University of Stuttgart
Stuttgart Wind Energy (SWE)
@ Institute of Aircraft Design

Recommendations for load validation of an offshore wind turbine with the use of statistical data – experience from alpha ventus

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SWE
WindForS Windenergie Forschungscluster

RAVE
RESEARCH AT ALPHA VENTUS
Eine Forschungsinitiative des Bundesumweltministeriums

Project Partners

SWE Stuttgart Wind Energy @ Institute of Aircraft Design

Institut für Aerodynamik und Gasdynamik IAG

ForWind Center for Wind Energy Research

Adwen AN AREVA GAMESA COMPANY

SENVION wind energy solutions

Work Packages

OWEA Loads

- **A. Load analysis and probabilistic load description**
- **B. Load-reducing control and load monitoring**
- **C. Design conditions for future wind turbines**

Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Bundesministerium für Wirtschaft und Energie

Projektträger

PtJ Projektträger Jülich Forschungszentrum Jülich

Koordination

Fraunhofer IWES

Introduction

Measurement campaigns for offshore wind turbines

- Once the design of the turbine has been certified a prototype can be built for testing.

IEC-61400 -13 Measurements of Mechanical Loads:

- “This standard is aimed at the test institute, the turbine manufacturer and the certifying body and clearly defines the minimum requirements for a mechanical loads test …”

Why do we need this?

- “In the design stage, loads can be predicted with aero-elastic models and codes. However, such models have their shortcomings and uncertainties, and they always need to be validated by measurement. “

The IEC 61400 – 13 Guideline

Open questions for offshore

Measurements

- How do we take into account the offshore environment? How do you include oceanographic measurements into the capture matrix? Should they even be included into the capture matrix?

Simulations

- How do we set up the simulation to represent the measurements taken? Do the measurement load cases (MLC) lead to a good comparison possibility with the design load cases (DLC)?

Validation

- **Is there a clear procedure for validation?**

On the subject of validation

General recommendations from Söker et al.

- Consistency of environmental conditions
- Consistency of turbine dynamic behaviour (frequencies)
- ***Consistency of turbine characteristic curves***
- ***Consistency of behaviour of loads and operational parameters (***time series ***and statistics)***
- Consistency of fatigue characteristic behaviour

[H. Söker, et al, A guideline to load validation, Wilhelmshaven: Paper presented at DEWEK 2006, Deutsche Windenergie Konferenz, DEWI, 2006.]

Methodology

Validation of computer models

GENERAL IDEA

- Use measurement data and compare it to simulation data on a statistical basis

BUT

- There are many **different offshore turbine** concepts (support structures, towers) so a general procedure is useful and necessary
- There are more **environmental effects** to take into account offshore, this leads to **large scattering**

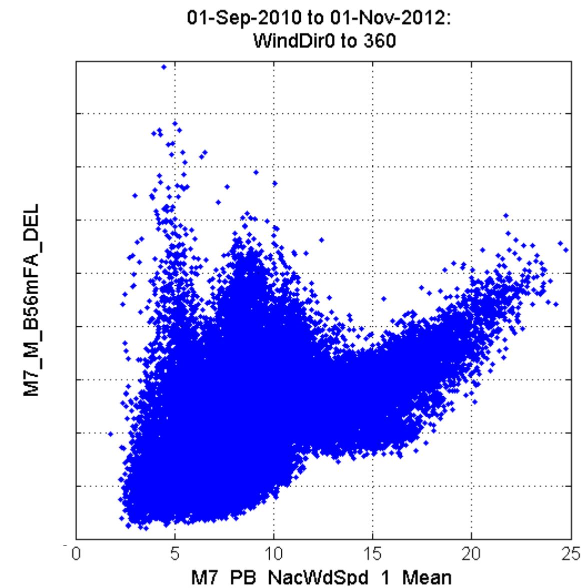


Figure: Fore-aft damage equivalent loads for case of power production

Methodology

How to go about the comparison?

Possible approaches

1. Carry out the IEC 61400-3 design load case (DLC 1.1 and 1.2) simulations for power production and show that the simulations are conservative (fatigue and maximums)

2. Use a design of experiments methodology with full factorial or Box-Behnken representation of the measured environmental statistics as input for simulations (Müller et al.[1])

3. Chose only specific range of measurement events within know boundaries and pick representative parameters as input for simulations

➡ Screened Statistical Data Comparison Method

[1: Müller, K. , Reiber, M., Cheng, P.W., 'Comparison of Measured and Simulated Structural Loads of an Offshore Wind Turbine at Alpha Ventus', Proceedings of 26th ISOPE, , Vol. 26, No. 3, Sept. 2016

Methodology

Screened Statistical Data Comparison Method

Screening of the data:

1. **List all meteorological and oceanographic parameters** needed for the validation, along with other parameters such as marine growth thickness and density.
2. Define which parameters need to be **binned**.

   E.g. wind speed.
3. Define which parameters will be **constrained**.

   E.g. only data from 5-7% turbulence intensity
4. Define which parameters are, for the purpose of the validation, constants.

   E.g. marine growth thickness or mean sea level

Methodology

Screened Statistical Data Comparison Method

Simulation parameters need to be set based on the screened data.

1. Determine a **mean value** representative of the bin or constraint

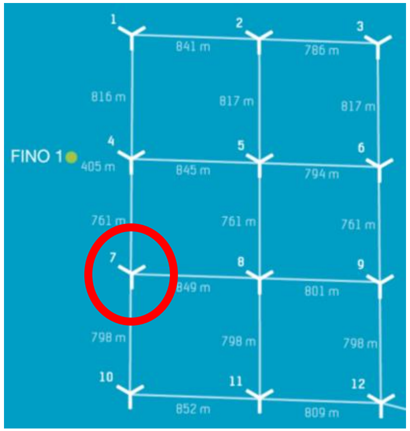
2. In the case that a bin or constraint is large, divide the constrained parameter into different mean values.

