IMPROVEMENT OF AEROSOL RETRIEVAL THROUGH CLOUD IDENTIFICATION

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ABSTRACT:

The stable aerosol retrieval algorithm needs a prior assumption of lidar ratio (the extinction-to-backscatter ratio), and the known aerosol type that is the prerequisite of the assumption, so how to identify the clouds from lidar profile is fundamental to acquire atmospheric optical parameter. CALIPSO is a space-borne lidar and it can observe the aerosol characteristic, but can not penetrate the thick clouds, the identification method used in CALIPSO just only limit in thin cloud, for example cirrus. In this paper, we will introduce another A-train satellite CloudSat, through the combination of these two satellite, we will not only detect the thick cloud and verify cloud identification capability of CALIPSO, but also obtain the more appropriate lidar ratio through recommend an aerosol model. After inversing, the property of aerosol optical depth in Wuhan, Hubei province is analyzed.

1. INTRODUCTION

The excellent spatial resolution provided by backscatter lidar makes it a powerful remote sensing tool for measuring the vertical distribution of clouds and aerosols in Earth's atmosphere. When flown in space, backscatter lidars can provide measurements of clouds and aerosols on a global scale (Zhaoyan Liu et al., 2004). The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite just achieve that goal. It was developed by NASA Langley Research Center in collaboration with the French Space Agency CNES. CALIPSO will be flown as part of the Aqua constellation, including also the Aqua, CloudSat, Aura, and PARASOL satellites (Winker et al., 2003).

Though space-borne lidar extend the observational scope, in reality, there are still some drawbacks exist, the large distance between the target and satellite, the high speed at which the satellite traverses the ground track, so the signal-to-noise ratios are low (Vaughan et al., 2004). Choose a proper lidar ratio is what we can do to improve the retrieval precision at present. The accuracy of the lidar ratio value used in the lidar inversions is dependent in part, on the correct identification of the type of aerosol (Omar et al., 2003). So discriminate the cloud and aerosols should be done first before inversing the lidar signal. But lidar signal is more quickly "extinguished" by scattering and absorption by atmospheric particles. As a result, the light from lidar cannot penetrate the thick clouds and the backscatter signal below the quite dense clouds is faint.

In recognizing of the above situation, we decide to combine another A-Train satellite CloudSat to compensate the deficiency of CALIPSO. The combination of CloudSat and CALIPSO will give us valuable new information and lead to improved predictions of how weather and climate might be changing. This time the observational region is selected in Wuhan, Hubei province (N:30°-31.5°,E:113.5°-115°).

2. INSTRUMENTS AND DATA

All the CALIPSO and CloudSat are active sensors, and provide aerosol and cloud vertical structure info respectively. CALIPSO used an innovative lidar and imaging system to see natural and human-produced aerosols and thin clouds that are invisible to radar, and sometimes even to the human eye. CALIPSO provides a new and unique perspective on the amount, height, and type of aerosols and thin clouds. CloudSat penetrates through clouds well beyond the sensitivity limit of Infrared (IR) radiation sounders, but is insensitive to small hydrometeors and will often miss tenuous cloud condensate at the tops of some clouds or clouds composed only of small liquid water droplets.

2.1 CALIPSO

The CALIPSO payload consists of three co-aligned nadir-viewing instrument:

    a two-wavelength, polarization-sensitive lidar (CALIOP)
    The Imaging Infrared Radiometer (IIR)
    . The Wide Field Camera (WFC)

These instruments are designed to operate autonomously and continuously, although the WFC acquires data only under daylight conditions. CALIOP uses two, redundant, diode-pumped Nd:YAG lasers producing linearly polarized output at 1064 nm and 532 nm (Winker et al., 2003). It utilizes three receiver channels: one channel measuring the 1064 nm backscatter intensity and the other two channels measuring orthogonally polarized components of the 532 nm backscattered signal. Dual 14-bit digitizers on each channel provide an effective 22-bit dynamic range. The receiver telescope is 1 meter in diameter. A redundant laser transmitter is included in the payload. An active boresight system is employed to maintain co-alignment between the transmitter and the receiver. In this experiment we choose 532nm total backscattered signal (two orthogonal polarization components at 532 nm, include parallel and perpendicular backscattered intensity).

