FLS200 as a Golden Floating Lidar

A verification campaign case study

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Introduction

The FLS200 is a floating LiDAR system produced by EOLOS Floating Lidar Solutions, which has been certified with stage-3 full commercial maturity. It mounts a ZX300M LiDAR provided by ZX Lidars and several other metocean instruments.

A golden Lidar is one that has been fully qualified, demonstrated to have excellent performance and therefore considered to be a reliable reference for validation campaigns. This concept is commonly used for fixed Lidars, but could it also be applied to floating Lidars? This study aims to answer this question by analysing the effect of using a floating Lidar as a reference in an offshore Lidar verification campaign.

To obtain stage 3 certification, EOLOS conducted a 3-month validation campaign using two FLS200 collocated units, which were tested against the met mast of the National Offshore Anemometry Platform (NOAH) in the UK. Both these units were fully qualified and characterized according to IEC standards. Therefore, they are eligible to be used as reference themselves as golden floating Lidars.

The aim of this work is to assess the impact on the uncertainty computation of using an FLS200 unit as reference instead of the met mast. This validation campaign is used to that end as a case study.

Being able to use the FLS200 as a reliable reference would greatly simplify the validation process of other floating Lidar units as they could be verified directly at the deployment site. This would reduce operational costs and times, and allow to validate the unit in environmental conditions that match the end use case.

Uncertainty Computation Methods

There are currently two guidelines that are being followed in the offshore wind industry to compute the classification and calibration uncertainty for floating Lidar systems (FLS). The IEC 61400-12-1 standard [1], which describes the calibration and classification requirements for remote sensing devices in wind energy applications in general; and the Lidar Uncertainty Standard Review (LUSR), which includes a review of uncertainty estimation when using Lidars [2]. This study will present uncertainty computation results according to both frameworks.

Classification Uncertainty

The classification uncertainty assesses the uncertainty in measurement caused by environmental variations during the specific measurement campaign (SMC) compared to the verification campaign. The formula used to calculate the classification uncertainty of the FLS is the following.

$$U^2_{class,FLS_i} = \left(\frac{v_i}{100}\right)^2 \sum_{j=1}^{M} \left(m_{FLS_j} |\bar{x}_{SMC,j,i} - \bar{x}_{ver,j,i}|\right)^2. \tag{1}$$

Where, for each wind speed bin i,

- U_{class,FLS_i} is the classification uncertainty of the FLS for the SMC.
- M is the number of sensitive environmental variables for the FLS type.
- m_{FLS_j} is the regression slope describing the sensitivity of the FLS to the environmental variable j.
- $\bar{x}_{SMC,j,i}$ and $\bar{x}_{ver,j,i}$ are the mean value of the sensitive environmental variable j as present in the SMC and the verification campaign, respectively.

Calibration Uncertainty

The calibration uncertainty is related to how similarly the verified and the reference device measure. The calibration uncertainty of the FLS using Ref as a reference, is computed through the following formula.

$$U^2_{cal,FLS_i}(Ref) = U^2_{cal,Ref_i} + U^2_{class,Ref_i} + U^2_{dev,FLS-Ref_i}. \tag{2}$$

Where U_{cal,Ref_i} is the calibration uncertainty of the reference, U_{class,Ref_i} is the classification uncertainty of the reference computed with Eq. 1, and $U_{dev,FLS-Ref_i}$ is the deviation term between the FLS and the reference, which depends on the standard, as described in Eq. 3.

$$U^2_{dev,FLS-Ref_i} = \begin{cases} \sigma^2_{FLS_i}/N_i + \Delta v_i^2, & \text{for IEC 61400-12-1} \\ \sigma^2_{dev_i}/N_i \quad \text{for } \Delta v_i < \sqrt{U^2_{cal,Ref_i} + U^2_{class,Ref_i}}, & \text{for LUSR,} \end{cases} \tag{3}$$

where $\sigma_{FLS_i}/\sqrt{N_i}$ is the standard uncertainty of the FLS measurements, Δv_i is the mean deviation of the FLS and reference measurements, and $\sigma_{dev_i}/\sqrt{N_i}$ is the standard uncertainty of the deviation of the FLS and reference measurements.

