Verifying dual-scanning lidar performance for offshore wind measurement

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New testing at the C-TEST site near Newcastle, UK, is helping to demonstrate the potential of dual-scanning lidar for offshore wind measurement campaigns. Data from the NEMO project shows the technology can deliver accurate wind speed and turbulence intensity measurements at multi-kilometre distances while reliably capturing extreme weather events.

Dual-scanning lidar (DSL), combining two long-range scanning lidar devices whose beams intersect at a measurement point of interest, is a promising measurement approach, particularly for offshore wind resource and site assessment. In principle, it can be applied to any location within the range of the scanning lidars, i.e., currently up to 10 to 15 km, depending on the technology and instrument type used. It may therefore cover many sites of interest for the development of offshore wind projects globally.

In Europe, and in particular in the German North Sea, this criterion is often not met. For this reason, the use of floating lidar, a vertically profiling lidar device mounted on an autonomous buoy, has been more prominent for offshore wind resource assessment.

By contrast, in Japan, DSL applications have been prioritised, as the first offshore project developments fell within the manageable range of the technology. In addition, DSL has been considered more promising for providing reliable turbulence intensity (TI) information, which is required for the structural design of an offshore wind farm project, as outlined in the 'Offshore Wind Measurement Guidebook', released by the Japanese 'New Energy and Industrial Technology Development Organization' (NEDO)[1].

In Europe, DSL has primarily been used for R&D-focused measurement campaigns such as in the OWA Global Blockage Effect in Offshore Wind (GloBE) project[2]. More project-level DSL applications are expected, including in Europe, for coastal sites or within existing offshore wind clusters where DSL devices can be installed on available wind turbine transition pieces or other offshore platforms.

Introducing the C-TEST test site

All these potential applications have one requirement in common. They must be preceded by verification of the measurement technology's performance under representative conditions to prove the measurement accuracy for that application. A suitable verification typically requires an offshore met mast at the target location capable of providing traceable reference measurements. These include mean wind speed and direction, as well as turbulence intensity (TI), gusts and extreme winds across the full range of site conditions relevant to the application.

With the Centre for the Testing of Environmental Sciences Technology (C-TEST), set up and operated by Oldbaum Services and utilising the National Offshore Anemometry Hub (NOAH, operated by Offshore Renewable Energy [ORE] Catapult) close to Newcastle in the UK, we identified a suitable test site for a measurement campaign.

Figure 1 shows its location and the test setup, including the North and South scanning lidar

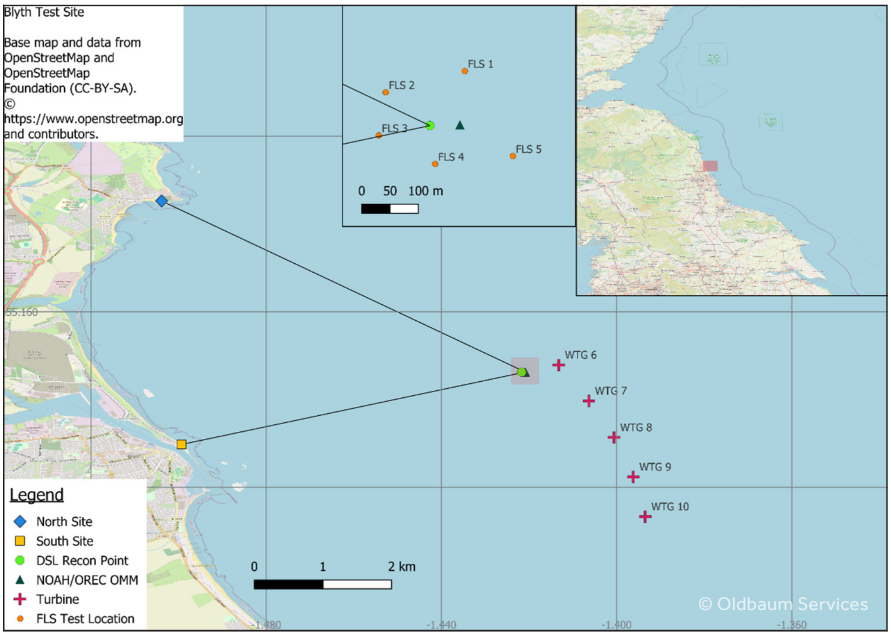

Figure 1: Setup of C-TEST test facility next to the NOAH met mast in close to Blyth, Northumberland, UK

Figure 2: Scanning lidar test pad at C-TEST South site. NOAH is seen next to the wind turbine to the left

site locations relative to the NOAH met mast, which served as the reference. It should be noted that NOAH has already been extensively used for performance verification testing of floating lidar systems (FLS), as indicated in the upper part of the map, both before and in parallel with the implementation of C-TEST.

The C-TEST North Site was established with support from the Newbiggin Maritime Centre, using its rooftop for the installation of the measurement equipment. The South Site is an autonomous container-based solution, as shown in Figure 2.

