouds. As expected, the signatures vary as a function of the feature type. We show that the SODA lidar ratio at 532 nm is in relatively good agreement with what is currently used in CALIOP operational product. The lidar ratio at 1064 nm is however different. The origin of the differences cannot as yet be clearly identified. It may be related to the 1064 nm calibration, the ocean surface product, or to residual errors in the identification of aerosol type. As the lidar ratio is linked to the aerosol absorption and the backscatter phase function, it will help to better understand the aerosol and cloud radiative properties at global scale in the visible and in the near infrared.

1. INTRODUCTION

We have introduced a simple methodology to retrieve the 532 nm lidar ratio from the Synergized Optical Depth of Aerosols (SODA) data set over the ocean [1]. For a few cases with different aerosol and meteorological conditions, winter and summer, and in day and night lighting conditions, the column lidar ratios retrieved with this methodology were quantitatively assessed using underflight data from NASA's airborne HSRL [1]. Here we present the global scale application of this algorithm over the ocean at both 532 and 1064 nm wavelengths.

2. LIDAR RATIO DISCUSSION

As in [1], all parameters are retrieved at a single shot resolution, and can then be averaged at the scale of interest. The CALIOP Vertical Feature Mask (VFM) is interpolated on a single shot basis and used for categorization. In the results we show here, we used a sliding window of 15 consecutive shots (60 shots were used in [1]) to retrieve the lidar ratio. However, the VFM is not averaged and the aerosol type is determined at the single shot scale. This increases the signal to noise ratio (SNR) and overcomes artificial discontinuities in the VFM aerosol types as in the current version of the VFM, the aerosol type is determined independently in each 5 km segment. The limitation of our procedure is of course that when the VFM is working well, we are introducing an artificial contamination at the boundary of a feature change (especially cloud/aerosol boundary). To take this limitation into account and keep only homogeneous scenes, we removed from the analysis features which averaged optical depth is higher by 0.05 with respect to the value of the (negative) logarithm of the average transmission. As this procedure is using the high SNR of the ocean surface echo we could detect and remove small liquid water clouds from the analysis even if they are not detected by the VFM. This may prove to be useful during daytime.

Inhomogeneous scenes represent around 26% of the aerosols observations during nighttime and have an effective optical depth of 0.3±0.3 whereas homogeneous aerosols (statistically marine aerosols) have an optical depth of 0.12±0.05. When the homogeneous flag is not used the overall global scale lidar ratio retrievals shift towards around 10 sr as we would expect from liquid water cloud contamination affected by multiple scattering. We will need to develop a VFM "averaging" procedure in the future but this will require careful thinking to determine the best way to take into account the different averaging scales and vertical structure of CALIOP classification scheme. As we will see the simple methodology we present here already shows clear aerosol type distinctions and illustrates the potential for global scale lidar ratio retrieval.

Figures 1 and 2 show maps of the global scale aerosol 532 nm lidar ratio retrieval over the ocean for June/July/August 2008 during nighttime (Fig. 1) and daytime (Fig. 2). As we can see, day and night lidar ratio retrievals are not identical but similar structures can be observed. As expected, nighttime data seems to be of better quality. Differences are seen between the high lidar ratios in the areas where dust and biomass burning aerosols are advected over the Atlantic west of Africa and the Arabian sea, and the areas of lower lidar ratios over open oceans.

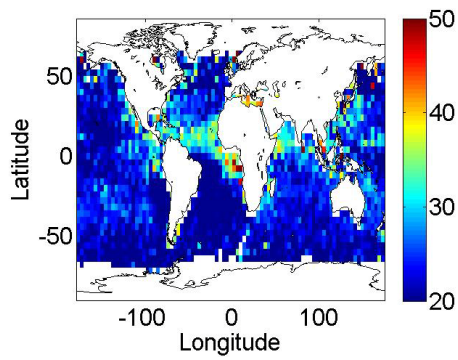

Figure 1. Map of global scale 532 nm lidar ratio retrieval over the ocean for June/July/August 2008 (nighttime). Only scenes without ice or liquid water clouds and classified as aerosols by the VFM are kept in the analysis.

