Space-borne Aerosol cloud High Spectral Resolution Lidar

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Abstract: The main spaceborne Payload ACDL (Aerosol and Carbon dioxide Detection Lidar) has been launched, tested and working in the 705 km orbit has three detection methods (HSRL, depolarization and energy detection), four laser wavelengths, five detection channels to acquire low altitude air optical properties to help quantify the impact of aerosols, clouds and fine particulate pollutants on the Earth's environment. The ACDL utilizes a Nd:YAG laser which incorporates a 1064nm stability master laser, a 1572 nm stability master laser, MOPA amplifier and Optical parameter oscillator to generate four wavelengths. The laser light scattered from aerosols back to the satellite, along with any solar background light, is collected by a one meter diameter telescope. The captured light is separated into five channels and obtained global aerosol attenuation backscattering coefficient, extinction coefficient depolarization ratio and so on. The presentation will describe the aerosol lidar present and discussion.

1. Introduction

Global measurements of the horizontal and vertical distributions of aerosols and their optical, micro-physical and properties are required to quantify the impacts of aerosols on human health, environment and global regional climate, clouds and precipitation. CALIPSO[1,2] , CATS[3,4] payloads have made tremendous efforts and obtained large amounts of valid data. To satisfy further high-precision aerosol measurement requirements, removing the need to assume the Lidar ratio, ACDL[5] and ATLID[6,7] payloads proposed HSRL and polarization detection. ATLID will use the Fabry-Perot filter to separate aerosol and molecular backscattering signals at 355nm. ACDL used an iodine filter to separate aerosol and molecular backscattering at 532nm. Further NASA will use 355nm and 532nm HSRL detection simultaneously in ACE plan[8,9]. The DQ-1 satellite including ACDL was launched on 22 April 2022, and worked continuously. The paper reported the ACDL payload aerosol detection system and results.

2. Payloads

The schematic diagram of the ACDL payload, as shown in Figure 1, primarily includes the laser transmitter, receiving telescope, lidar receiver, and electronic box system. The parameters are listed in table 1. The lidar emits four wavelengths 532 nm, 1064 nm, 1572.02 nm (on line for CO_2 measurements) and 1572.08 nm (off line) at a PRF of 20 Hz with a pulse duration of 200 μs. The double pulse design was compatible with differential absorption intensity of carbon dioxide concentration integral path, Actually, the PRF for aerosol detection effect was equal to 40 Hz. The Nd:YAG laser which incorporates a 1064 nm stability master laser, a 1572 nm stability master laser, a MOPA (Master Oscillator Power Amplifier) amplifier and an optical parameter oscillator to generate 1572 nm on/off wavelength. The 1064 nm seeder is locked on the center of the Iodine absorption line with a frequency stability of within 5 MHz at 532 nm during 10000s.

For the fast steering mirror, ACDL utilizes the piezoelectric ceramics to match the optical axis of the transmitt and reception paths. The four wavelength were expanded in off-axis telescope. The laser signal scattered from aerosols back to the satellite,

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along with solar background light, is collected by a one meter diameter C/SiC (Carbon fiber reinforced Silicon Carbide matrix composites). For the polarization detection, the parallel polarization signal is sum of the parallel channel and HSRL channel (after calibrated). when calculation the molecules intensity, depolorization of and molecules should be taken into account. The Iodine cell was set saturation vapor pressure to assure the absorption intensity for different dynamic range of aerosol and cloud backscattering light.

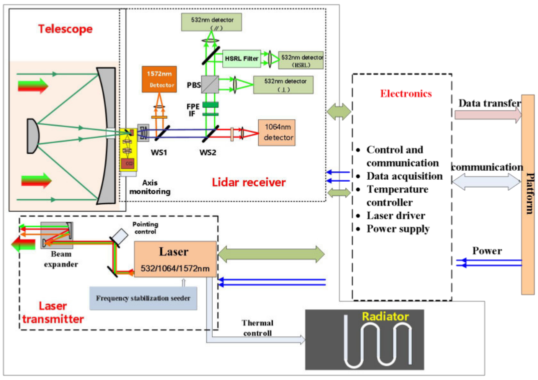

Figure 1. ACDL payload diagram

WS1， WS2： wavelength Splitter， FPE： Fabry-Perot Etalon, BS: beam splitter

Table 1. ACDL payload main parameters

Parameter	Value
Wavelength /pulse energy	532.2 nm/150 mJ 1064 nm/130 mJ 1572.024 nm(on)/75 mJ 1572.085 nm(off)/30 mJ
PRF	20 Hz（Double pulse 200 μs）
FOV	≤200 μrad
Divergence angle after laser beam expansion	<100 μrad
Polarization	400:1 (532 nm//， 532 nm⊥)
Aperture	1.0 m
Interference Filter (IF)	30 pm@532nm
Sampling	50 MS/s
Vertical Data resolution	24 m
Mass	860 kg
Lifetime	≥8 years

