

▶ **ROBUST ACTIVE WAKE CONTROL**
WIND DIRECTION MEASUREMENT UNCERTAINTY DRIVEN
ANALYSIS IN A SENSOR-EQUIPPED WIND FARM

MARCO TURRINI, NASSIR CASSAMO, H.LINKS, K. HERMANS, L. LAAS

18TH JANUARY 2023

› **ROBUST ACTIVE WAKE CONTROL**

SENSOR ASSISTED WIND FARM OPTIMIZATION (SAWOP)

WHAT IS SAWOP

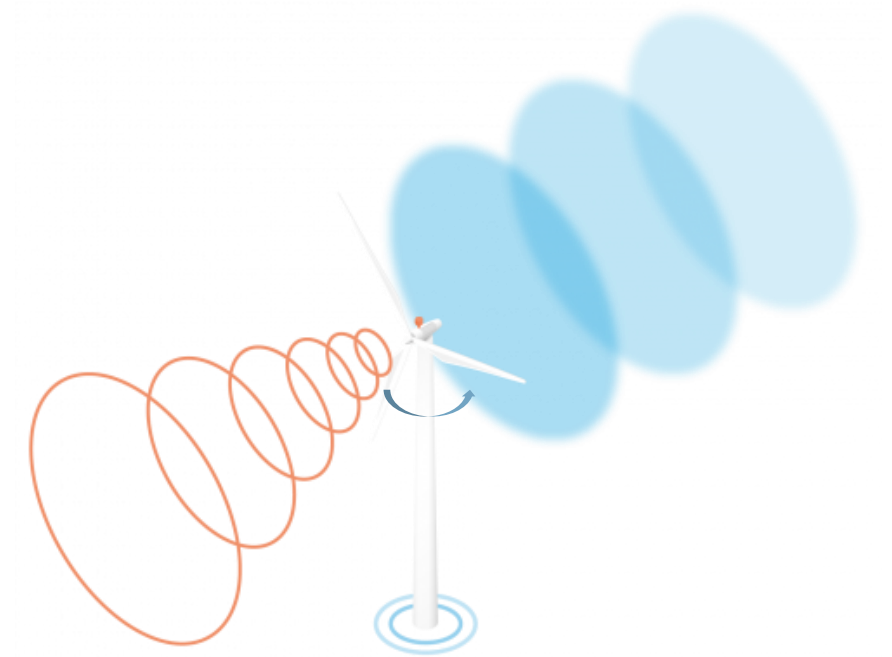
ROBUST ACTIVE WAKE CONTROL

WIND DIRECTION UNCERTAINTY

ROBUST CONTROL EFFECTS – YAW

ROBUST CONTROL EFFECTS – POWER

DISCUSSION



ROBUST ACTIVE WAKE CONTROL

SENSOR ASSISTED WIND FARM OPTIMIZATION (SAWOP)

Klim Fjordeholme Wind Farm (Danmark, onshore)

- 21 Turbines
- 1. 8 iSpin anemometers
- 2. Nacelle LiDAR Nb1
- 3. Nacelle LiDAR Nb2
- 14 months of measurements