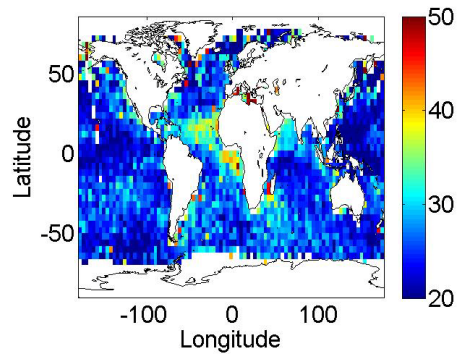

Figure 2. Same as Fig. 1 for daytime data.

The main difference between daytime and nighttime comes from the marine aerosol lidar ratio which is determined by diurnal variations in the lidar signal and sea spray. The lower SNR and higher calibration uncertainties render the retrieval more difficult for daytime, especially at lower optical depths. The optical depths are around 0.12 (nighttime) and 0.14 (daytime) for columns with only one layer of marine aerosol and the average 532 nm lidar ratios are around 24.8 sr and 27.9 sr, respectively. If the lidar ratio differences were due only to errors in the optical depth retrieval, an error of 0.02 (which is difficult to achieve with current space remote sensing capabilities) would explain the ~15% differences seen here. Considering the calibration uncertainty, molecular scattering correction, and real geophysical variations between day and night, understanding with certainty the magnitude of the errors introduced by daytime measurements will require in-depth investigations. In the following text, only nighttime data are used and discussed.

3. LIDAR RATIO BY AEROSOL TYPES

When discussing aerosol types in this work, it has to be understood as: according to the VFM, there is no liquid or ice cloud in the atmospheric column and only one type of aerosol is present. This holds true for both 532 nm and 1064 nm lidar ratio. There is a large uncertainty associated with CALIOP 1064 nm calibration and it has been recalibrated with the ratio of 532 to 1064 nm ocean surface echo using a procedure similar to [2].

3.1 Marine aerosols

Fig. 3 shows the map of marine aerosols 532 nm lidar ratio for June/July/August 2008 for nighttime data. The lidar ratio of aerosols is mostly around 20 sr with some higher values near continental areas.

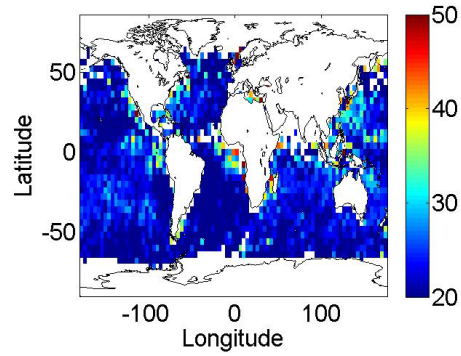

Figure 3. Same as Fig. 1 but only aerosols classified as "marine" using the VFM and our averaging procedure.

Figure 4 shows the distribution of the same observations at 532 nm and 1064 nm. Table 1 summarizes the statistical properties of the data. Larger values of the lidar ratio are expected to come from mixed aerosol types close to the coasts as seen in Fig. 3.

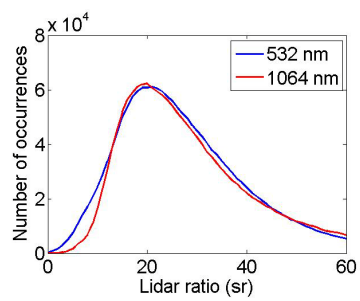

Figure 4. Lidar ratio distribution for marine aerosols at 532 and 1064 nm.

As we can see in Table 1, the average lidar ratio we retrieve at 532 nm is in between the value of 20 sr currently used in CALIOP inversion procedure (for marine) and the 28 sr value proposed by [3]. Further investigations will be needed to fully understand those differences but it is a promising indication that performing lidar ratio retrievals at global scales is an achievable goal even for the low optical depths of marine aerosols and considering the relatively low SNR of CALIOP.