Consider the relatively weak backscatter for tenuous aerosol and cloud approaches the limits of feature detection with CALIOP, thus varying degrees of horizontal averaging is performed to reduce noise and reveal tenuous features, reported at 333m,1,5,20, or 80km depending on the feature, the vertical resolution is30m from the surface to 8.2km; higher than 8.2km it is 60m (Vaughan et al., 2004).

Altitude Range (km)	Horizontal Resolution (km)	Vertical Resolution (m)
30.1–40.0	5.0	300
20.2–30.1	1.67	180
8.2–20.2 1	1	60
−0.5–8.2	0.33	30
−2.0–−0.5	0.33	300

Table 2. CALIOP spatial resolution of downlinked data.

2.2 CloudSat

The primary CloudSat instrument is a 94-GHz, nadir-pointing, Cloud Profiling Radar (CPR). Its orbit is sun-synchronous, maintaining a roughly fixed angle between the orbital plane and the mean solar meridian. The purpose of the experimental CloudSat mission is to measure the vertical structure of clouds from space and, for the first time, will simultaneously observe cloud and precipitation.

CloudSat's vertical resolution is 480m with 240m sampling, and the horizontal resolution os approximately 1.4km (cross-track)×2.5km (along-track) with sampling roughly every 1km (CloudSat Standard Data Products Handbook, 2007). A unique feature that CloudSat brings to the constellation is the ability to fly a precise orbit enabling the fields of view of the CloudSat radar to be overlapped with the lidar footprint and the other measurements of the constellation. The precision of this overlap creates a unique multi-satellite observing system for studying the atmospheric characteristic.

3. THE EXPERIMENTAL METHOD

In this study the central aim is solve some problems exist in aerosol retrieval. For instance, because lidar can not penetrate the thick clouds (32-33 degree north latitude), some spatial information lost, as figure 1 show. How to describe this region's aerosol character is what we care about. Traditional method just interpolates the data by using aerosol parameter around this region and don't consider the real aerosol distribution status, further more, each profile only use the same lidar ratio. So how to give a more useful and applied algorithm is what we care about.

3.1 CALIPSO-CloudSat

We use CALIPSO lidar level 2 vertical feature mask, data release versions:1.10, compare with version 2.01, and then use CloudSat 2B-GEOPROF validate the correctness of feature discrimination by CALIPSO algorithm. Choose their observation in the same day and as two satellites interval of time is 15s, we can suppose them providing nearly simultaneous observation.
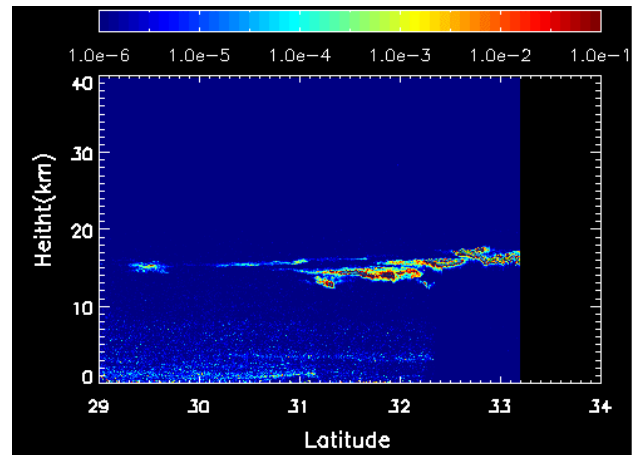

Figure 1. Aerosol signal observed by CALIPSO

3.2 Aerosol retrieval

Aerosol optical depth is representative of the airborne aerosol loading in atmospheric column, and is important for identification of aerosol source regions and aerosol evolution. The most classical analysis of ground-based lidar is far-point calibration and backward retrieval algorithm to ensure stability of the solution, this will not always be possible for all targets detected by the CALIPSO lidar (Young et al., 2002).