Case Study Description (FLSa - FLSb - mast)

The verification campaign described in the introduction consists of two FLS200 units, from here on referred to as FLSa and FLSb, which are measuring concurrently next to a met mast. For this study, it is useful to contemplate three distinct campaigns: verification of FLSa against the met mast, verification of FLSb against the met mast, and verification of FLSa against FLSb. The aim is to compare the uncertainty of the first campaign versus that of the latter. To that end, the computation strategy depicted in Fig. 1 is followed.

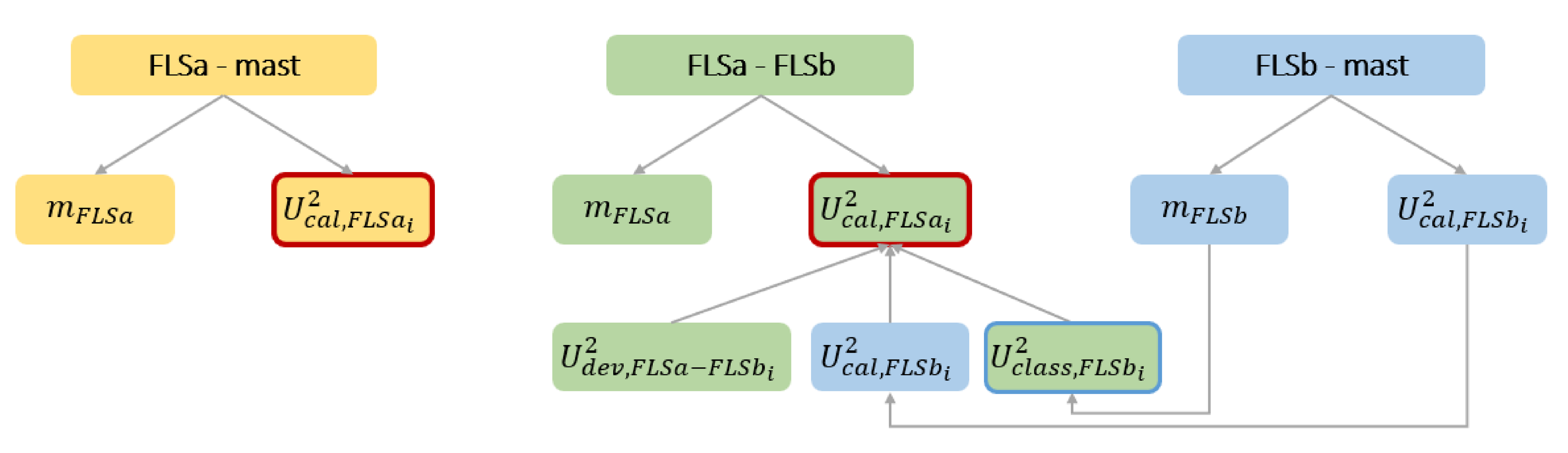

Figure 1: Computation method flowchart.

The FLS200 type is only sensitive to the wind shear exponent, and therefore the sensitivity slopes m_{FLSa} and m_{FLSb}, are determined solely for that variable. Additionally, note that the calibration uncertainty of the mast is known and its the classification uncertainty is assumed to be 0.

Results

The regression slopes describing the sensitivity of the FLS200 to shear exponent are shown in Fig. 2, for each of the three considered campaign combinations. The slopes, and therefore the sensitivity, of FLSa (blue) is greater than that of FLSb (yellow) when using the mast as a reference. That is a reason why FLSb has been chosen to be the golden Lidar candidate. When using FLSb as a reference (red), the slope of FLSa is significantly reduced compared to when using the met mast (blue). The reason for that is that the tested unit and the reference are of the same type and therefore they have a similar sensitivity to the same variables. Consequently, the likelihood of detecting the responsiveness of the tested unit to those variables diminishes. However, the classification uncertainty of FLSb will be well represented in the final uncertainty budget by the combination of two terms: the classification uncertainty of the reference U_{class,FLS_b} and the classification uncertainty of the tested unit U_{class,FLS_a}, related to yellow and red lines respectively through Eq. 1.

