CALIBRATION OF 1064NM CHANNEL AND RETRIEVAL OF AEROSOL EXTINCTION FROM CALIOP

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ABSTRACT

We described an algorithm to retrieve aerosol type and extinction by using CALIOP data. The algorithm consists of three parts; aerosol detection, re-calibration of 1064nm channel and retrieval of aerosol type and their extinction. The aerosol mask method was based on the aerosol/cloud discrimination schemes originally developed for analyses of the ship-based radar and lidar data [1,2].

Retrieval algorithm of aerosol type and extinction was based on a three-channel algorithm developed using the ship-based lidar data [3]. The unique feature of the algorithm was that the algorithm used two backscattering coefficient at 532nm and 1064nm and depolarization ratio at 532nm and it allowed the mixture of three different types (small particles, dust and sea-salt) in the same grid.

In order to apply the retrieval algorithm to CALIOP data, re-calibrate the CAIOP 1064nm signal was performed using water clouds. The water clouds were discriminated by the cloud particle type algorithm [4]. We examined a ratio of derived values of backscattering coefficient at 1064nm to the value in the CALIOP standard product. The mean value of the ratio was about 0.8 and the ratio showed a latitudinal dependence. The aerosol retrieval algorithm was successfully applied to one-year of CALIOP data.

1. INTRODUCTION

Vertical profile of aerosols was one of the key elements in climate studies. Direct and indirect radiative forcing of aerosols strongly depends on the vertical distribution of aerosols. One of the main aims of the study was to estimate the global distribution of aerosol extinction. Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) started observations since June 2006. CALIPSO carried backscatter lidar, Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP). CALIOP has three channels, i.e., two total backscattering at 532nm and 1064nm and one backscattering for perpendicular channel. These new information should help our understanding of the role of aerosols on the climate system.

The first task for the analyses of aerosols was the detection of aerosols in CALIOP data. We relied on a cloud/aerosol discrimination method based on the ship-based radar and lidar data obtained in the mid-latitude cruise data [1]. We also tested the method for the data taken during the tropical western pacific cruise data [2]. We further modified the cloud mask scheme to analyze CloudSat and CALIOP data. There was a standard cloud and aerosol mask scheme, called Vertical Feature Mask (VFM) for CALIOP data. We found several differences in the cloud detection between the VFM and our scheme. The VFM detected much larger fraction of low-level clouds compared with our results. Since the cloud detection directly affects the detection of aerosols, it is expected that the aerosol detection based on our cloud-aerosol discrimination method should be different from the VFM.

Another issue in the analysis of CALIOP data was the accuracy of the calibration of 1064nm channel. The calibration of 1064nm channel was carried out by using the backscattering coefficient at 532nm. When the ratio of the two backscattering coefficient βs (here after color ratio) was defined as β(1064nm)/ β(532nm), the color ratio was assumed to be 1 for cirrus cloud in the standard CALIOP product [7 Hostetler]. The authors in [5] showed there was a problem in the calibration of 1064nm.

For the analyses of aerosol extinction in CALIOP data, We relied on the method that used three two total backscattering at 532nm and 1064nm and one backscattering for perpendicular channel in order to derive aerosol types and extinction. This method was originally developed for the ship-based lidar data and we modified it to apply CALIOP data. Since our method basically required all information of the three channels in CALIOP measurements, we also made an effort to develop a method to calibrate 1064nm channel of CALIOP. The first part of the manuscript dealt with the calibration of 1064nm channel in CALIOP measurements. Second part was related to the aerosol masking and retrieval of aerosol type and extinction. Section 2 described the aerosol mask method, calibration of 1064nm channel by using water cloud signals and also aerosol retrieval algorithm. Section 3 described the results of calibrating 1064nm channels. The aerosol mask results and results of aerosol type and their extinction were found in section 4.

2. THEORETICAL PROCEDURES

Algorithms consists of three parts; (1) aerosol masking, (2) calibration of 1064nm channel and (3) retrieval of aerosol type and extinction from the three channel information of CALIOP data.

We started with the CloudSat and CALIOP merged data sets where both sensors have vertical and horizontal resolution of 240m and 1.1km, respectively. Prior to the aerosol masking, pixels that contain clouds should be removed by using the results of cloud mask derived from CloudSat and CALIOP. Then we further increased the grid size in horizontal direction to 3.3km in order to increase the signal to noise ratio. Then we applied the aerosol mask to determine pixels that contained aerosols, where the backscatter signal exceeded the sum of the estimated signals due to molecules and remaining noise at each range gate. The coherence filter was also applied to remove the spurious signals.

