OBSERVATIONS OF WIND PROFILE OF MARINE ATMOSPHERE BOUNDARY LAYER BY SHIPBORNE COHERENT DOPPLER LIDAR

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ABSTRACT

Pulsed Coherent Doppler Lidar (CDL) system is so good as to prove the feasibility of the marine atmosphere boundary layer detection. A ship-mounted Coherent Doppler lidar was used to measure the wind profile and vertical velocity in the boundary layer over the Yellow sea in 2014. Furthermore, for the purpose of reducing the impact of vibration during movement and correcting the LOS velocity, the paper introduces the attitude correction algorithm and comparison results.

1. INTRODUCTION

Marine accounted for 70% of the surface of the earth. Marine atmosphere Boundary Layer (MABL) is the connection between sea surface and free atmosphere. The flux of air-sea interface is a major parameter to description the matter-energy interaction. The detection of wind field of MABL has important significance to the flux calculation.

Researchers perform a lot of experiments to detect the wind field in MABL. At present, Buoy, wind tower, ocean surveying vessel, radiosonde and weather radar are used in wind observation. Comparing to the techniques above, the sensitivity is typically lower than lidar. Conventional measuring method is difficult to provide high-precision wind velocity, especially vertical speed, which is demanding for the measurement of air-sea boundary layer turbulence flux. The CDL system is an available tool which has high spatial and temporal resolution in the clear atmosphere and 3D scanning mode are used for measurements of the wind field and the atmospheric turbulent flow [1]. feasible. But the ship motion should be considered or else wind speed especially the vertical velocity, which impact on the calculation of the flux, would be inaccuracy [5].

This paper introduces the experimental investigation which was carried out to measure the wind field of MABL of the Yellow Sea and the Bohai Gulf by pulsed CDL in 2014.The Yellow Sea is the northern part of the East China Sea, which is a marginal sea of the Pacific Ocean. It is located between mainland China and the Korean Peninsula. It is linked with the Bohai Sea (the innermost gulf of the Yellow Sea on the coast of Northeastern and North China) by the Bohai Strait. The Yellow Sea is effected by temperate monsoon climate, so in winter the weather is cold and dry while in summer it’s warm and moist. In winter (from October to next March), the wind of the North Yellow Sea is from the north-west and the average wind speed is 6~7m/s. At the same time, the wind speed of the South Yellow Sea is 8~9m/s. In April, these waters experience the change of monsoons which lead to the instability of the wind direction. In May, due to the southerly monsoon, the average wind speed is 4~6m/s. In summer (from June to August), the wind is always from the south, and the average speed is 4~6m/s. The lidar MABL experiment was carried out in May 2015 while the wind is mainly coming from the south. Wind profile and the validation with radiosonde during the cruise test are presented in this paper.

2. METHODOLOGY

Lidar is one of the most accurate remote sensing techniques that transmit a laser beam into the atmosphere and detect the backscattering of

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velocities the characteristic of the wind field can be deduced. The 3D beam scanner and detection range of 3 km enable the system to monitor the whole marine boundary layer. Because of the all-fiber structure adoption, the system is stable, reliable and high-integrated. The diagram of pulsed CDL setup is shown in Fig. 1. The system specifications are summarized in Table 1.

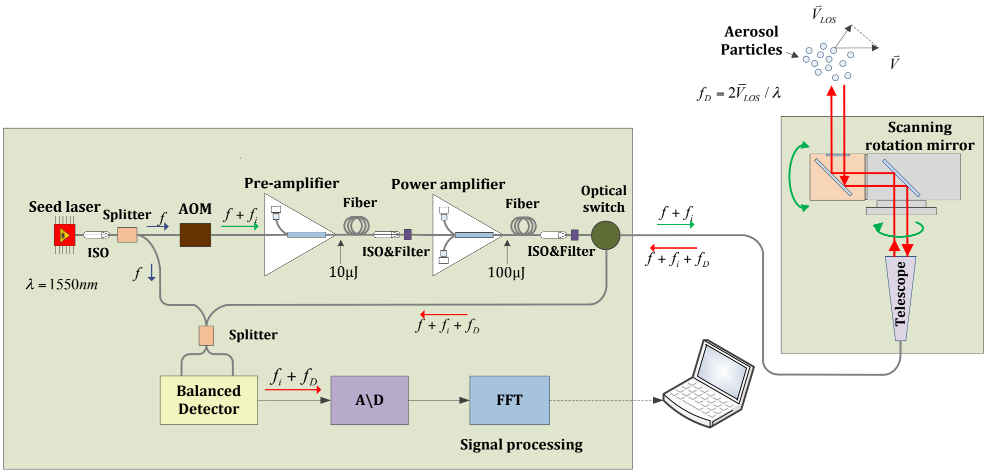

Fig.1.The pulsed CDL setup. A 1.5-µm semi-conductor single frequency laser and an Erbium doped fiber amplifier is used as the transmitter. A fiber optical circulator and a telescope are used as the optical transceiver.