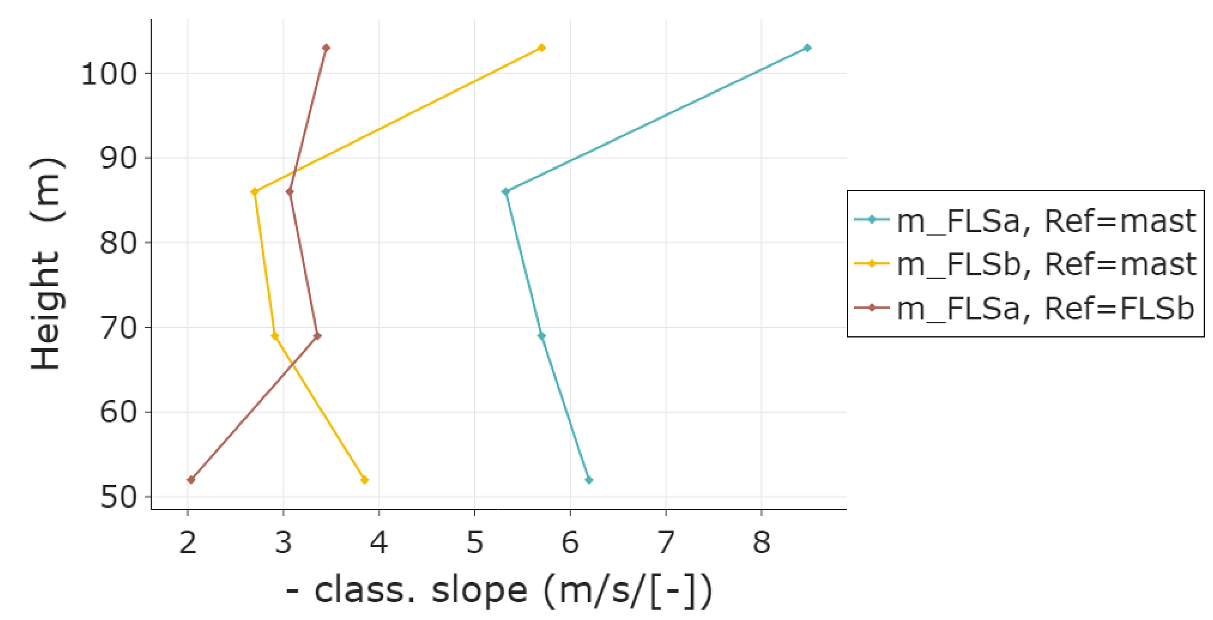

Figure 2: Regression slopes with inverted sign, describing the sensitivity to shear exponent of FLSa and FLSb using the mast and FLSb as a reference, for each measuring Lidar height.

The calibration uncertainty sources of FLSa at 103 m from Eq. 2 are shown in Fig. 3. Each column shows the results of using different standards, IEC 61400-12-1 (left) and LUSR (right), and the first two rows show the results of using different references, met mast (top) and FLSb (middle). The bottom row shows a direct comparison of the different references.

By comparing the left and right column, it can be seen that the calibration uncertainty is smaller for LUSR compared to the IEC 61400-12-1 standard, due to the deviation term $U_{dev,FLSa-Ref_i}$. This is a known outcome of the LUSR method.

The bottom row shows that the resulting calibration uncertainty is comparable when using the met mast or the FLSb as a reference. However, in some wind speed bins, using the FLSb results in lower uncertainty. This is particularly notable when following the IEC 61400-12-1 standard. The reason for this is that the deviation term $U_{dev,FLSa-Ref_i}$ is lower for the FLSb reference compared to the mast, as evident from the comparison of the top and middle row. This can be attributed to the fact that deviations between instruments of the same type (FLSa and FLSb) are generally expected to be lower than those between instruments of different types (FLSa and mast).