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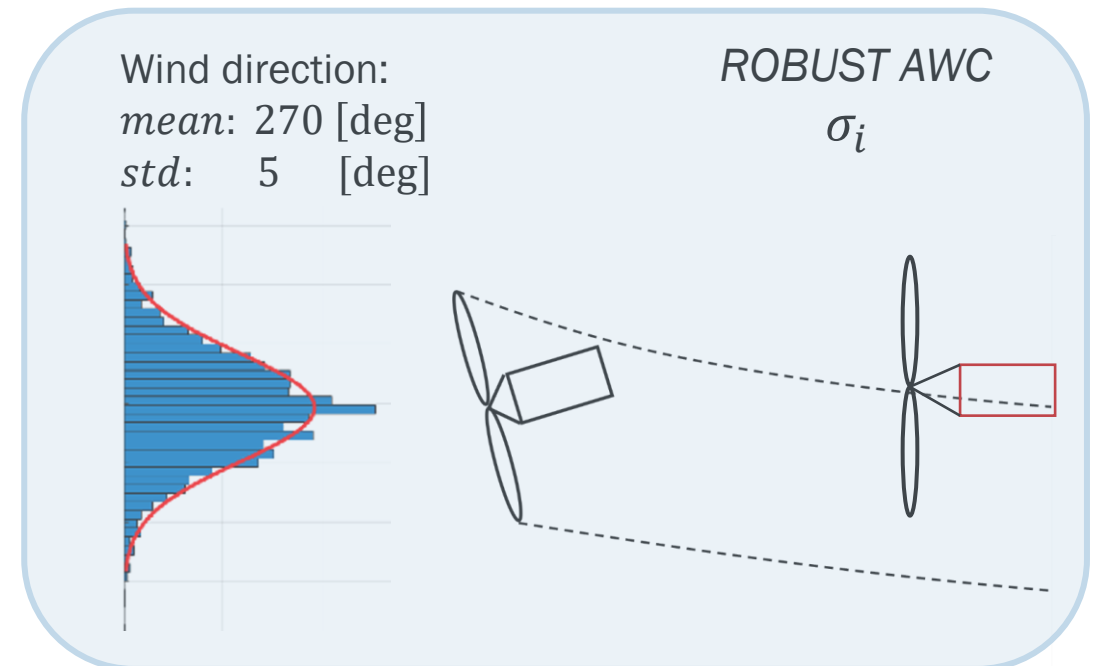
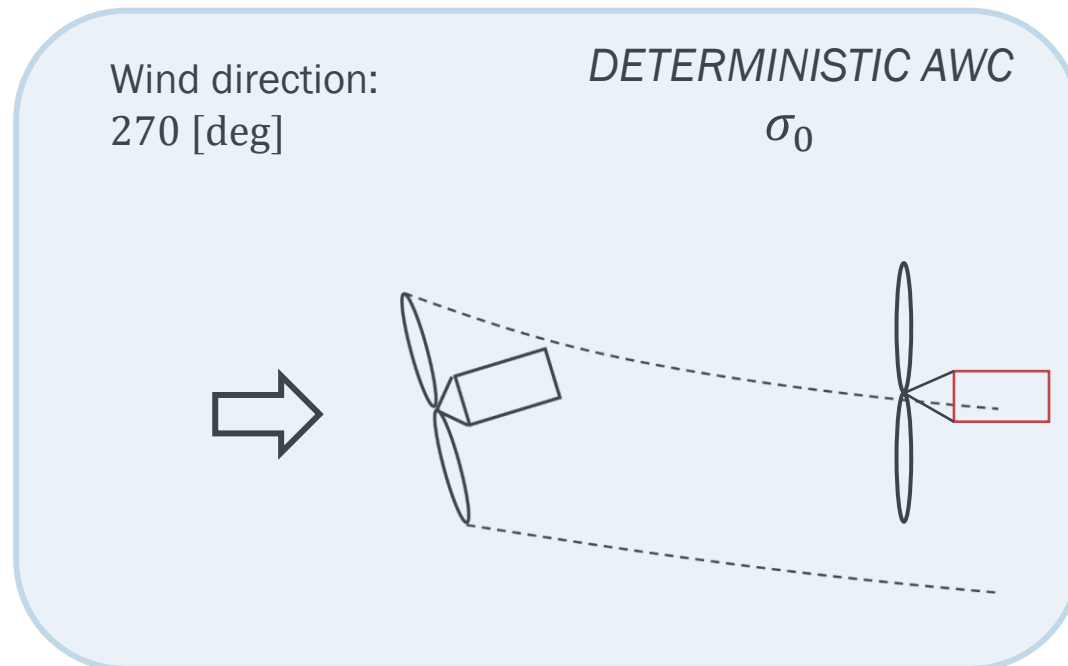
OVERVIEW

Wake redirection strategies rely on a number of measurable quantities: wind direction, speed, yaw angle, turbulence...