In the standard CALIOP procedure, the calibration of the 1064nm channel was performed by using ice clouds. Contrary, we considered the water clouds. The water cloud pixels were determined by the cloud particle type algorithm developed in [3]. We also used the results of aerosol mask to find the records where there was no aerosol or ice cloud layers above water clouds.

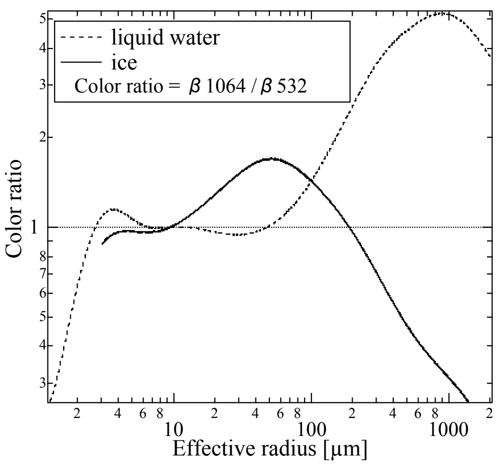

Figure 1. The color ratio, defined as β(1064nm)/ β (532nm), for liquid water and ice particles as a function of effective radius.

The color ratios of water and ice particles were calculated using Mie theory (Figure 1). Water and ice particles were assumed to be sphere.

The color ratio of ice particles turned out to show strong size dependence, e.g., the color ratio was generally larger than 1 and reached 2 at 30μm and the particles larger than 200μm showed the color ratio to be smaller than 1. The ratio of the water particles was found to be close to unity for the effective radius ranging from 5μm to 50μm. The authors in [6] also performed the similar calculations but for non-spherical particles and the color ratio of non-spherical ice showed the shape dependence and there was also a weak dependence on size. The color ratio ranged from about 0.6 to 0.9.

Thus we concluded that the better calibration of 1064nm channel could be achieved by using water clouds. Attenuation correction due to molecules was taken into account in the calibration procedure.

Finally we described the three-channel algorithm based on [3] for the extinction and aerosol type retrievals. We considered water-soluble (as small aerosols), dust and sea-salt particles. In the retrieval, the dry mode radii, standard deviations, and the refractive indices for each aerosol component were prescribed. There were several modifications from [3] . That is, effect of relative humidity on mode radii was taken into consideration due to the hygroscopic growth of mode radius. The effect of relative humidity on refractive indices was also considered. And depolarization ratio of dust aerosols depends on its radius where dust was assumed to be spheroid. All these three components could co-exist in the same CALIOP grid box in the algorithm.

Contrary to the widely used Fernald method, which used one channel information to analyze lidar measurements, our algorithm allowed to retrieve the vertical distribution of the lidar ratio, defined as extinction coefficient divided by the backscattering coefficient.

The accuracy of the algorithm was evaluated by the comparison of optical thickness measured by with Sky-radiometer and the retrieved values. The mean errors were about 10%, though theoretically possible uncertainties in the extinction could be larger than 10%.

When the signal to noise ratio of signal(s) were large, it became impossible to use all three channel information. In such case, the algorithm was designed to switch to one channel method where the lidar ratio was assumed to be 47.5 [sr].

3. RESULTS AND DISCUSSIONS

In the following analyses, one year of CALIOP data sets, from June 2006 to May 2007 were used to obtain calibration constant for 1064nm channel and also aerosol extinction.

We have conducted the calibration for day time and night time. Once calibration have been done, we derived the correction factor defined as the β(TU)/ β(standard) where β(standard) and β(TU) denoted the backscattering coefficient at 1064nm in the standard CALIOP product and the retrieved value in this study, respectively. We analyzed the zonal mean properties of the correction factor for summer (from June 2006 to August 2006) (Figure 2). The similar analyses but for winter (from December 2006 to February 2007) was shown in Figure 3.

