

Observations of Wind Profile Using a Coherent Doppler Lidar at Zhongshan Station, Antarctica

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Abstract: For further study of the characteristics of Antarctic atmospheric wind-field and its spatiotemporal variations, a compact, all-fiber pulsed coherent Doppler lidar (PCDL) was deployed in January 2020 at Zhongshan Station (69.37°S, 76.37°E), Antarctica, by the 36th Chinese National Antarctic Research Expedition. The PCDL emits a laser at a wavelength of 1550 nm, with a pulse energy of 110 μ J, a repetition frequency of 10 kHz and employs a 100 mm telescope as a coaxial transmitter and receiver to collect atmospheric backscatter. A lidar container equipped with a window system is customized to house the PCDL system for long-term stable operation. It is capable of measuring continuous wind profiles in real time with a spatial resolution of 30 m and a temporal resolution of 1 min. The maximum detection range is up to 1.5 km. The comparison results between the lidar and an anemometer show a root mean square deviation (RMSD) of 0.36 m/s and 5.1° for wind speed and direction, respectively. Over 1000 hours' observation datasets have been obtained annually from 2020 to 2023, and utilized to study the atmospheric boundary layer in Antarctica. Additionally, one case of continuous observations is depicted as well.

1. Introduction

The polar atmosphere is an important part of the global atmospheric system. The atmosphere over the Polar Regions is more sensitive to global climate change than other areas [1], making it an ideal location for understanding the climate change and disruptions. The vertical structure of wind vectors is one of the primary elements to describe the state of polar atmosphere. It is of high confidence that the wind field (speed and direction) is closely related to sea ice trends and surface-atmosphere energy exchange [2]. Consequently, knowledge of polar atmospheric wind is of great significance for studying the polar atmosphere.

Currently, due to the inherent difficulties in exploring the polar regions, the polar atmosphere is still poorly understood. The radiosondes are the contemporary and main means of profiling wind speed and direction in the polar regions, which have been used for the past 50 years at several research stations [3]. As one of the most powerful active remote sensing technologies, lidar has been widely used in the observation and research of the Earth's

atmosphere in recent decades, yielding outstanding contributions to the development of atmospheric science. By utilizing the fluorescence tracers (such as free metal Fe and Na atoms), the atmospheric temperature in the polar mesosphere and lower thermosphere has been monitored using fluorescence resonant lidars [4]. Employing the Rayleigh integration technique, the polar atmospheric temperature from lower stratosphere to mesosphere has been probed by Rayleigh lidars [5,6].

The first lidar in Antarctica was successfully installed in 1974 at the Amundsen–Scott South Pole station for the purpose of aerosol and cloud sensing [7]. Furthermore, a more sophisticated Boltzmann temperature lidar system, which simultaneously emits two lasers at 374 nm and 372 nm, was deployed at the South Pole to observe the polar mesospheric atmosphere during the same time. Significant scientific findings have been achieved through these measurements [8]. With the assistance of the vib-rotational Raman spectroscopy technique, temperatures of the troposphere in Antarctica have also been retrieved [9].

after its on-site installation and adjustments in the container.

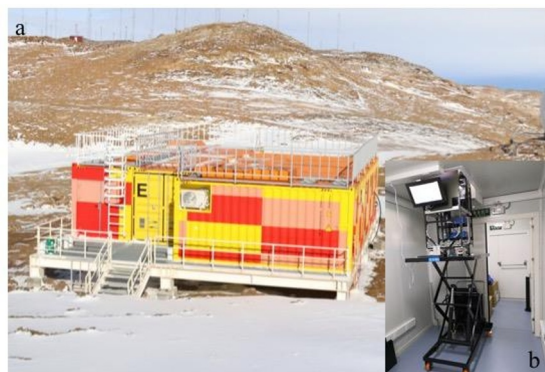


Figure 2. The lidar observation containers and wind lidar at Zhongshan Station.

Due to the deficient aerosol levels in Antarctica and their distribution within the ABL, the detection range of the lidar evolves with time. The PCDL was assembled and readjusted on-site in January 2020 and has been in routine operation since then. Over 1000 hours' observation datasets have been obtained annually from 2020 to 2023. Monthly observation days are illustrated in Figure 3.