Measurements are uncertain due to both the variability of these quantities and the accuracy of the sensors used.

➡ Robust AWC is a technique that aims to **consider such uncertainty within the design phase of the controller.**

Past research has shown that the power gain is most sensitive to the variability of the wind direction. Therefore, only robustness for the wind direction was considered in this work.



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WIND DIRECTION UNCERTAINTY QUANTIFICATION – METHOD

To simulate the slow dynamics of the turbines' yaw controllers the analysis is performed over blocks of 10 minutes windows to match commonly used standards from other sensors. (a)

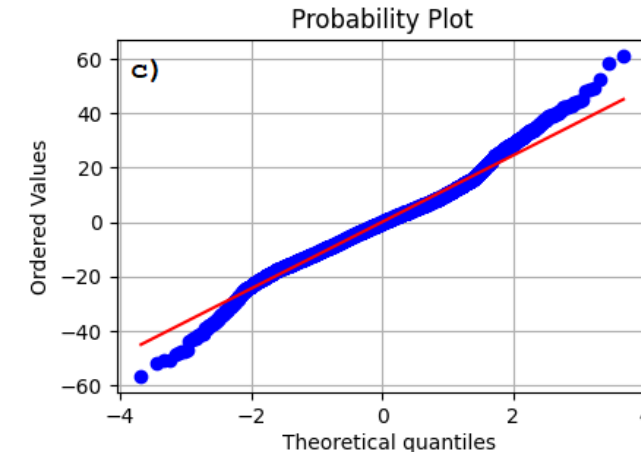
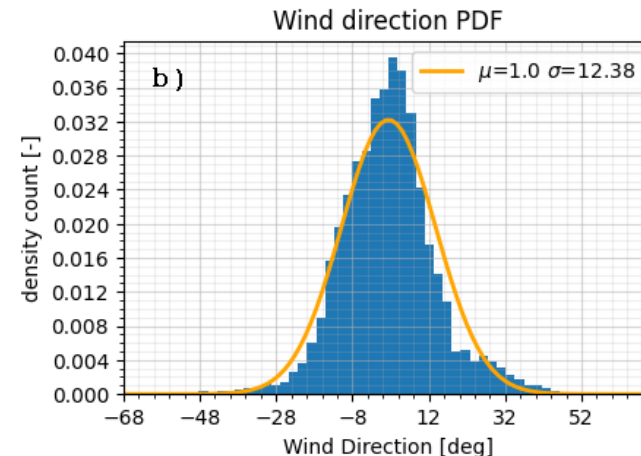
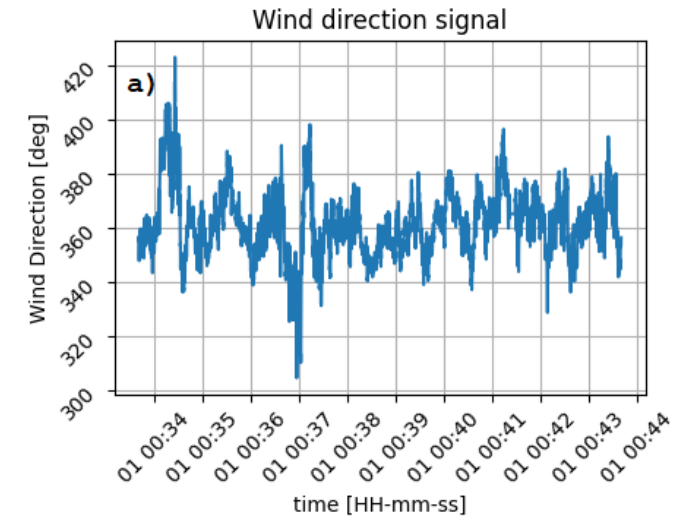
The high-frequency signal is partitioned and then normalized by the circular mean .

Then, a normal density function is fitted to the zero-average transformed signal. (b,c).