Both in day and night, and in summer and winter, the correction factor depends on latitude and ranged from 0.7 to 1. Global average of the annual mean value was about 0.8. The value smaller than 1 indicated the β(standard) was overestimated. In general, the latitude increased, the correction factor increased despite of the day and night difference and seasonal differences. The trend could be explained by the thermal effect as follows; The CALIPSO always moves from south to north during day-time and north to south during night time. Thus thermal effect such as deformation of sensor configuration, increased as latitude increased in day-time. In night-time, the accumulated thermal effects on the sensor may be gradually relaxed. The thermal effect on the 1064nm signals was first pointed by [5]. Our results of the correction factor also supported their explanation/hypothesis.

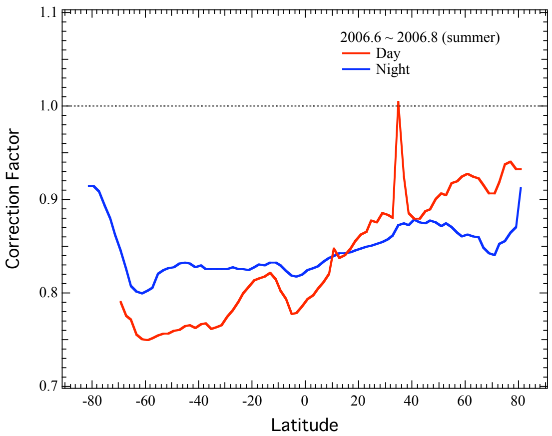

Figure 2. Zonal mean properties of the correction factor, defined as β(TU)/ β(standard), where β(standard) and β(TU) denoted the backscattering coefficient at 1064nm in the standard CALIOP product and the retrieved value in this study. Day time and night time values were separately analyzed.

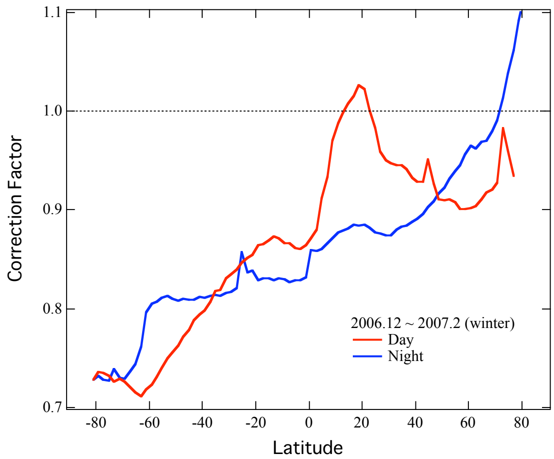

Figure 3. Same as Figure 2 but for winter time period.

The relatively large value in polar region and 40° in summer and 20° in winter could be due to the insufficient sample numbers or misclassification of ice as water particles.

It was straight forward to show that the correction factor retrieved in this study corresponds to the averaged value of the color ratio of ice particles. The average value of 0.8 was consistent with the theoretical estimation in [6] for non-spherical ice particles.

Then the results of aerosol masking were shown in Figure 4. The data was taken in August 1 2006, thick dust layer from Saharan desert region was detected below 4km by CALIOP. Existence of dust could be indicated by the large depolarization ratio (Figure 4d). The comparisons of our mask results and the VFM were shown in Figures 4f and g, respectively. Feature type 1 (blue) and 2 (orange) indicated clouds and aerosols for our method. Our scheme could avoid water cloud contamination in dust layers, while the VFM showed some misclassification of aerosols (indicated by 3: orange) as clouds (indicated by 2; blue).

Finally the extinction coefficient for three aerosol types were estimated by the three-channel algorithm described in section 2. The same aerosol layer shown in Figure 3 were examined here. Status number indicated the status of the retrievals, i.e., 0 (red) and 1(pink) for 3ch-method and 2 for 1channel method (Figure 5b). It was found that the three-channel algorithm successfully was applied to these dust aerosol layers. The extinction coefficient for small particles, sea-salt particles and dust particles were shown in Figures 5c, d, and e, respectively. The total extinction of the three aerosol types was shown in Figure 5g. The results indicated the major aerosol component was dust as expected from the source region (i.e., Saharan desert) and large depolarization.