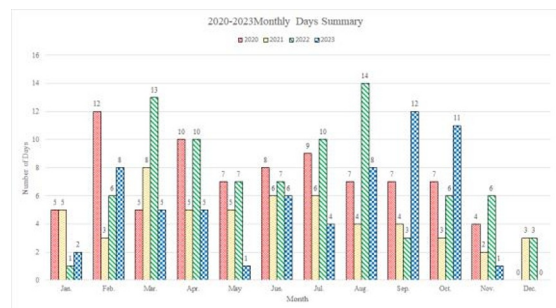


Figure 3. Statistics on the monthly observation days of the PCDL from 2020 to 2023.

3. Results

One case of continuous wind profile observations, including horizontal wind speed and direction, is depicted in Figure 4. It illustrates the time series of wind vectors obtained using the PCDL from 17:13 on 02 July to 03:57 on 07 July 2022. It uses arrows to indicate the wind vectors; the length of the arrow denotes the wind's intensity and the direction of the arrow denotes the wind's direction. Additionally, a color bar is used to represent wind speed; the faster the wind, the redder the hue. The temporal variation of horizontal speed and direction can be displayed vividly in one image.

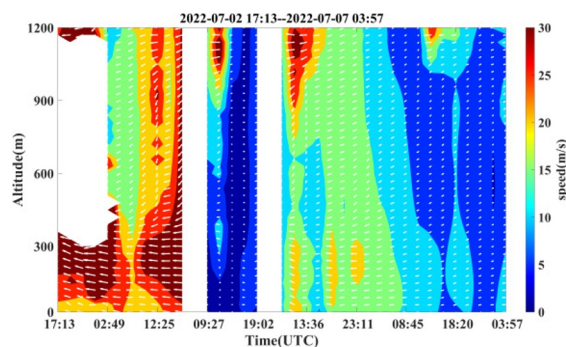
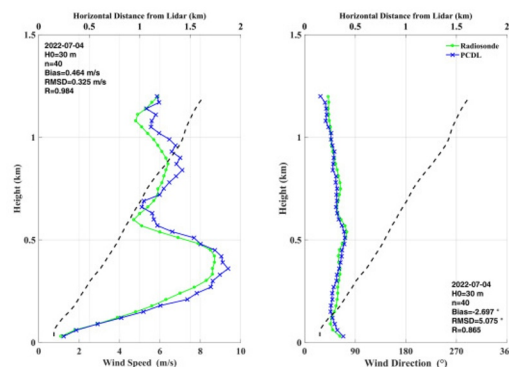
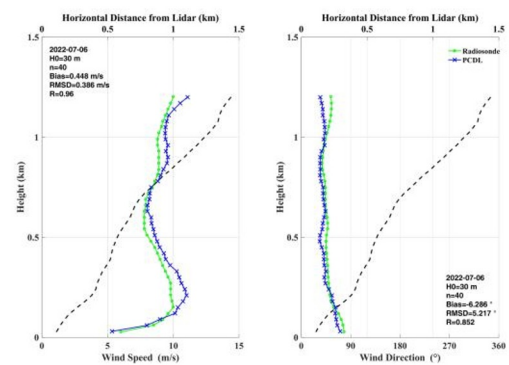


Figure 4. Temporal variation of wind fields measured using PCDL at Zhongshan Station from 02 to 07 July 2022.

Vaisala radiosondes of the RS41-SG type were launched once a day from 02 to 07 July 2022, to gather additional vertical meteorological parameters. The horizontal wind speed and direction were independently calculated using variations in the GPS satellite carrier frequency [12]. Two cases of coincident PCDL and radiosonde measurements at Zhongshan Station were compared and shown in Figure 5.



(a)



(b)

Figure 5. The comparisons of horizontal wind speed and direction measured using PCDL

(blue line) and the radiosonde (green line) at Zhongshan Station. (a) Wind profiles of RS41-SG radiosonde and lidar at 17:15 on 04 July 2022; (b) Wind profiles of RS41-SG radiosonde and lidar at 17:14 on 06 July 2022.

