

# Spaceborne Aerosol and Carbon dioxide Detection Lidar (ACDL) Development and On-orbit Performance

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**Abstract:** Spaceborne Aerosol and Carbon dioxide Detection Lidar (ACDL) is the major payload on Atmospheric Environment Monitoring Satellite (AEMS, also named as DQ-1), which was launched on April 16<sup>th</sup>, 2022. ACDL is a novel spaceborne lidar, which integrates two lidar systems in a set of lidar setup, using a 1572 nm integrated path laser differential absorption (IPDA) method to measure the global CO<sub>2</sub> column concentrations (XCO<sub>2</sub>), and using a 532 nm high spectrum resolution lidar (HSRL) method to measure the vertical profiles of aerosols and clouds. The main parameters of ACDL are described. ACDL has worked 2 years, and the performance continues to be excellent. The three wavelength double-pulse laser is operating with high frequency stability. The global XCO<sub>2</sub> and aerosol profiles from 82° N to 82° S over land and sea in the daytime and nighttime are presented. The global XCO<sub>2</sub> with accuracy of better than 1 ppm was validated. Typical aerosol and clouds profiles are shown.

## 1. Introduction

The important atmospheric environmental factors that affect global climate change are greenhouse gases CO<sub>2</sub> and CH<sub>4</sub>, as well as atmospheric aerosols and clouds, among which CO<sub>2</sub> and CH<sub>4</sub> are the most important greenhouse gases for global warming [1]. Space-borne lidar for active monitoring of greenhouse gases could operate all daytime, have a high probability of penetrating clouds, and are hardly affected by aerosols.

To meet the important requirements of environmental monitoring and climate change research, high-precision monitoring of global air quality and major greenhouse gas CO<sub>2</sub> concentration is the major mission objective of AEMS. ACDL is the main payload of the AEMS satellite, which is operating in a sun-synchronous orbit at 705 km altitude. The orbit inclination of 98.2° provides global coverage between 82°N and 82°S. The main goal is to obtain global atmospheric CO<sub>2</sub> column concentration distribution, then provide quantitative scientific data for the accurate assessment of CO<sub>2</sub> sources and sinks [2]. The second goal is to measure the vertical profiles of global atmospheric aerosols and clouds with high accuracy, and to study their impact and

role in monitoring air quality and global climate change. ACDL has achieved innovative breakthroughs: the first space-borne global CO<sub>2</sub> concentration measurement lidar and the first spaceborne HSRL based Iodine filter for atmospheric aerosols and clouds profiles measurements. The main parameters and on-orbit performance will be shown. High accuracy XCO<sub>2</sub> and aerosol profiles measurements are presented.

## 2. ACDL description

ACDL uses HSRL detection technology to measure the optical parameters profiles of the atmosphere aerosols and clouds [3, 4], and uses IPDA technology to measure CO<sub>2</sub> column concentration [5]. The two different lidar principles are integrated into the ACDL lidar to measure CO<sub>2</sub> and aerosols and clouds simultaneously.

The schematic diagram of the ACDL is shown in Figure 1, mainly including the laser transmitter, receiving telescope, lidar receiver and electronic box system. The lidar emits triple-wavelength (532 nm/1064 nm/1572 nm) frequency stabilized double-pulses from the same power laser, and the time interval of double pulses is 200 μs. Two power lasers are designed to maintain long lifetime of 8 years,

and one power laser for backup operation. The laser transmitter consists of frequency stabilization seeders, three wavelength pulsed laser, a pointing control mirror and a beam expander. The CW seeder at 1572 nm is locked to the CO<sub>2</sub> absorption line, and seeder laser at 1064 nm is frequency-doubled to obtain 532 nm and locked to Iodine absorption line. The lidar system is coaxial, and the transmitter axis pointing could be adjusted to match the field of view (FOV). The lidar receiver consists of a 1572 nm detector, a 1064 nm detector, and three 532 nm detectors. The 532 nm channels include a HSRL detector, a parallel detector, and a polarization detector.

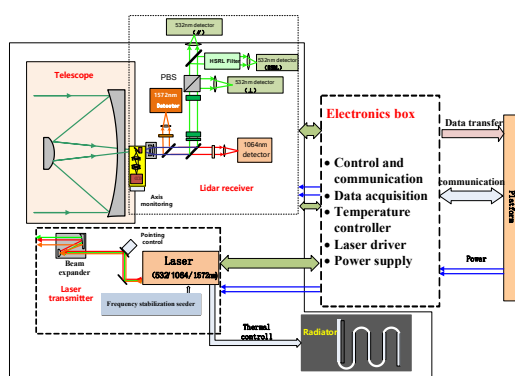


Figure 1. Schematic diagram of ACDL lidar



Figure 2. AEMS satellite

The AEMS satellite is shown in Figure 2, and ACDL is mounted on the top. Table 1 shows the main parameters of the ACDL. The main operation modes include standby mode, detection mode, calibration mode and safe mode. The accuracy and long-term stability of the IPDA lidar system used for XCO<sub>2</sub> measurements are validated before launch. Standard deviations (STDs) of less than 1 ppm are validated [6].