The circular standard deviation value is also computed to validate the value obtained by the fitting.

$$\mu_{circ} = \arctan \left(\sum_{i=1}^N \sin(WD_i), \sum_{i=1}^N \cos(WD_i) \right)$$

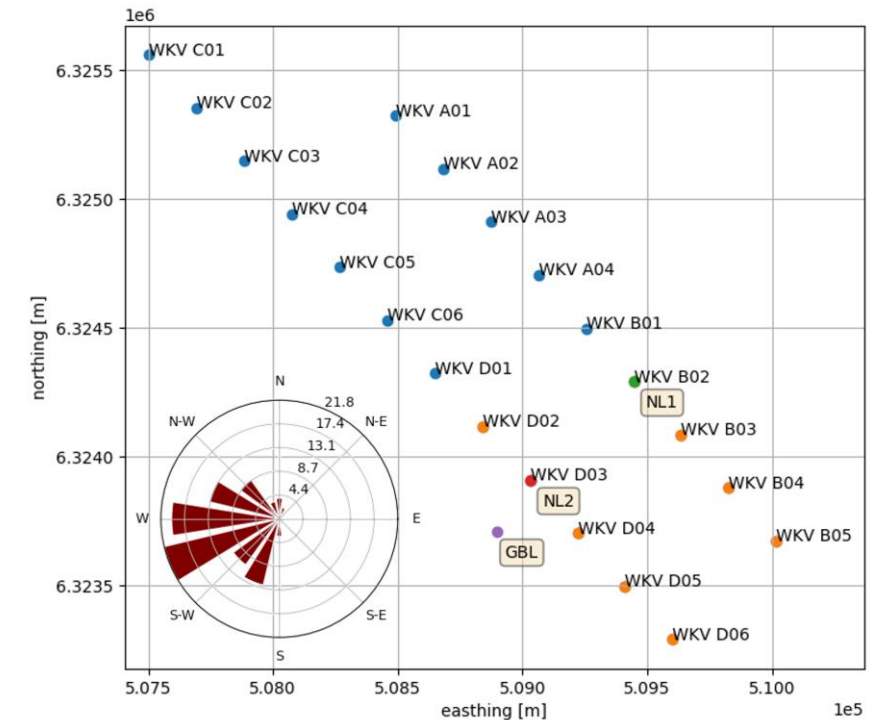
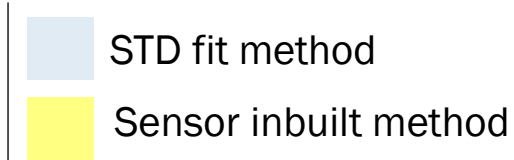
$$\sigma_{circ} = \sqrt{\frac{1}{N} \sum_{i=1}^N (WD_i - \mu_{circ})^2}$$



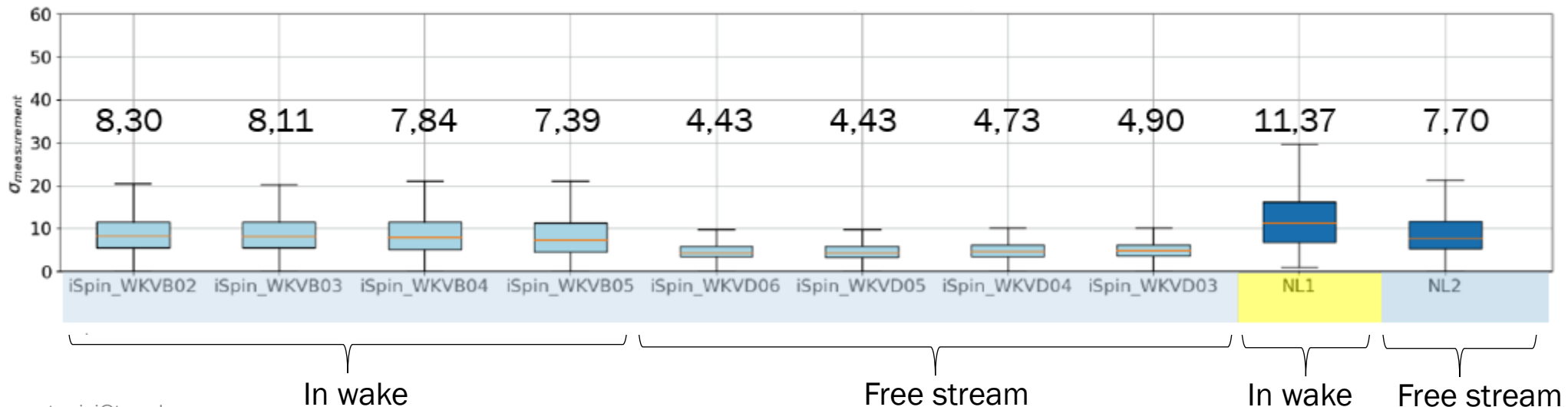
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WIND DIRECTION UNCERTAINTY QUANTIFICATION – RESULTS