NOAH provides a highly valuable reference, not only because it delivers high-quality data at the point of interest, including a reference vertically profiling lidar at the base of the 100 m met mast for measurements at even greater heights, but also because it has provided offshore reference conditions for more than ten years. This has enabled a detailed understanding of the site and its specific climatology.

To complement this, the recently established C-TEST has added additional atmospheric measurement equipment, including a ceilometer, microwave radiometer and vertically staring Doppler lidar instruments.

Dual-scanning lidar performance verification

As part of the R&D project 'NEMO – New methods for turbulence measurements and models in offshore wind'[3], funded by the Fraunhofer-Gesellschaft within the 'International Cooperation and Networking' (ICON) programme, we had the opportunity to trial three scanning lidars of type Vaisala 400S in a performance verification test at C-TEST between April and August 2025.

The devices were set up in a triangle defined by the C-TEST geometry, with a distance of approximately 6 to 7 km between each scanning lidar and the NOAH meteorological mast to the east. A similar distance separates the north and south test pads, both located onshore directly at the coast. At the north pad, we installed two scanning lidar devices of the same type but from different generations. Combined with the 400S located on the south pad, these formed a dual-scanning lidar pair.

The results represent the first publicly presented findings of this kind at this distance. They confirm that DSL systems are capable of providing accurate and precise wind resource data at these distances, see Figure 3. The wind speed correlation with the met mast data is comparable to that of an FLS typically installed in close proximity to the met mast. This is confirmed by the observed regression parameters, which serve as key performance indicators (KPIs) and lie well within the acceptance criteria of the 'Offshore Wind Accelerator (OWA) Roadmap for the commercial acceptance of floating lidar technology'[4].

The same applies to the TI data, see also Figure 3, which show good correlation with the met mast reference. Performance metrics including Mean Bias Error (MBE), Root Mean Squared Error (RMSE) and Representative TI Error indicate a slight underestimation of TI by the DSL. However, performance remains acceptable within 1% mean bias and 1.5% representative TI error, thresholds often regarded as suitable acceptance criteria for both FLS and DSL technology.

Accurate measurement in extreme weather conditions

While the mean performance of a wind measurement device is typically assessed using bin averaged quantities, its ability to capture extreme events can be studied by examining time series data for individual events in greater detail. During the NEMO measurement campaign, we observed the effects of a major storm named Floris by the UK Met Office[5].

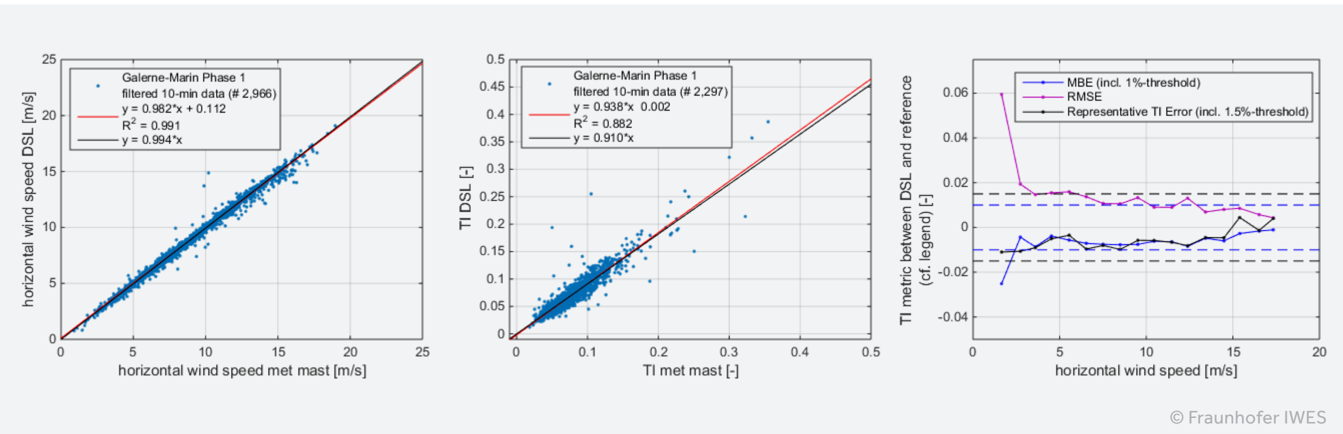

Figure 3: Results of DSL performance verification test for 10-min mean wind speed and TI, for one of the trialled DSL pairs

The results presented here represent a major step forward in the global adoption of DSL technology in the offshore wind industry.

Figure 4 shows the wind time series for the Floris period obtained from DSL, NOAH and ERA5[6] reanalysis data, all at a reference height of approximately 100 m. The DSL data from devices installed at the coast match the met mast reference very closely, with a deviation of less than 1.3%, which is well below the wind speed reference uncertainty of the met mast. ERA5, by contrast, shows a considerable underestimation of the extreme event.