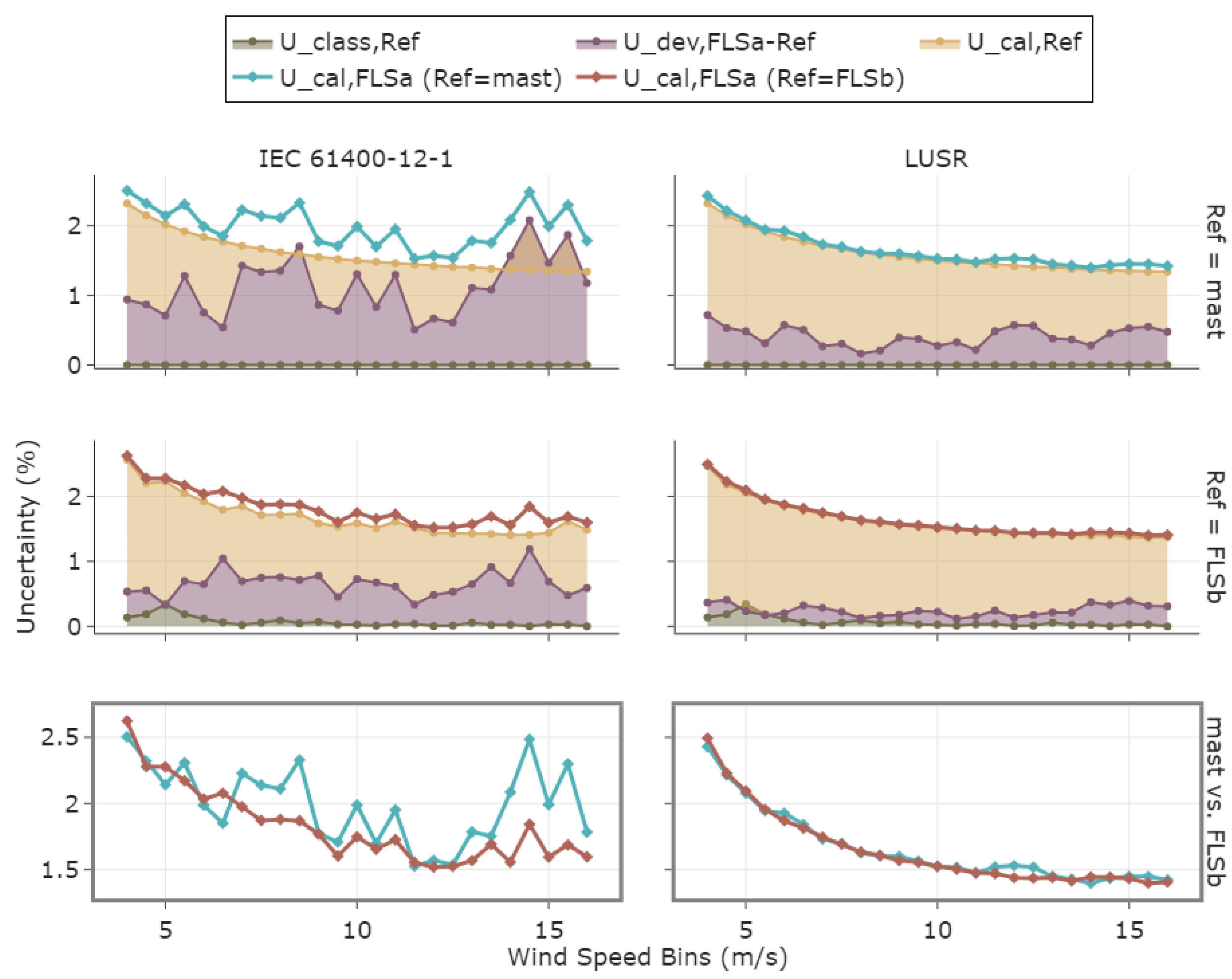

Figure 3: Calibration uncertainty sources of FLSa at the height of 103 m for each wind speed bin. Using IEC 61400-12-1 standard (left) and LUSR (right); using the met mast (top) and FLSb (middle) as a reference, and a comparison of both (bottom).

Conclusions

This study suggests that the FLS200 type can be utilized as a reference in verification campaigns, serving as a golden floating Lidar. In a specific case study where two FLS200 units are compared to a met mast, it is demonstrated that using a golden floating Lidar results in either equal or lower final calibration uncertainty for most wind speed bins compared to a traditional met mast. The classification uncertainty is taken into account by considering both the classification uncertainty of the golden floating Lidar and that of the tested unit.

Although the utilization of a golden floating Lidar can reduce overall uncertainties due to lower deviations between instruments of the same type, it still maintains similar levels of uncertainty as those obtained with a met mast. This ensures the cumulative nature of uncertainties and provides robustness to the technology.

The acceptance of floating golden Lidars by the industry would represent a paradigm shift in validation campaigns. This technology would enable validations to be carried out directly at the deployment site, leading to lower validation costs and shorter campaign timelines. Additionally, it would allow for a more accurate characterization of the unit's performance under realistic environmental conditions.

References

[1] IEC 61400-12-1. Wind power generation systems - part 12-1: Power performance measurement of electricity producing wind turbines. 2017.

[2] J. Gottschall M. Courtney J. Hughes C. Mallinson B. Gribben, E. Burnett. Lidar uncertainty standard review methodology review and recommendations. 2028.