In the analyzed dataset: values in the range of 4 – 11 degrees, with peaks for **waked** sensors.



South West sector (160-300 [deg])



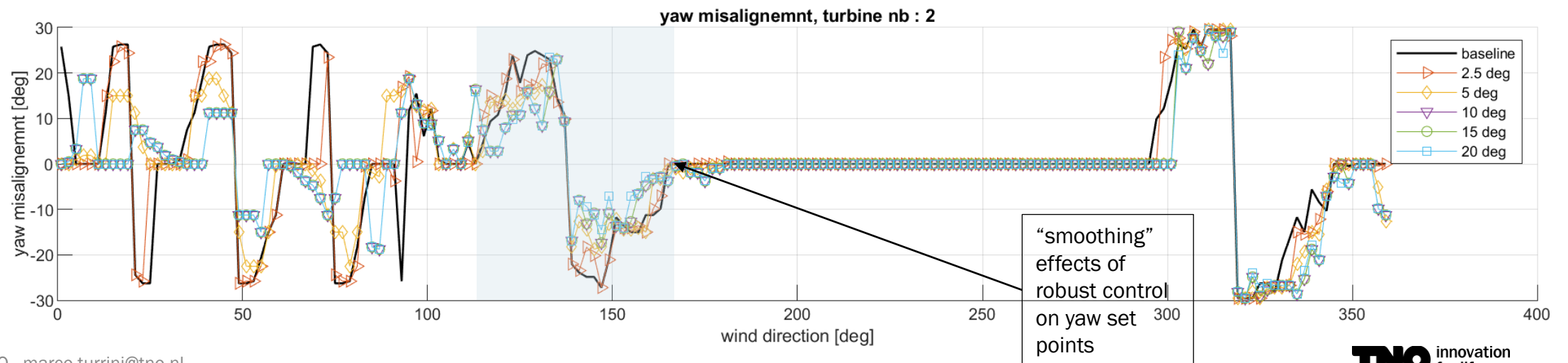
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ROBUST OPTIMIZATIONS – YAW

Robust control effect:

- less total yaw (negative yaw magnitude ratio)
- Less variations in yaw per wind direction change (negative variation ratio)

		$\sigma = 2.5$ [deg]	$\sigma = 5$ [deg]	$\sigma = 10$ [deg]	$\sigma = 15$ [deg]	$\sigma = 20$ [deg]
Yaw magnitude* ratio	[%]	-3.94	-14.14	-21.59	-21.78	-22.78
Yaw variation** ratio	[%]	-8.25	-25.13	-22.13	-20.43	-19.20