Table 1.Specifications of the CDL.

CDL	Specification
Wavelength	1.5µm
Repetition rate	10kHz
Pulse energy	150µJ
Speed measurement range	±50m/s
Speed accuracy	≤0.3 m/s
Scanner pointing accuracy	0.1°
Scan speed	1-55 °/s
Spatial resolution	30m
Measurement range	30m to 3000m
Power dissipation	<150W
weight	<50kg

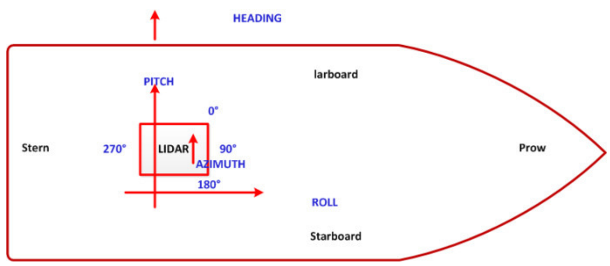

Fig.2. The installation Diagram of the ship-mounted CDL.

A ship-mounted Coherent Doppler lidar was used which causes the errors of wind profile retrieval. At the same time, the speed of the ship itself and ocean wave will be stacked to the line-of-sight velocity. The impact on the vertical speed is much more obvious. So the correction of the direction of the transmitting laser beam in geographic coordinate system is very essential. It can be precisely calculated from the attitude data during movement by an algorithm of attitude transformation. In order to acquire the speed, position and attitude angles of the vessel during movement, a two-antenna differential GPS and an inertial navigation system were installed on the ship-mounted CDL. The inertial navigation system was fixed on the base of the scanner to keep constant relative angles with reference to the transmitting laser beam. After installation, a calibration is performed to determine the initial orientation of the laser beam.

Radiosonde is an accurate meteorological measuring means of MABL profile. But the balloon is unrecyclable and the temporal resolution is low. The CDL system which has high

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radiosonde were conducted for 17 days and comparison results were obtained to verify the feasibility of attitude calibration.

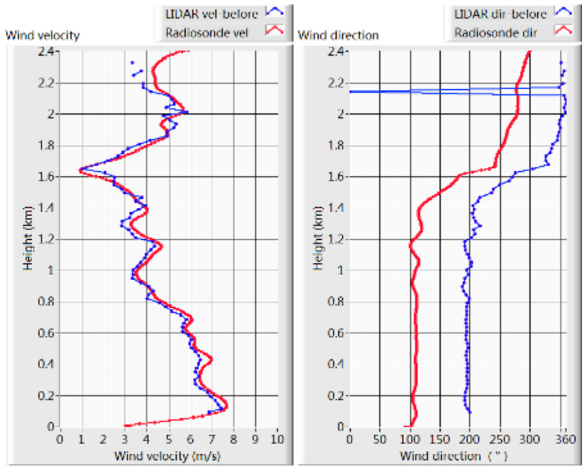
3. RESULTS

To test the modification results, selecting the data detected by CDL at the corresponding time points when the radiosonde was set up and averaging the data for 1 min. This corresponded to a time series with 20 values. The spatial resolution of CDL and radiosonde was 30 m and 10 m, respectively. Measurement range was 3 km and 9 km, respectively.

The data of fixed measurement at15:00 (UTC+8h), May 9, 2014 and the data of underway measurement at 7:00 (UTC+8h) May 13, 2014 were chosen as modification instances. We compared the wind velocity and direction in Fig.3~6.The disparity of wind velocity between before and after the modification was small when the ship was anchored, while the disparity was bigger when the ship was voyaging.

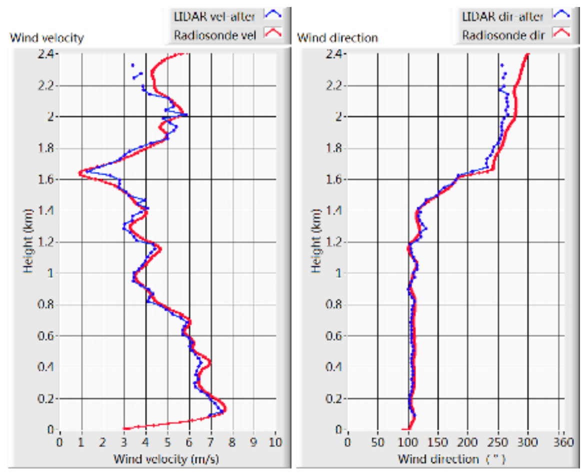
Fig.3 and Fig.4 show the results of the anchored measurement at 15:52 (UTC+8h), corresponding to the longitude 37.00°N and latitude 122.86°E. The heading angle recorded by inertial navigation system was 269.30°, the practical heading angle was 359.30°. In the coordinate system of the ship, the North azimuth was 0° and the pitch angle was 59.98° recorded by sever-system. In the geographic coordinate, the North azimuth was 267.94° and the average value of pitch angle was 59.19°. The standard deviation of the pitch angle was 0.04° so that the swing of the ship was not obvious. The difference of wind direction between before and after attitude modification was 90° due to the different coordinate definition.