Table 1. Statistical properties (mean and standard deviation) of the lidar ratio distribution for the aerosol type "marine".

Marine	Lidar ratio 532 nm	Lidar ratio 1064 nm
SODA	24.8 (±12.6) sr	23.6 (±13.5) sr
CALIOP-OP	20 (±6) sr	45 (±23) sr

For 1064 nm the value we retrieve is much different from the 45 sr used in CALIOP inversion. If this value is correct it would mean there is an overall error of 100% in our retrieval. So either the SODA optical depth would be biased low by around 0.1 or the 1064 nm calibration would still be in error by 100% even after recalibration using the ocean surface. Although none of this is impossible considering neither SODA or the 1064 nm calibration uncertainty have been fully investigated, this large error would remain a challenge to account for (see section 4). Our result is furthermore in much better agreement with the value of 21 sr at 1064 nm based on High Spectral Resolution Lidar observations and Constrained Ratio Aerosol Model-fit (CRAM) [4]. It has also to be kept in mind that the aerosol lidar ratio is identified from a classification based on the VFM which determines what is called "marine aerosol" in this analysis, and as seen from Fig. 3, may include pollution from land.

3.2 Dusts

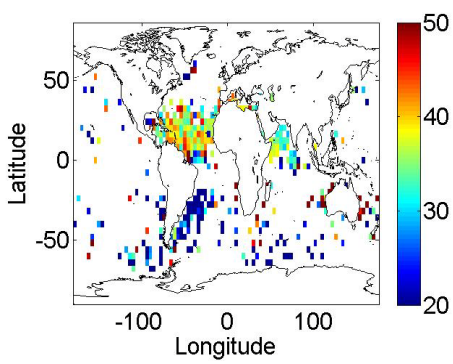

Figure 5. Same as Fig. 3 but only aerosols classified as "dust" are kept in the analysis.

Fig. 5 is the same as Fig. 3, but shows dust rather than marine aerosols. Dust aerosol over the northern Pacific appear to be rarely observed but a well defined structure is visible over the Atlantic, west of North Africa which corresponds to the advection of Saharan dust over the ocean. Most of the expected dust observations have lidar ratios between 30 and 50 sr in this map. An area with low lidar ratios (around and lower than 20 sr) is visible around South America where we do not expect to see important dust sources. Determining the origin and nature of those aerosols requires further investigations but the low lidar ratio is consistent with liquid water cloud contamination.

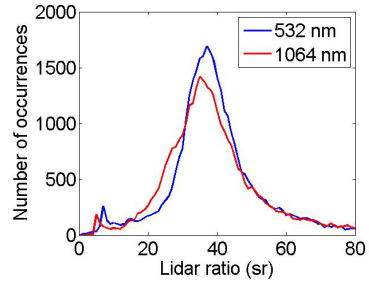

Figure 6. Lidar ratio distribution for dust aerosols at 532 and 1064 nm.

Figure 6 shows the distribution of the same dust observations at 532 nm and 1064 nm and Table 2 summarizes the statistical properties of the data. Most of the distribution at both 532 and 1064 nm peak around 40 sr (Fig. 6). At 532 nm, our result 38.0 (±7.5) sr is extremely close to the value of 40.0 (±20) sr used in CALIOP inversion although with a much lower dispersion. Although there is a strikingly good agreement at 532 nm, it is not the case at 1064 nm. We retrieve 36.3 sr whereas the inversion uses a value of 55 sr based on in-situ measurements during the NAMMA field campaign in 2006 [5]. This is consistent with two color solutions based on CALIOP and HSRL data. Limiting the analysis to Saharan dust area (100W to 0 and 0 to 35N) we obtain slightly higher values (36.6 sr at 1064 nm) but it is not enough to explain the differences and further investigations are needed.

Table 2. Statistical properties (mean and standard deviation) of the lidar ratio distribution for the aerosol type "dust".