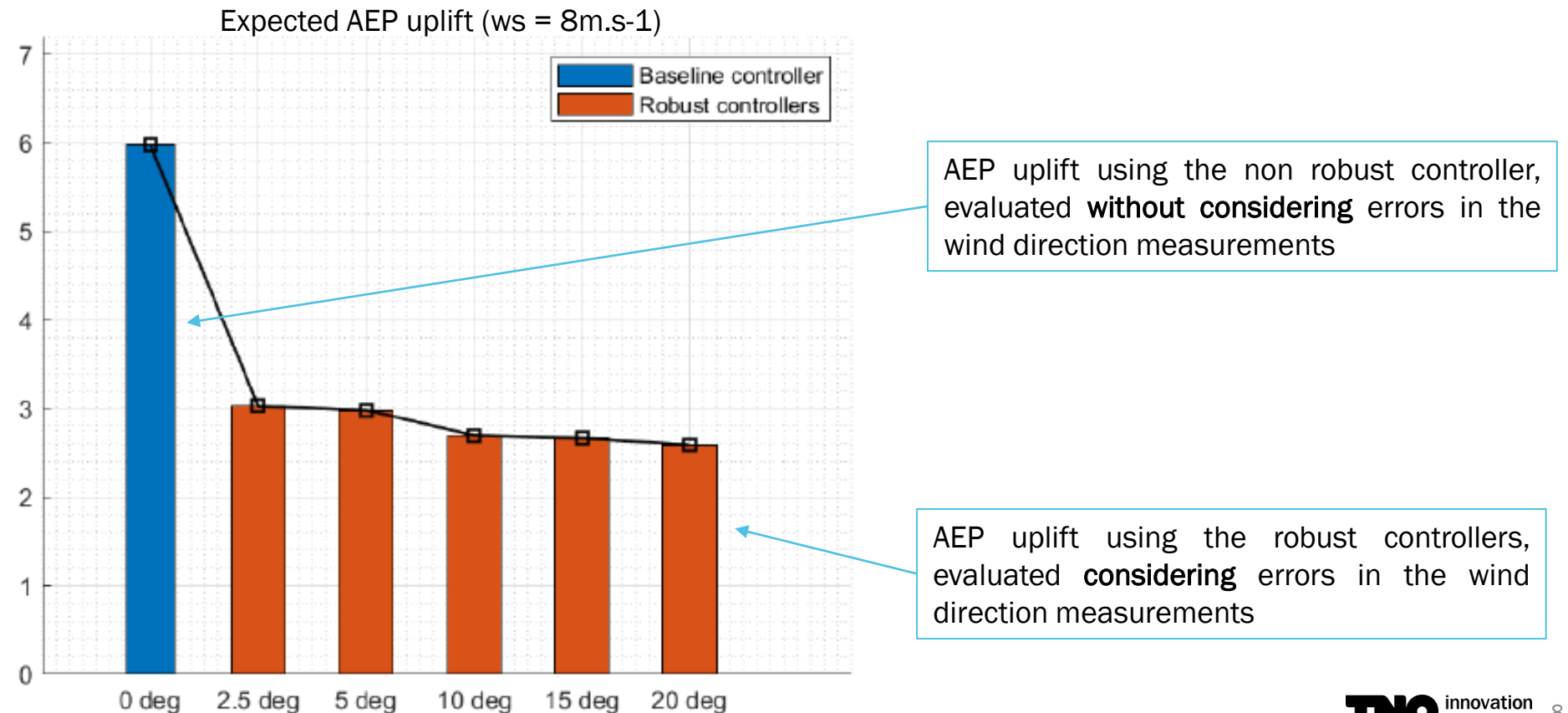


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ROBUST OPTIMIZATIONS – POWER PERFORMANCE

The results are presented in terms of total farm AEP uplift if to consider **only one wind speed bin: 8m.s⁻¹**

As the uncertainty value used in the controller design, the expected AEP uplift strictly decreases.