The bias, root mean square deviation (RMSD), and correlation (R) were calculated simultaneously to further statistically evaluate the differences in horizontal wind speed and direction measured using the PCDL and radiosonde, respectively. The comparison results between the lidar and an anemometer indicate a RMSD of 0.36 m/s and 5.1° for wind speed and direction, respectively. One profile captured on 04 July 2022 using the radiosonde and lidar shows good agreements at each height. The wind speeds increased from 1.5 m/s near the ground to approximately 9 m/s at about 400 m, then decreased to 5 m/s at about 700 m. The wind direction changed from east near the ground to northeast.

4. Conclusions

For further study of the characteristics of Antarctic atmospheric wind-field and its spatiotemporal variations, a Coherent Doppler Wind Lidar was developed by Institute of Oceanographic Instrumentation, Qilu University of Technology (Shandong Academy of Sciences), and deployed at Zhongshan Station during China's 36th Antarctic scientific expedition. The results demonstrate that the developed Wind Lidar system can provide stable and reliable wind field data, making it an effective approach for observing low-altitude atmosphere in the Antarctica.

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5. References

[1] IPCC Report, “*Climate change 2007: The physical science basis, contribution of working group I to the fourth assessment report of the*

intergovernmental panel on climate change,” (Cambridge University, 2007).

[2] F. A. Haumann, N. Gruber, M. Münnich, I. Frenger, S. Kern, “Sea-ice transport driving Southern Ocean salinity and its recent trends,” *Nature*, **537**, 89–92 (2016).

[3] G. Lesins, T. Duck, J. Drummond, “Climate trends at Eureka in the Canadian high arctic,” *Atmos.-Ocean* **2010**, **48**, 59–80.

[4] X. Chu, W. Pan, G. Papen, C. S. Gardner, and J. Gelbwachs, “Fe Boltzmann temperature lidar: design, error analysis, and initial results at the North and South Poles,” *Appl. Opt.* **41**(21), 4400–4410 (2002).

[5] W. Pan and C. S. Gardner, “The temperature structure of the winter atmosphere at South Pole,” *Geophys. Res. Lett.* **29**(16), 49-1–49-4 (2002).

[6] C. Ban, W. Pan, R. Wang, et al, “Initial results of Rayleigh scattering Lidar observations at Zhongshan station,” *Infrared and Laser Engineering*, **2021**, **50**(03):78-85.

[7] V. N. Smiley, J. A. Warburton, B. M. Morley, “South Pole ice crystal precipitation studies using lidar sounding and replication,” *Antarct. J. U. S.* **10**, 230–231 (1975).

[8] X. Chu, Y. Nishimura, Z. Xu, et al, “First Simultaneous Lidar Observations of Thermosphere-Ionosphere Fe and Na (TIFe and TINa) Layers at McMurdo (77.84° S, 166.67° E), Antarctica With Concurrent Measurements of Aurora Activity, Enhanced Ionization Layers, and Converging Electric Field,” *Geophysical Research Letters*, **47**, (2020).

[9] F. Liu, R. Wang, F. Yi, et al, “Pure rotational Raman lidar for full-day troposphere temperature measurement at Zhongshan Station (69.37° S, 76.37° E), Antarctica,” *Optics Express*, **29**(7), (2021).

[10] Z. Wang, R. Wang, H. Li, et al, “Applied research on low-altitude wind field using coherent Doppler wind lidar at Zhongshan Station, Antarctica,” *Chin. J. Polar Res.* **34**, 11–19 (2022).

[11] H. Li, Z. Wang, et al, “Remote Polar Boundary Layer Wind Profiling Using an All-Fiber Pulsed Coherent Doppler Lidar at Zhongshan Station, Antarctica,” *Atmosphere*, **14**901(2023).

[12] H. Iwai, M. Aoki, M. Oshiro, S. Ishii, “Validation of Aeolus Level 2B wind products using wind profilers, ground-based Doppler wind lidars, and radiosondes in Japan,” *Atmos. Meas. Tech.* **14**, 7255–7275(2021).