**Table 1. Main parameters of ACDL**

Parameter	Value
Laser wavelength (in vacuum)	1572.024 nm (On-line), 1572.085 nm (Off-line) 1064.490 nm 532.245 nm
Laser energy <sup>(a)</sup>	150 mJ@532 nm 130 mJ @1064 nm 75 mJ @1572 nm
Frequency stability of pulsed laser	1572 nm: ≤0.6 MHz@10000 s 532 nm: ≤5 MHz@10000 s
Pulse duration	≤50 ns
Pulse repetition rate	20 Hz @1572 nm 40 Hz @532 nm and 1064 nm
Polarization ratio@532nm	>400:1
Divergence angle	<0.1 mrad
Telescope aperture	1000 mm
FOV	<0.2 mrad
Receive channel	532 nm HSRL channel 532 nm parallel channel 532 nm polarization channel 1064 nm aerosol channel and altimeter channel 1572 nm CO <sub>2</sub> channel
Data acquisition	50 M/s
Mass	~ 860 kg
Lifetime	≥8 years

(a) :Normal mode with highest energy at 1572 nm

### 3. On-orbit measurement

ACDL has worked 2 years, and fired more than 1.12 billion double-pulse shots on orbit. The energy at each wavelength is measured by internal energy monitor, as shown in Figure 3. The single frequency double-pulse laser maintained good performance. For long lifetime consideration, the laser energy is reduced when ACDL started to operate. On Oct.7, 2023, the laser diode current is adjusted to increase 1572 nm pulse energy.

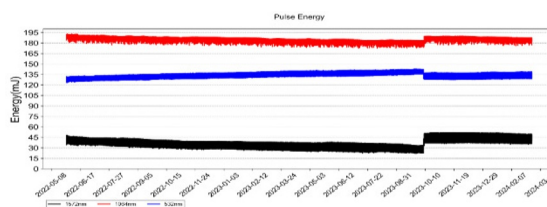


Figure 3. Triple-wavelength pulse laser energy monitoring

The 1572 nm laser pulse output wavelength (On-line) is monitored by heterodyne mixing

frequency measurement module continuously, as shown in Figure 4. The RMS of the 1572 nm laser pulse frequency is about 0.4 MHz, and the Allan deviation at 10000 seconds is less than 0.03 MHz, as shown in Figure 5.

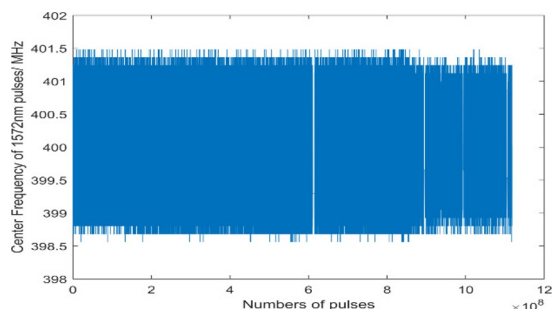


Figure 4 . The heterodyne mixing frequency of 1572 nm On-line pulse laser

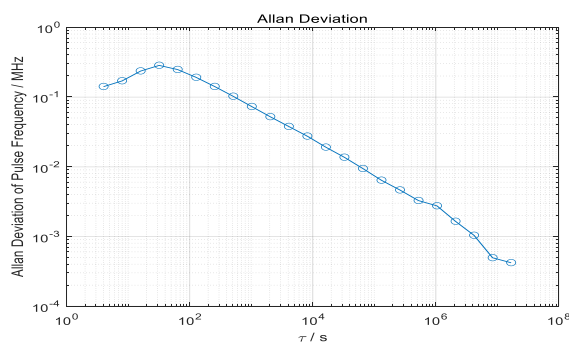


Figure 5. 1572 nm pulse laser frequency Allan Deviation

#### 4. Data products

The data products of ACDL with different level are described in Table 2.

