Development of 1.5 μm all-fiber pulsed coherent Doppler wind lidar

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Abstract: A 1.54 μm eye-safe all-fiber pulsed coherent Doppler lidar (CDL) system is developed to measure wind profiles. The laser is operated with 300μJ pulse energy and pulse width of almost 500 ns and pulse repetition rate of 10 kHz. The diameter of optical telescope is 100 mm. Spectra of 10k pulses are accumulated to increase the SNR of the signal for retrieving the Doppler shift of the light of sight (LOS) wind speeds. The profiles of wind vector are retrieved less than 20 seconds. Field experiments are implemented to validate the CDL performance. Good agreement is shown between the CDL and the balloon results with wind speed and direction errors of 0.73m/s and 5.2° . Airborne wind lidar experiments are also successfully carried out in 2015.

Keywords: Wind measurement, Pulsed Doppler lidar, coherent detection, all-fiber

1. Introduction

A coherent Doppler lidar (CDL) is proved to be an effective tool for wind profiles measurement[1] , windshear[2] and wake vortices detection [3] in clear air with high temporal and spatial resolution and high accuracy in the lower atmosphere layer. A number of groups have been developing and validating such CDL system with 10 μm CO_2 laser[4] ,1 μm solid laser[5], 2 μm solid laser[6], 1.6 μm solid laser[7] and 1.5 μm fiber laser[8]. The 2 μm and 1.5 μm coherent Doppler lidar are promising measurement methods for wind remote sensing. All-fiber CDL systems at 1.5 μm are very popular for wind measurement in the boundary layer in the last few years because of its eye safety, compact size, flexible arrangement [9]. Thanks to the cost-efficient commercially available components, this technology is much attractive and commercial all-fiber CDL systems have been developed by several companies since 2004[10]. The all-fiber CDL system is suitable for airborne platform, because the fiber laser is insensitive to vibration and temperature.

In this contribution, we demonstrate an all-fiber pulsed CDL system for wind profiles sensing. Field experiments are implemented to validate the CDL performance, and the wind profiles are compared with the results from balloon and wind profile radar. Airborne wind lidar experiments are also successfully carried out, and the wind profiles are compared with the results measured by balloon theodolite and ground based wind lidar.

2. System configuration

The system are coupled with polarization maintaining fibers with single-frequency polarized eye-safe all-fiber laser[11]. The schematic diagram of the CDL system is shown in figure 1. The CDL system consists of an all-fiber laser source based on the master oscillator power amplifier (MOPA) design, an optical transceiver with a special designed, robust fiber circulator, and a heterodyne detection unit with real-time signal pre-processor based on field programmable gate array (FPGA). The CDL system is compact with size of 450 mm×400 mm×400 mm and mass of 45 kg. A laptop is used to control the lidar system, and to calculate the line-of-speed (LOS) of the wind. After getting 8 radial wind speed in velocity azimuth display (VAD) scan mode, the wind profiles would be retrieved by the CDL through the method of Levenberg–Marquardt（LM）. The information of platform position, attitude and speed data could be also received to eliminate the effect of the moving platform.