The tradition lidar equation and method to retrieval atmospheric parameters are given as the following equation:

$$P(r) = C_0 T_0^2 [(\beta_{\pi,m}(r) + \beta_{\pi,a}(r))/r^2] \exp[-2\int_0^r \sigma_t(r')dr']$$
(1)

$$N(r) = \ln[P(r)r^2]$$
(2)

Then extinction coefficient can be expressed though Klett method into the following equation:

$$\sigma(r) = \frac{\exp[(N-N_0)/k]}{\sigma_0^{-1} + \frac{2}{k}\int_r^{r_0} \exp[(N-N_0)/k]dr'}$$
(3)

From the functions above we could see some variable exist, P(r) is the received signal from ground-based lidar, r, means the height above ground surface, C_0 is the system coefficient, T_0 is the total atmospheric transmittance of zone of incomplete overlap, σ_t, $\beta_{\pi,m}$ and $\beta_{\pi,a}$ are the total extinction coefficient, the molecule and aerosol backscatter coefficients, respectively. In Equation (3) σ_0 and N_0 are the known value at a far point (Klett et al., 1981; Vladimir et al., 2004).

This algorithm gives the summation of atmospheric molecular scatter and aresosol scatter, whereas Fernald's

solution considers the different of these two components effects on laser's attenuation. In this inversion, lidar ratio $S_a = \dfrac{\sigma_a(z)}{\beta_a(z)}$ is an important hypothetical parameter, different aerosol type correspond to different lidar ratio in each profile. Molecular backscatter-to-extinction ratio is $S_m = \dfrac{8\pi}{3}$ (Horst, 1991). The solution for σ_a reads:

$$\sigma_a(z) = -\frac{S_a}{S_m}\sigma_m(Z) +$$

$$\frac{p(z)z^2 \exp[2[\frac{S_a}{S_m}-1]\int_z^{z_c}\sigma_m(z)dz]}{\dfrac{p(z_c)}{\sigma_a(z_c)+\frac{S_a}{S_m}\sigma_m(z_c)} + 2\int_z^{z_c}p(z)z^2 \exp[2[\frac{S_a}{S_m}-1]\int_z^{z_c}\sigma_m(z')dz']dz}$$

$$(4)$$

To calculate the integral of extinction coefficient, aerosol optical depth (AOD) is then received. The aerosol optical depth is the optical depth due to extinction by the aerosol component of the atmosphere.

But in difference with the signal obtained from ground-based lidar P(r), the lidar which loaded in CALIPSO returns the attenuated backscatter coefficient, β'. Here, the signal we acquire is defined by the follow equations:

$$\beta'_{532,Total}\ (z) = [\beta_{parallel}(z) + \beta_{perpendicular}(z)]T^2_{532}(z) \qquad (5)$$

$$T^2_{532}(z) = \exp[-2\int_0^r\sigma_t(z')dz'] \qquad (6)$$

$\beta_{parallel}(z)$ and $\beta_{perpendicular}(z)$ represent the backscatter coefficient in 532nm parallel channel and 532nm perpendicular respectively. $\sigma(z)$ is the volume extinction coefficient at range r, $T^2_{532}(z)$ is two-way transmittance from the lidar to the scattering volume at range z. (Hostetler et al., 2006).

By combining the AERONET's (AErosol Robotic NETwork) data with a credible clustering technique we can determine aerosol categories (Omar, 2006). In Hubei province we divide aerosol in 4 types: polluted dust, pollute continental, clear continental and biomass burning and their lidar ratio are 65sr, 70sr, 35sr, 70sr respectively.

4. PRODUCTION AND ANALYSIS

Through CALIPSO vertical feature mask data, we obtain the figure 2. from this figure we can see there six different colours exist, ultramarine means clear air, light blue means cloud, green is the aerosol, yellow and brown means surface and subsurface respectively, and red is the region where signal lost since thick cloud above and lider attenuated seriously.