The wind velocity measured by CDL were consistent with that of radiosonde with the RMS error better than 0.90 m/s before modification and 0.84 m/s after modification below 2.4 km. Low Signal Noise Ratio (SNR) makes the data unavailable higher than 2.4 km.



(a) (b)

Fig.3.Anchored observation below 2.4 km (before attitude modification): Wind velocity and wind direction measured by radiosonde (red line) and CDL (blue line) at 15:52 (UTC+8h), May 9, 2014. (a)Wind velocity. (b)Wind direction.

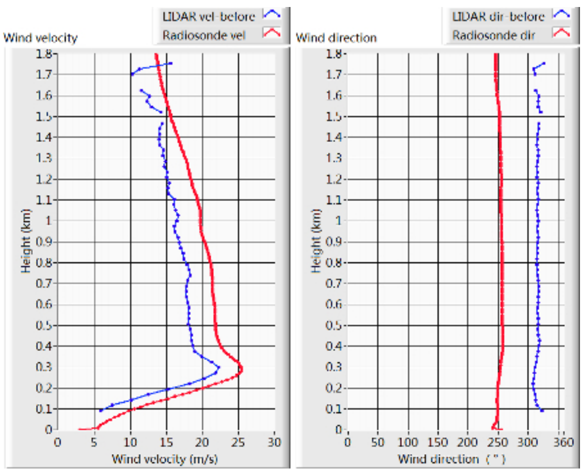


(a) (b)

Fig.4.Anchored observation (after attitude modification): Wind velocity and wind direction measured by radiosonde (red line) and CDL (blue line) at 15:52 (UTC+8h), May 9, 2014. (a)Wind velocity. (b)Wind direction.

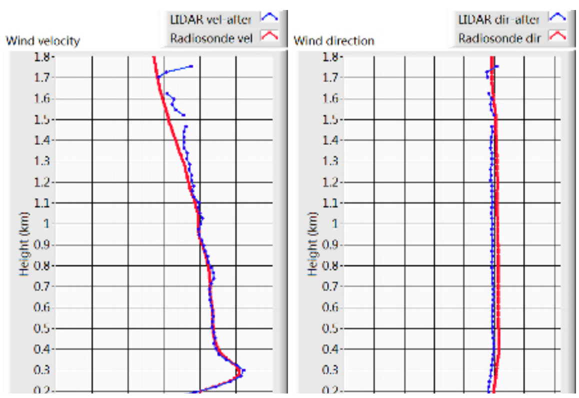
Fig.5 and Fig.6 show the results of the voyage measurement at 07:44 (UTC+8h), corresponding to the coordinate (38.93°N, 119.75°E). The heading angle recorded by inertial navigation system was 299.40°, the practical heading angle was a slight swing of the ship.

The comparison of the results between CDL and radiosonde were better below 1.4 km. The east component of ship's speed was 3.2 m/s and the north component was 3.7 m/s recorded by inertial navigation system. So the speed of the ship was 4.9 m/s. The wind velocity was shown in Fig.6 after the ship speed was calibrated. The results up to 1.8 km altitude of the wind velocity measured by CDL were inconsistent with that of radiosonde with a large RMS error of 3.66 m/s before attitude correction and were consistent with that of radiosonde with a RMS error of 0.63 m/s after correction.



(a) (b)

Fig.5.Voyage observation (before attitude modification): Wind velocity and wind direction measured by radiosonde (red line) and CDL (blue line) at 07:44 (UTC+8h), May 13, 2014. (a)Wind velocity. (b)Wind direction.



(UTC+8h), May 13, 2014. (a) Comparison of wind velocity. (b) Comparison of wind direction.

4. CONCLUSIONS

The observations of MABL wind profile by 1.5-μm all-fiber pulsed CDL system were conducted successfully. Our research team calibrated the speed and direction of the wind field and verified the possibility of attitude correction through the comparison experiment with radiosonde. The CDL is a practical tool for MABL wind field research and a powerful technique for the wind flux. The subsequent significance is to calculate the turbulence flux by vertical and horizontal wind velocity.

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