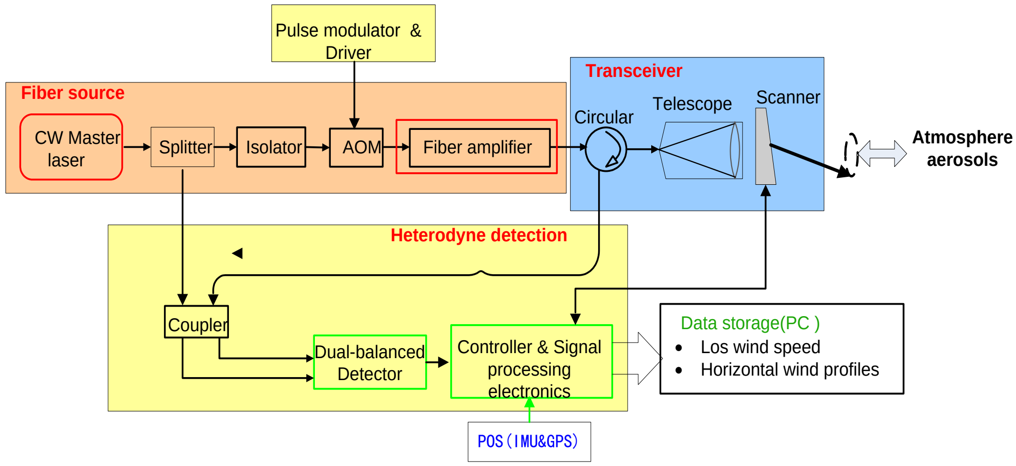

Figure 1. The block diagrams of the CDL system

An eye-safe, narrow-linewidth, polarized, pulsed, fiber laser based on master oscillator power amplifier (MOPA) configuration is acted as the source of the lidar[12]. The laser is composed of a single-frequency, narrow-linewidth external cavity diode laser, and multistage fiber amplifiers. The Distributed Feed Back Laser Diode (DFB-LD) with 10 kHz linewidth and 20mw power is used as the seeder laser. The seeder is divided into two parts by the 1×2 optical coupler. One part (about 0.8mW) is used as the local oscillator, for heterodyne detection. The other part is pulsed modulated and frequency shifted (160MHz) by the acousto-optic modulator (AOM) at repetition rate of 10 kHz, pulse duration of 470ns. Through multi-stages fiber amplifiers, fiber laser with pulse energy of 300μJ, linewidth of 1.1MHz at wavelength of 1540nm is obtained.

The optical transceiver combines a circulator, a telescope and an optical scanner. The transceiver could separate transmitting fiber laser and signal backscattered by aerosols. The optical diameter of the telescope is 100 mm. The output beam from telescope is conically scanned by a compact refractive scanner with 20° deflection angle.

In the heterodyne detection unit the local oscillator from seeder is mixed with signal backscattered by aerosols from transceiver. The heterodyne signal from the InGaAs balanced receiver is sampled by the high speed AD converter with the sample rate of 1G bps. The range resolution is 30m (200ns). Fast Fourier Transform (FFT) of 1024 points and power spectrum accumulation with 10000 pulses are implemented in every range gate. Accumulated power spectra in every azimuth are sent to the computer through RS422 interface to process the wind profiles. The specifications of the system are summarized in the table 1.

Table1. The specifications of the CDL system

Parameter	**value**	**Parameter**	**value**	**Parameter**	**value**
Wavelength	1540nm	Aperture	Φ100mm	PRF	10 kHz
Pulse energy	300μJ	Scanner	20° deflection angle	AD	1G/s ,10bit
Pulse width	470ns	IF	160MHz	Resolution	30m

3. Experiments

Since the equipment was complete in 2014, we have carried out a series of experiments. One verification test was taken out with the GPS balloon and wind profile radar during Sep.4th to Sep. 6th, 2014 in Hefei. The lidar worked for about 40 hours continuously. A troposphere wind profile radar was working at the same time. A GOS meteorological sounding balloon was released at the time of 17 o'clock, Sep. 5th.The measurement results of coherent Doppler lidar is shown in the figure 2. We can see that measurement range was so close because of the thick fog.