3. Lidar data

During the in-orbit testing, ACDL obtained molecular attenuation backscatter profiles in Figure 2 by applying HSRL retrieval methods [10,11] on the May 20th 2022. This paper we will focus on results obtained for March 8th 2023 which include continental, oceanic and snow covered areas. The orbit track consider here is shown in Figure 3.

Figure.4 showed the aerosol backscattering coefficient distribution, where the red line indicates the surface of the earth. The lidar data vertical and horizontal resolution were 48m and 20km respectively. Figure.5 shows the aerosol extinction coefficient distribution.

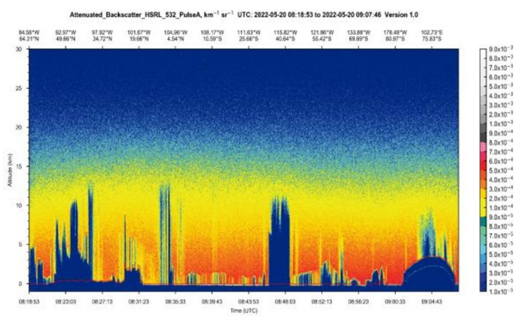

Figure 2. molecular backscattering profile

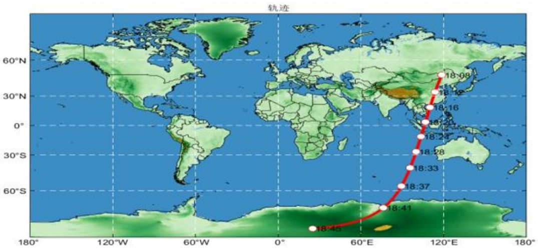

Figure 3. ACDL footprint distribution

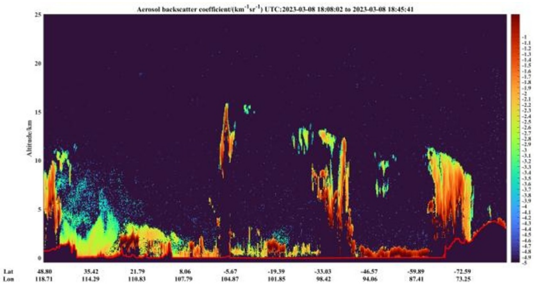

Figure 4. 532 nm Aerosol backscattering coefficient

Because of the sand dust in spring over the Asia continent in Figure 4-8., the Aerosol extinction and backscattering coefficient were dominantly higher than that over the ocean. The backscattering and extinction coefficient at 1064 nm is much smaller than that at 532 nm in Figure 7. and 8., so as to the figure looks more clear-sky present.