This observation confirms that DSL technology is not only able to withstand extreme conditions reliably but can also provide accurate measurement data for comprehensive site assessment studies covering both normal and extreme conditions. This is again the first referenced observation of this measurement capability at a range of 6 to 7 km.

Key findings

In summary, the NEMO measurement campaign at the C-TEST dual-scanning lidar testing facility leads to three main conclusions.

First, the wind speed performance of DSL under conditions representative of offshore wind resource and site assessment campaigns, particularly where distances between DSL devices and the measurement point range from 5 to 10 km, is comparable to that of on-site FLS and therefore meets the needs of the offshore wind industry.

Second, DSL can also provide turbulence intensity data relevant as a site parameter for the structural design of offshore wind farms under these conditions without additional motion correction, as required for FLS, or bias correction.

Third, even extreme wind events caused by major storms can be captured by DSL, both in terms of system reliability and measurement accuracy.

These findings are highly significant for the further development of DSL technology and its acceptance within the offshore wind industry. They feed directly into ongoing standardisation efforts, including the IEC 61400-50-5 project initiative, which is currently developing and building consensus around a technical specification for the use of scanning lidar wind measurement technology.

Aligned recommendations and guidance will include, as a key component, the requirement and specification for DSL testing as implemented at C-TEST. In this way, C-TEST offers the wind industry not only a test site but also a demonstration of a concept with significant impact for future offshore wind resource assessment and siting.

In addition, C-TEST provides increasingly valuable opportunities for ongoing wind energy research and beyond, mapping wind conditions at a uniquely equipped site, which may in future be developed into a super-site for the validation of numerical models and key wind and atmospheric datasets.

This development and achievement would not have been possible without efficient public and private funding, the use of key national infrastructure and the support of community institutions such as the Newbiggin Maritime Centre. Innovation and standardisation of new methods depend on the interplay between the provision of innovative solutions, their thorough implementation and testing, and R&D funding that provides the resources needed to gather the evidence required for industry adoption and acceptance.

We believe the results presented here represent a major step forward in the global adoption of DSL technology in the offshore wind industry.

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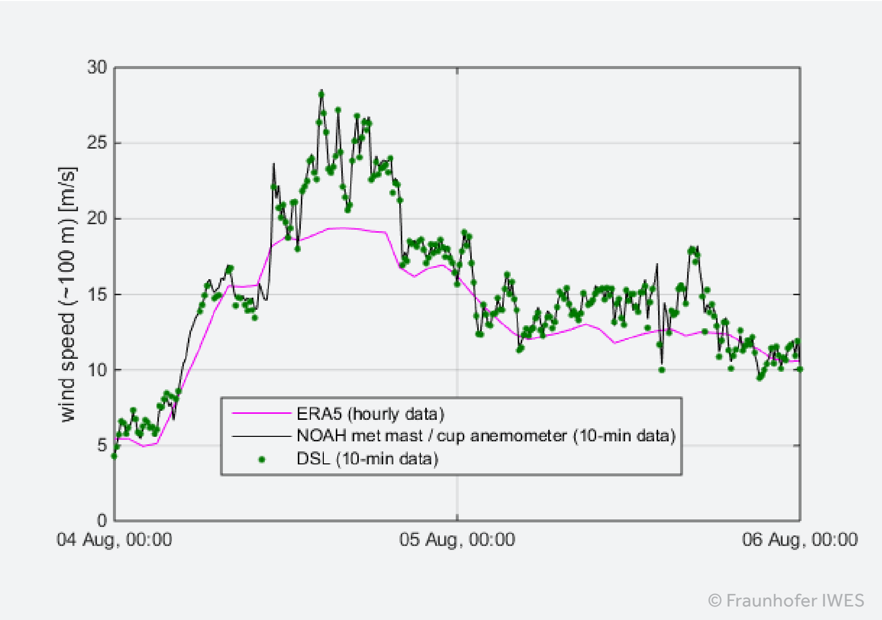

Figure 4: Storm event Floris in August 2025, as captured by DSL, NOAH met mast and ERA5 reanalysis data

References

[1] https://www.nedo.go.jp/english/ZZFF_00002.html

[2] https://www.carbontrust.com/news-and-insights/news/owa-globe-measurement-campaign-extended-to-bolster-data-and-analysis-on-global-blockage-effect-in-offshore-wind-farms

[3] https://www.iwes.fraunhofer.de/en/research-projects/current-projects/nemo.html

[4] https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/accelerator-roadmap-for-the-commercial-acceptance-of-floating-lidar-technology

[5] https://www.metoffice.gov.uk/about-us/news-and-media/media-centre/weather-and-climate-news/2025/amber-warning-in-force-as-storm-floris-impacts-uk

[6] ERA5 is the fifth generation reanalysis provided by the European Centre for Medium-Range Weather Forecasts (ECWMF) – cf. ERA5 hourly data on single levels from 1940 to present