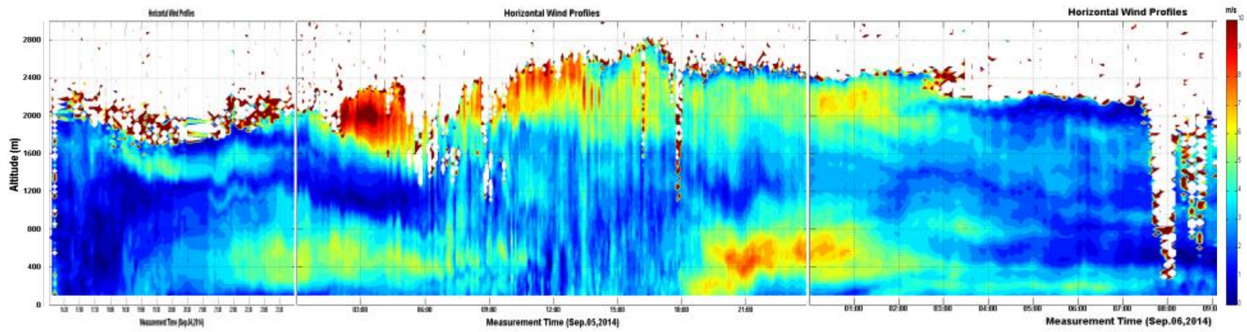

Figure 2. The wind profiles distribution with time

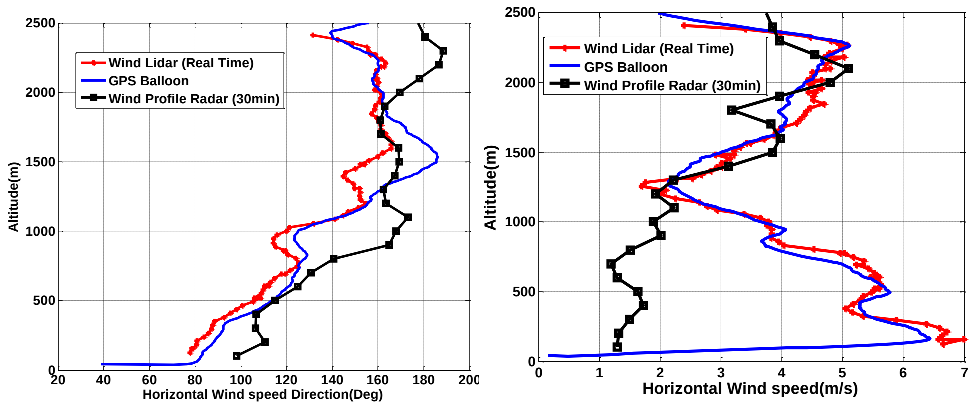

Figure 3. The comparison between the lidar, Radar, and the GPS sounding

The wind profile of the comparison between three instruments is shown in the figure 3. We can see that wind profiles from the lidar and GPS sounding balloon have better consistency. The standard deviation of the wind speed difference is about 0.73m/s, and the wind directions is about 5.2 degrees. The results of the troposphere wind profiles radar is affected by the low SNR below 1000m altitude.

Airborne CDL validation experiment is carried in Roncheng city, Shangdong province, China on Jan 19, 2015. The CDL system is installed in a propeller aircraft with the speed of 50m/s speed and flight height of 2000m. An POS system composed of Inertial Navigation System (INS) and global positioning system(GPS) is installed together with the lidar. Wind profiles measured from airborne CDL are compared with ground-based CDL and aerological theodolite in the campaign simultaneously to assess the airborne CDL performance. The whole flight time was lasted about 5 hours. Figure 4 is show the wind profiles from the airborne lidar, ground lidar and the balloon aerological theodolite on January19, 12:22, . The wind speed standard error between the three system are less 1m/s, and the wind direction differences are about 10° ,as shown in. Especially, wind speed standard error between airborne lidar and balloon aerological theodolite is less 0.4m/s, with wind speed coefficient of correlation of 0.9867.

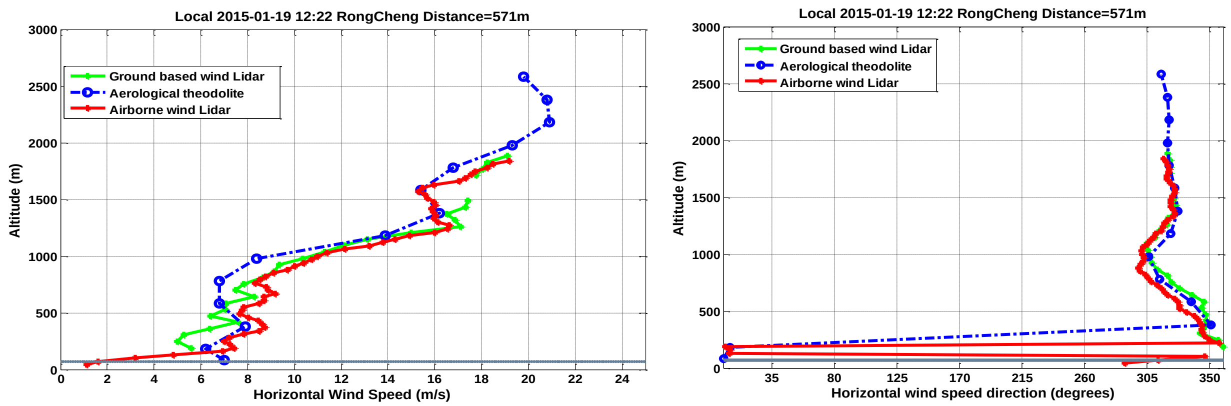

Figure 4. The wind speed profiles comparisons between the three systems.

4. CONCLUSIONS

A 1.54 μ m eye-safe al-fiber pulsed coherent Doppler lidar (CDL) system is developed for wind profiles measurement. Several experiments were carried out for performance verifications. Good agreement is shown between the CDL and the balloon results with wind speed and direction errors of 0.73m/s and 5.2° in Hefei. Airborne wind lidar experiments are also successfully carried out in 2015, and the wind profiles are compared with aerological theodolite and ground based wind lidar. The differences of the wind speed between them are less than lm/s.

5. References

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