Based on the initial CALIOP measurements, an improved version of the cloud-aerosol discrimination algorithm has been implemented for this release. Nevertheless, several types of misclassifications are still occurs with some frequency. For example figure 3 give us the vertical feature mask by using version 2.01, from this figure we find the Regions between 32.3 and 33.2 degrees north latitude, lost signal is much less than figure 2.
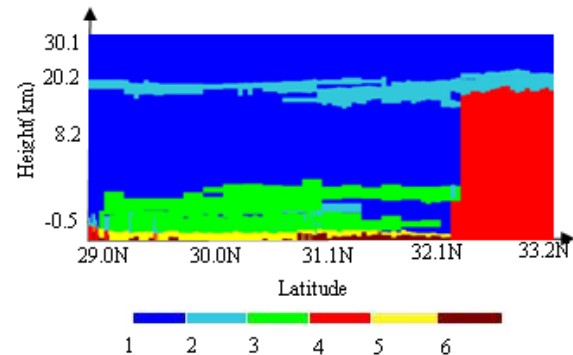

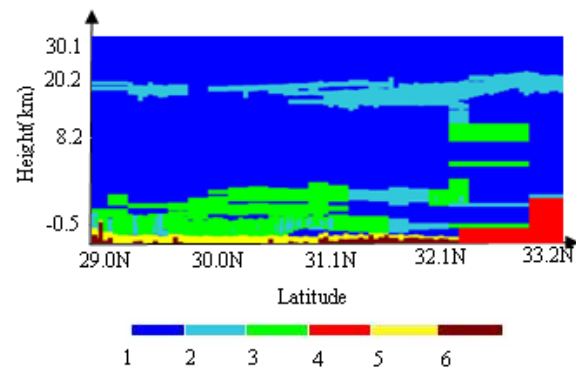Figure 2. vertical feature mask in 2006.08.14 through version 1.10

Figure 3. vertical feature mask in 2006.08.14 through version 2.01

All the result is calculating from CALISPO observation parameters, by utilizing the layer mean attenuated backscatter at 532 nm, the layer-integrated 1064-nm to 532-nm volume color ratio, and the midlayer altitude. None efficient implement is used inspect the outcome before. As a result, CloudSat is introduced in our paper. Different cloud distribution can be seen in figure 4 and figure 5, which aero time and region is correspond to figure 1. The CALIOP 532 nm total attenuated backscatter and vertical feature mask is shown in Fig. 1 to Fig. 3. Generally observed differences between lidar- and radar-derived cloudiness that have been previously reported are seen in Fig. 3 and Fig 4. When CloudSat (radar satellite) and CALIOP (lidar satellite) both detect clouds, the lidar observes higher cloud tops than the radar. This difference is expected because lidar is more sensitive to small hydrometeors than radar; small ice crystals and water droplets are ubiquitous near cloud tops. The radar penetrates to the surface through nearly all clouds unlike most lidars, which generally saturate at optical depth values not much greater than 3. From Fig. 4 and Fig. 5 cloud located in higher latitude is the cumulus.
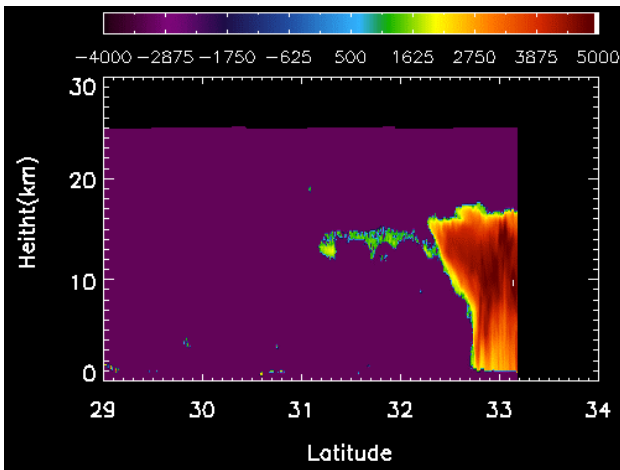
Figure 4 CloudSat radar reflectivity from 2B-GEOPROF product
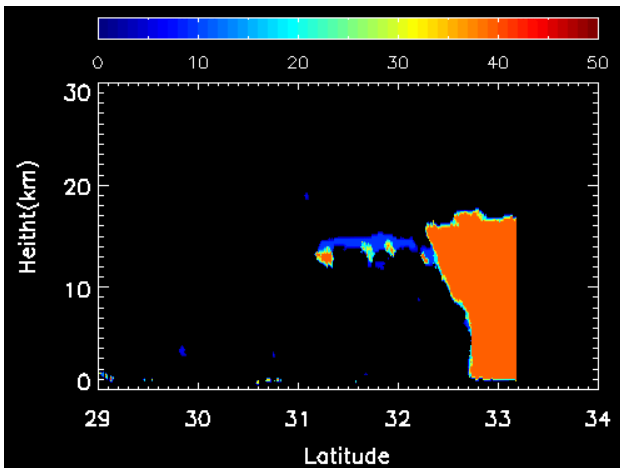