Dust	Lidar ratio 532 nm	Lidar ratio 1064 nm
SODA	38.0 (±7.5) sr	36.3 (±9.5) sr
CALIOP-OP	40 (±20) sr	55 (±17) sr

4. COMMENT ON 1064 NM CALIBRATION AND CIRRUS LIDAR RATIO

As we have seen, the values of the 1064 nm lidar ratio for marine aerosols and dust are quite different from what is currently used in the operational CALIOP algorithm. To ascertain whether the problem lies in the calibration or in the SODA lidar ratio retrieval, we examine below the SODA lidar ratio retrievals for ice clouds. Ice particles have large size parameters and the resulting lidar ratios may be relatively independent of wavelength.

We start by selecting those columns that contain only ice clouds (i.e., homogeneous scenes, excluding aerosols and liquid water). Recognizing, however, that there could be occasional misclassifications of water

clouds and dense dust layers as ice clouds and that ice clouds have an important signature in depolarization, δ, we have also used a supplemental threshold defined as

$$\delta = \frac{\langle \gamma_{perp} \rangle}{\langle \gamma_p \rangle - \langle \gamma_{perp} \rangle} > 0.2, \quad (1)$$

where γ_{perp}, is the integration of the total column 532 perpendicular channel and γ_p is the total column particulate integrated backscatter at 532 nm.

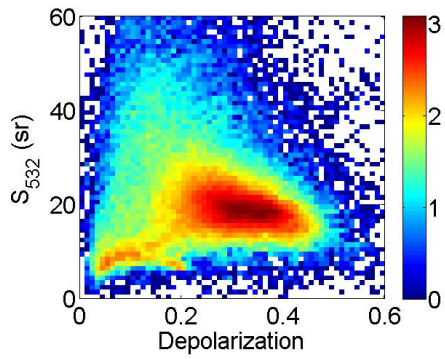

Figure 7. 532 nm lidar ratio for ice clouds as a function of the depolarization (color code is the decimal logarithm of the number of observations).

Fig. 7 shows the 532 nm ice cloud lidar ratio as a function of the depolarization. Most of the observations with low lidar ratios (expected to come from liquid water clouds) also have low depolarization ratios.

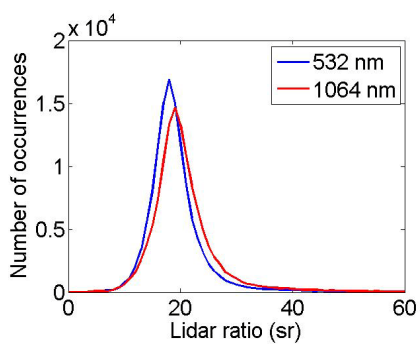

Figure 8. Lidar ratio distribution for cirrus clouds at 532 and 1064 nm.

Table 3. Statistical properties (mean and standard deviation) of the lidar ratio distribution for ice clouds.

Cirrus Type	(Effective) Lidar ratio 532 nm	(Effective) Lidar ratio 1064 nm
SODA	18.1 (±2.9) sr	19.4 (±3.4) sr
CALIOP-OP	15 (±6) sr	-

Fig. 8 shows the distribution of the ice clouds lidar ratio at both wavelengths and Table 3 summarizes the statistical properties of the data. As we can see, both lidar ratio are very similar. If there are no variations of the backscatter coefficients, optical depths or multiple scattering between 532 and 1064 nm, this would mean the overall calibration in our analysis is good within ~7%. Error compensation is possible but the low dispersion of the curves show promise.

For ice clouds, the lidar ratio (Table 3) are higher for SODA than what is used in the operational product. This has been extensively discussed for a high quality subset of the available observations (single layer semi transparent cold cirrus clouds) in [6].

5. CONCLUSIONS AND PERSPECTIVES

The global scale lidar ratio retrieval is a new space remote sensing capability offered by CALIPSO within the A-Train which will allow improvements in aerosol type discrimination, enhancements of the CALIOP extinction profile retrievals and may help to reduce the uncertainty on aerosol and cloud radiative forcing.

6. REFERENCES

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