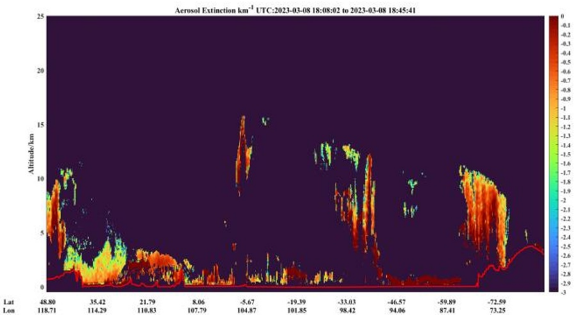

Figure 5. 532nm Aerosol extinction coefficient

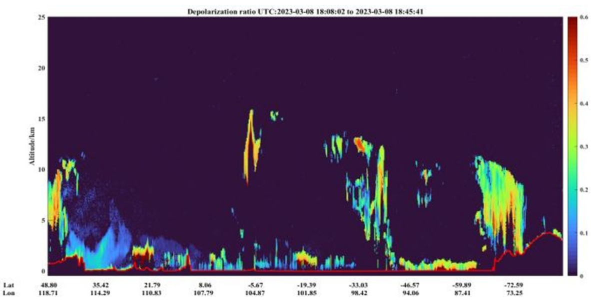

Figure 6. 532 nm depolarization ratio

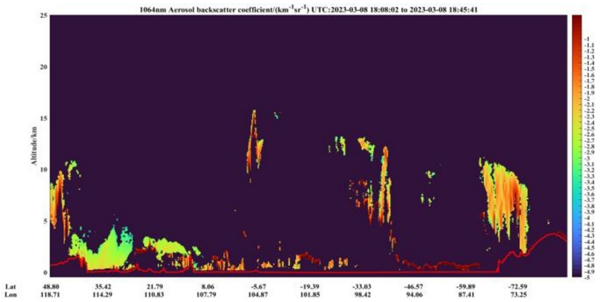

Figure 7. 1064 nm aerosol backscattering coefficient

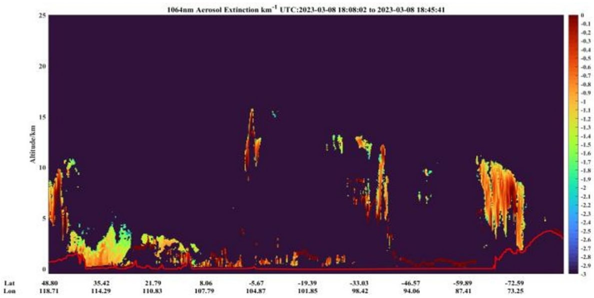

Figure 8. 1064 nm aerosol extinction coefficient

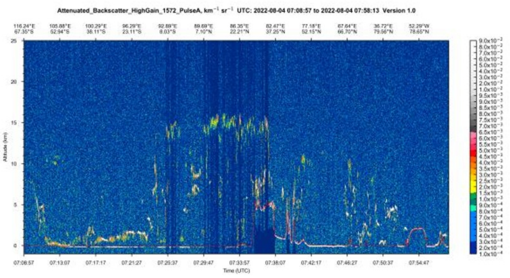

Figure 9. 1572 nm Aerosol attenuation backscattering coefficient

There were several validations of ACDL results using ground lidar net data (Santa-Cruz （28.472°N，16.247°W）of MPLNET and Dun-Huang lidar site(40.348°N,93.709°E). the validation example results are shown in Figure 10.

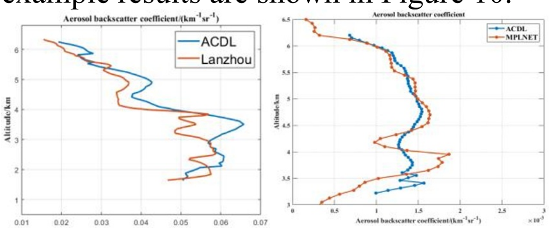

Figure 10. Aerosol backscattering coefficient comparison

There was 30 km distance between ACDL footprint and the Santa-Cruz lidar, while 20km between footprint and Dun-Huang lidar. The

Santa-Cruz lidar data in Figure 10. was averaged about 30 min with a 75 m vertical resolution. The Dun-Huang lidar data in Figure 10. was averaged about 20 min with a 48m vertical resolution. While the ACDL data was 40km horizontal resolution.

An example comparision of daytime 532 nm SNR between ACDL and Calipso is shown in Figure 11. It should be noted that Calipso at this time, was operating for more than 16 years, and thus its power was markered lower decreasing its SNR.
. Below the planetary boundary layer, the SNR of ACDL was higher than 20. which could assure the measurement error within 20%. While the SNR during the 2 km and 15 km altitude was more than 10.

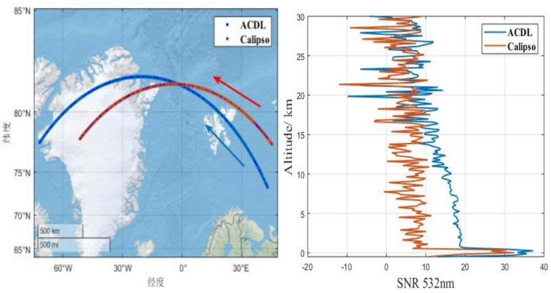

Figure 11. SNR distribution

4. Conclusion

ACDL has been running 2yrs now, and is obtaining aerosol and molecular optical properties Using lidar ratio measurements at 532 nm and extrapolating then to other wavelengths. And then higher accuracy optical properties can be calculated. The four wavelengths data including depolarization data can be used retrieve to aerosol and cloud phase classification by color ratio or lidar ratio.

5. Acknowledgments

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