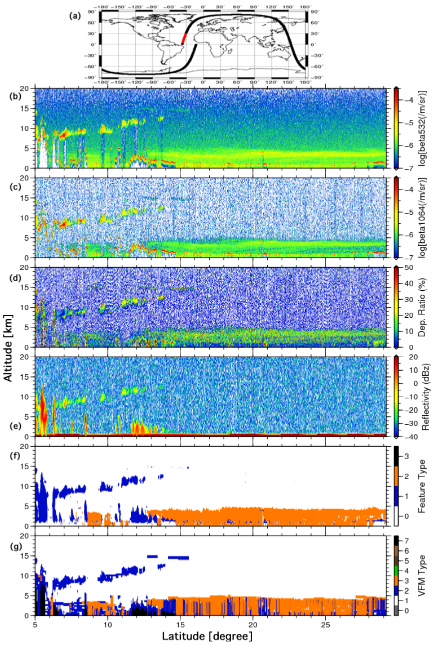

Figure 4. Dust layer from Saharan desert regions observed by CALIOP. (a) orbit of CALIPSO. (b) backscattering coefficient at 532nm, (c) re-calibrated backscattering coefficient at 1064nm, (d) depolarization ratio at 532nm, (e) radar reflectivity factor from CloudSat, (f) Feature type for the aerosol mask schemed in this study, (g) The feature type from the VFM.

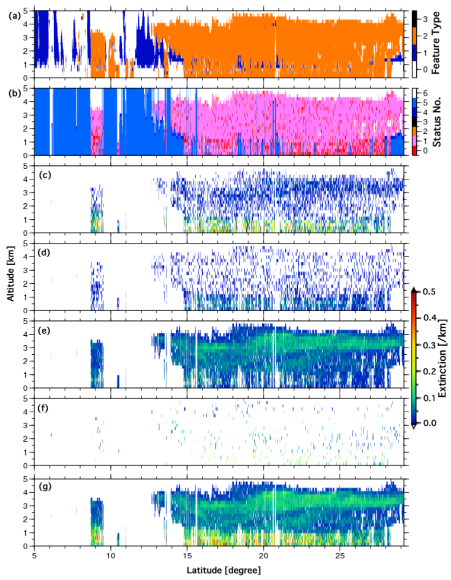

Figure 5. (a) Feature type from aerosol/cloud mask, (b) Status number of the retrievals by the three channel method, (c) Extinction coefficient for small particles, (d) same as (c) but for sea-salt, (e) that for dust, (f) total extinction retrieved by the 1-channel method, (g) total extinction coefficient by the three channel method.

REFERENCES

[1] Okamoto H., T. Nishizawa, T. Takemura, H. Kumagai, H. Kuroiwa, N. Sugimoto, I. Matsui, A. Shimizu, A. Kamei, S. Emori, T. Nakajima, 2007: Vertical cloud structure observed from shipborne radar and lidar : mid-latitude case study during the MR01/K02 cruise of the R/V Mirai, J. Geophys. Res, **112**, D08216, doi:10.1029/2006JD007628.

[2] Okamoto H., T. Nishizawa, T. Takemura, K. Sato, H. Kumagai, Y. Ohno, N. Sugimoto, A. Shimizu, I. Matsui, T. Nakajima, 2008: Vertical cloud properties in the tropical western Pacific Ocean: Validation of the CCSR/NIES/FRCGC GCM by shipborne radar and lidar, J. Geophys. Res., 113, D24213, doi:10.1029/2008JD009812.

[3] Nishizawa T., H. Okamoto, N. Sugimoto, I. Matsui, A. Shimizu, K. Aoki, 2007: An algorithm that retrieves aerosol properties from dual-wavelength polarization lidar measurements, *J. Geophys. Res.*, vol. 112, no. D6, p. D06 212, 2007. DOI: 10.1029/2006JD007435.

[4] Yoshida Y., H. Okamoto, Y. Hagihara, H. Ishimoto, 2010: Global analysis of cloud phase and ice crystal orientation from CALIPSO data using attenuated backscattering and depolarization ratio, *J. Geophys. Res.*, in press.

[5] Hunt W. H., D. M. Winker, M. A. Vaughan, K. A. Powell, P. L. Lucker, C. Weimer 2009: CALIPSO lidar description and performance assessment, J. Atmos. Oceanic. Technol, 26, DOI: 10.1175/2009JTECHA1223.1

[6] Bi L., P. Yang, G. W. Kattawar, B. A. Baum, Y. X. Hu, D. M. Winker, R. S. Brock, and J. Q. Lu, 2009: Simulation of the color ratio associated with the backscattering of radiation by ice particles at the wavelengths of 0.532 and 1.064 µm, J. Geophys. Res., 114, D00H08, doi:10.1029/2009JD011759.