Table 2. Data products of ACDL

Level	Data Products	Product Description	File Format
L0	Satellite downlinked data from AD acquisition of ACDL	Raw data	RAW
L1A	Data products for aerosol measurement, including waveforms for 532 nm and 1064 nm channels, geolocation information, etc.	Waveform products @532 nm /1064 nm	HDF5
L1B	Data products for CO <sub>2</sub> measurement, including 1572 nm channel waveforms, geolocation information, etc.	Waveform products @1572 nm	HDF5

L2A	attenuation backscatter coefficient of 532 nm Perpendicular/532 nm parallel / 532 nm HSRL/1064 nm	Attenuated backscatter coefficient	HDF5
L2B	differential absorption optical depth (DAOD) at 1572 nm	DAOD	HDF5
L2C	Cloud and aerosol products, including height of aerosol layer, aerosol backscattering and extinction coefficient, depolarization ratio, lidar ratio, color ratio, etc.	Cloud and aerosol data products	HDF5
L2D	CO <sub>2</sub> column concentration, etc.	XCO <sub>2</sub>	HDF5

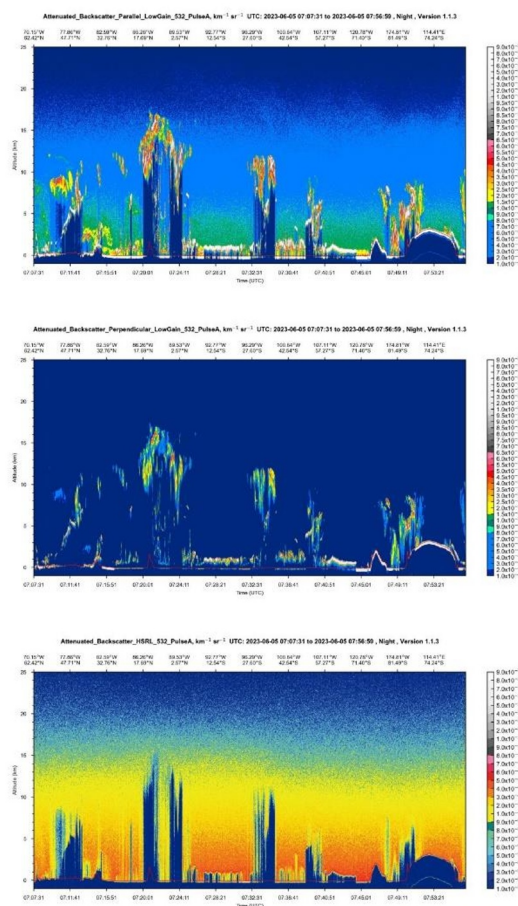


Figure 6. Attenuated backscatter coefficient profiles at 532 nm from parallel, polarization and HSRL channel.

The typical data products of Level 2A at 532 nm are shown in Figure 6, including the attenuated backscatter coefficient profiles of aerosols and clouds obtained from parallel channel, polarization channel and HSRL channel. The XCO<sub>2</sub> distribution in June 2022 measured by

the ACDL in days and nights with  $1^\circ \times 1^\circ$  grid is shown in Figure 7. The space-borne lidar has obtained  $\text{CO}_2$  column concentration data with high coverage, because the laser could penetrate thin clouds and could use backscattered signal from thick clouds. The  $\text{XCO}_2$  measured accuracy is validated to be less than 1 ppm when compared to  $\text{XCO}_2$  data from TCCON sites.

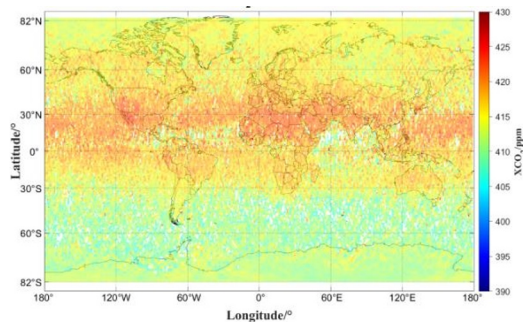


Figure 7. ACDL one month measured  $\text{XCO}_2$  with  $1^\circ \times 1^\circ$  grid

## 5. Summary

ACDL is the first space-borne  $\text{CO}_2$  detection lidar and first aerosol measurement HSRL based Iodine filter, which has finished 2 years continuous operation. The lidar main parameters and some on-orbit monitoring parameters are presented, and the laser show excellent performance. High frequency stability with Allan deviation less than 30 kHz at 10000 s for 1572 nm pulse laser is validated in space. Data products of ACDL with different levels are described, and typical data products are presented. For the first time we could obtain  $\text{XCO}_2$  in bipolar zone and in nighttime, which is useful for global climate study. The data inversion methods will be improved.

## References

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