https://wes.copernicus.org/preprints/wes-2026-94#EC1

EC1: 'Comment on wes-2026-94', Etienne Cheynet, 15 Jun 2026 reply

The manuscript addresses an interesting topic of clear relevance to Wind Energy Science. The discussion provides useful information on wind-speed errors and on the practical advantages and limitations of the different hard-target test methodologies. However, I find that the wind-energy implications of the required angular accuracy could be discussed more broadly.

Reply: We would like to thank the Editor for providing helpful constructive comments on the manuscript and have provided a response to the points raised after each paragraph below.

At present, the discussion mainly considers the effect of angular errors on wind speed. This is relevant, but the acceptable angular error depends strongly on the intended application. For example, an error of 0.2° may be acceptable for estimating one-point turbulence statistics at a range of 1 km, but too large for coherence studies based on two lidars with nearly parallel beams, as highlighted during the COTUR experiment by Cheynet et al. (2021). I therefore recommend that the authors clarify which level of angular accuracy, calibration procedure, or hard-target test is appropriate for different applications, including mean wind-speed estimation, one-point turbulence statistics, and two-point turbulence statistics. This broader discussion would help strengthen the manuscript's relevance to Wind Energy Science, rather than framing the work mainly as a technical contribution to Doppler wind lidar technology.

Reply: Thank you for this comment. We focussed the discussion on the impact of elevation angle errors specifically on wind speed since this is the primary measurement quantity used to derive both mean wind speed and turbulence statistics. If the elevation angle error is accurately determined for a system, the error can be accounted for in the setup of the device by applying an offset to the setup (i.e. a calibration), which is common practice. It is therefore unclear why the elevation angle error tolerance would be required to be different for one-point versus two-point turbulence statistics. In both cases, it is desirable to determine the elevation error of the device(s) as accurately as possible so that the setup can be adjusted accordingly (calibrated) to measure at the desired height. As emphasised in the manuscript, this is critical because of the typically very low elevation angles (<5°) of the beams and the implications this has due to the significant vertical variations in both mean wind and turbulence conditions within the lower atmospheric boundary layer (i.e. 0-400m).

The literature review should also be completed and better contextualised with respect to previous and recent work on long-range scanning lidars for wind-energy applications. Vasiljević et al. (2016) is mentioned only briefly, although it contains relevant quantitative information on static pointing accuracy, hard-target mapping, backlash, and repeatability of long-range WindScanner systems. I recommend that the authors compare their results with those reported by Vasiljević et al. (2016). This would help readers assess whether the present results are consistent with earlier long-range scanning lidar systems and, if not, whether the differences may be due to differences in hardware or calibration procedure.

Reply: Thank you for highlighting this missing information. We have referred to other relevant studies: Bruch and Conan, (2025); Meyer et al., (2026), Mann et al., (2026), and Rouholahnejad et al., (2026). We have also expanded on references to Vasiljević et al. (2016) and added the

following text both referring to and comparing our results with the useful relevant quantitative information provided for the long-range WindScanner system from Vasiljević et al. (2016):

Static pointing accuracy and hard target mapping

Section 1: *Uncertainties in the beam position determined from this [hard targeting] approach have been found to be on the order of ±0.05° (Vasiljević et al., 2016; Oldroyd et al., 2024).*

Section 3.1**:** *The NOAH reference target was scanned 16 times throughout the test period (10 days) yielding $\sigma_{\phi e}$ = 0.01°. This variation is well within the reported accuracy of the scanner head of the system ±0.1° and within the accuracy of ±0.05° reported for the long-range WindScanner system (Vasiljević et al., 2016).*

Repeatability

Section 2.4: *We found that for temporally consecutive multi-elevation PPI scans of the same static hard target, ϕ_{lidar} was constant (see Figure A2, Appendix A1). This repeatability within the scan resolution of 0.01° has also been noted for the long-range WindScanner system (Vasiljević et al., 2016).*

Backlash

Section 2.3.4**:** *In scanning lidar systems, mechanical backlash, defined as the effect of motion lost as the scan head mechanism reverses direction, can introduce small positioning errors (e.g. ±0.025°; Vasiljević et al., 2016).*

Bruch, W. and Conan, B.: Mean Wind Profile Departure from Log Law in the Lower Marine Atmospheric Boundary Layer for Different Wave–Wind Conditions Using Scanning Wind Lidar Measurements, Journal of Physical Oceanography, 55, 1771 – 1788, https://doi.org/10.1175/JPO-D-24-0225.1, 2025.

Meyer, P. J., Rott, A., Schneemann, J., Pauscher, L., Gramitzky, K., and Kuhn, M.: Experimental validation of the Sea Surface Calibration for scanning lidar static elevation offset determination, Journal of Physics: Conference Series, 3224, 022 049, https://doi.org/10.1088/1742-6596/3224/2/022049, 2026.

Rouholahnejad, F., Lunel, T., and Gottschall, J.: Beyond the Intersection Point: OffshoreWind and Turbulence reconstruction from Horizontally Separated Dual-Doppler Scanning Lidar Beams, Wind Energy Science Discussions, 2026, 1–38, https://doi.org/10.5194/wes-2026-99, 2026.

In addition, Mann et al. (2026), which includes some of the present manuscript's co-authors, reports a related offshore lidar campaign focused on turbulence measurements in the marine boundary layer and novel hard target tests. This recent study could be used to provide more context on the wind-energy applications and practical motivation for accurate beam positioning.

Reply: Thank you for highlighting the study. We now refer to the study when discussing the literature for sea surface methods in the introduction (Section 1).

Section 1: *Sea surface scans have also been shown effective in directly estimating and correcting elevation angle errors for multiple scanning lidars during a measurement campaign (Mann et al., 2026).*

References:

Cheynet, E., Flügge, M., Reuder, J., Jakobsen, J. B., Heggelund, Y., Svardal, B., ... & Godvik, M. (2021). The COTUR project: remote sensing of offshore turbulence for wind energy application. Atmospheric Measurement Techniques, 14(9), 6137–6157.

Mann, J., Patel, A., Sjöholm, M., Thorsen, G. R., Simon, E. I., Hung, L. Y., & Gottschall, J. (2026). An experimental campaign to measure turbulence in the marine boundary layer. Wind Energy Science Discussions, 2026, 1–27.

Vasiljević, N., Lea, G., Courtney, M., Cariou, J. P., Mann, J., & Mikkelsen, T. (2016). Long-range WindScanner system. Remote Sensing, 8(11), 896.