Figure 5. CloudSat cloud confidence mask from the 2B-GEOPROF product

Via these contrast, we found in this case CALIPSO version 1.10 data maybe more reliable. Then add Omar's aerosol model for aerosol classification. Each CALIPSO profile has different features at different height, feature type and the corresponding lidar ratio in each layer can be acquired. Table 2 below gives the example of aerosol information of the in each profile at three different locations.

	1st profile	2nd profile	3rd profile
Profile's Location	N:33.72° E:113.28°	N:30.67° E:112.73°	N:30.04° E:112.56°
Layer number	1	1	2
Layer Top Altitude	Top:3.09km Base:0.99km	Top:3.39km Base:3.06km	Top1:3.48km Base1:3.15km Top2:3.09km Base3:0.78km
Layer	Biomass	Clear	1. Clear

Type	Burning	Continental	Continental 2. Biomass Burning
Layer lidar ratio	70sr	35sr	35sr 70sr

Table 2 the example of aerosol information of the in each profile at three different locations.

From these lidar ratios, more accurate extinction coefficient is retrieved. In respect that lidar can provide high resolution vertical profile, integrated aerosol optical depth can be analyzed as layers in different altitude. In vertical direction, divide aerosol in three layers. As shown in figure 5, analyze aerosol change character in Wuhan, Hubei province. Through image below, we found that in autumn is higher than other season. The boundary layer and troposphere layer aerosol optical depth is always higher then stratosphere layer, but if cirrus exist, stratosphere aerosol optical depth obviously increase, as shown in August 14, 2006 and October 01, 2006.
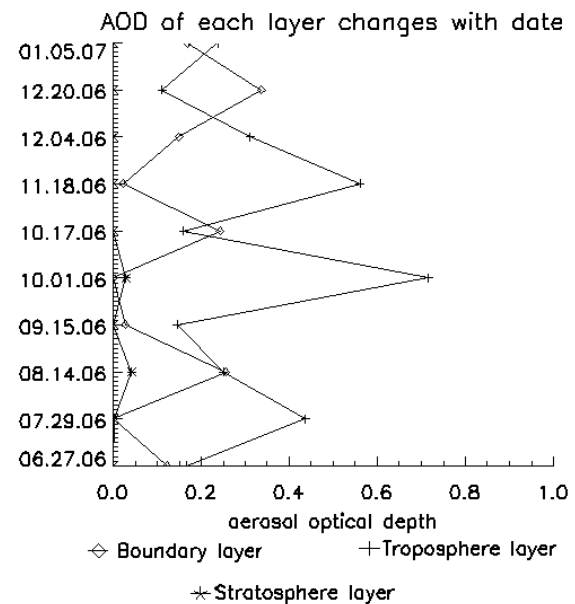

Figure 5. distribution of aerosol optical depth in different layers change with time, in Wuhan

5. SUMMARY

In this paper we first use the CloudSat to validate the CALIPSO's cloud-aerosol classification algorithm, and then choose the best data version and combine Omar's aerosol model gives the aerosol lidar ratio of each profile. Due to lidar's high spatial resolution we divide the atmosphere in different layer and retrieval result shown aerosol in Wuhan is always mass in boundary layer and troposphere, but cirrus make the stratosphere optical depth increase quickly, this phenomena illuminate that aerosol emission is influence from human handing.

Further, Wuhan aerosol optical depth in autumn is higher than other time, it is maybe because the abundant precipitation in summer and snowfall in winter.

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