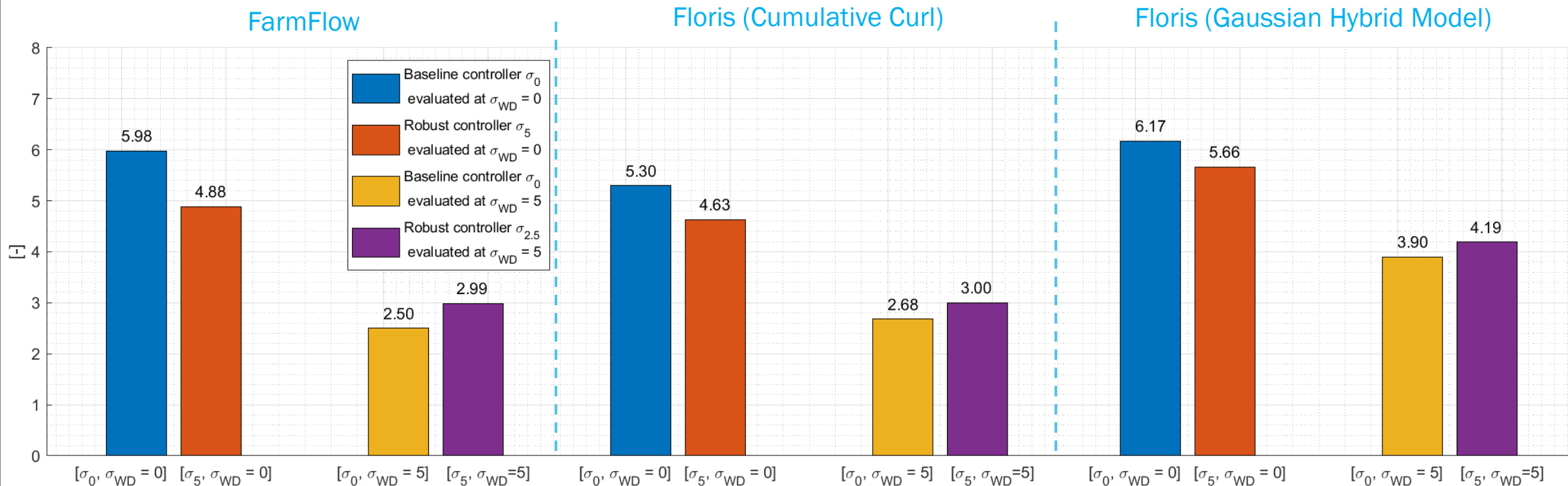


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ROBUST OPTIMIZATIONS – POWER PERFORMANCE

The baseline controller σ_0 is achieving higher AEP gains (21% increase) if compared to the robust controller σ_5 when no wind direction errors are considered ($\sigma_{WD} = 0$),

When wind measurements errors are considered, the AEP uplift is higher (19% increase) under effect of a robust controller σ_5



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OBSERVATIONS, CONCLUSIONS AND DISCUSSION

- The data from 8 iSpins and 2 Nacelle LiDARS was used to obtain an estimate of the uncertainty of the wind direction measurements during operations. STD in the range of 4-11 degrees were observed.
- It was seen that the consideration of uncertainty, in the wind direction during the design of the controllers σ_i impacted the farm operation in :
 - A decrease in total yaw misalignment angles.
 - A decrease in total yaw change per wind direction set point change.
 - Lower AEP gain than standard AWC controller σ_0 if evaluated with no errors in the wind direction measurements
 - Higher AEP gain than standard AWC controller σ_0 if evaluated with errors in the wind direction measurements
- Work follow ups:
 - Effect on loads.
 - Dynamic simulations (and control).
 - Motion uncertainties (floating wind).
- Less focus on modeling and more on uncertainty assessment using arrays of sensors to assess wind direction uncertainty ?
- Robust control has value but adds complexity in control design and sensor data treatment. How can that be standardized ?

› **THANK YOU FOR YOUR TIME – QUESTIONS?**
MARCO.TURRINI@TNO.NL

THIS PROJECT IS EXECUTED WITH SUBSIDY FROM THE
MINISTRY OF ECONOMIC AFFAIRS AND CLIMATE, NATIONAL
REGULATION EZ-SUBSIDIES, TOPSECTOR ENERGY EXECUTED
BY THE NETHERLANDS ENTERPRISE AGENCY. RVO
REFERENCE NUMBER TEHE118022.

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