    E.g. wind wave misalignment is filtered from +60 to -60 degrees, the simulated misalignment can be +45, 0 and -45 degrees.

3. Determine the **number of seeds** that are appropriate for each simulation

Application of methodology in alpha ventus

Measurement campaign



AV7 – statistical & 50Hz data

- SCADA
- strain gauges
- accelerometers

⇨ calibration
plausibility checks

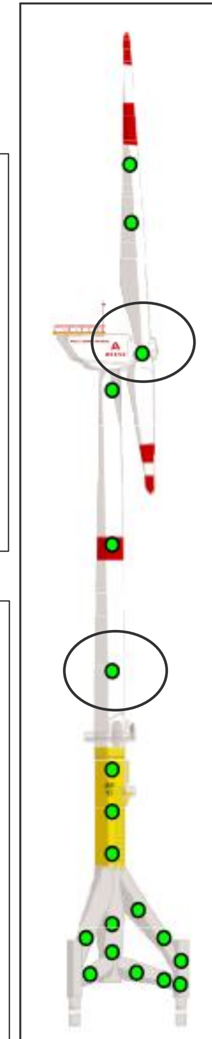
FINO1 – statistical data

Meteorological measurements

e.g. - wind speed
- wind direction
- air temperature

Oceanographic measurements

e.g. - current
- wave conditions (sig. wave height, wave length)



[Figure1: http://www.fino3.de/images/stories/alpha-ventus.jpg
Figure2: http://rave.iwes.fraunhofer.de/raveResources/projects/images/Abbildung1_tuffo.png
Figure3: http://www.dewi.de/dewi_res/fileadmin/pdf/publications/Publikations/1.3_Kuehnel.pdf]

Modeling of the turbine

SWE-Flex5 coupled with Poseidon

SWE - Flex5

- dynamic simulation of onshore wind turbines with max. 28 degrees of freedom

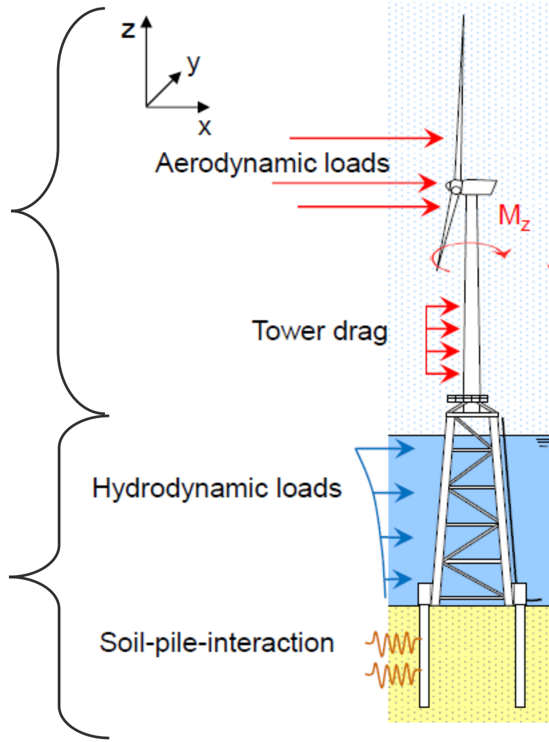
Poseidon (University of Hannover)

- linear finite element code specially designed for wave loaded space frame structures

Flex5 + Poseidon

- Integrated approach
- Coupled turbine, substructure and foundation model
- Validation model of AV04 jacket mounted turbine by Kaufer[1]

- Flex 5
- Poseidon

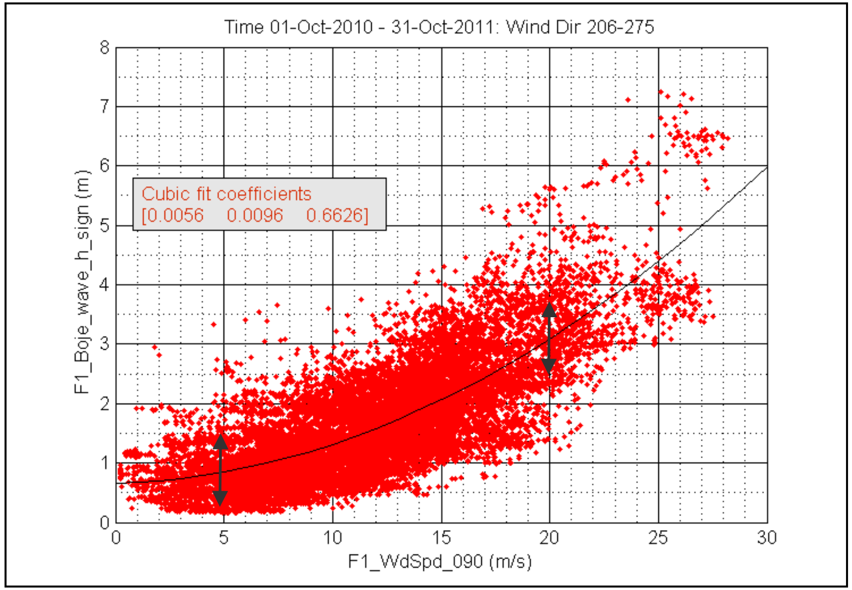


[1: Kaufer D. 'Validation of an Integrated Simulation Method using High Resolution Measurements from Alpha Ventus', ISOPE 2013, Anchorage, Alaska]

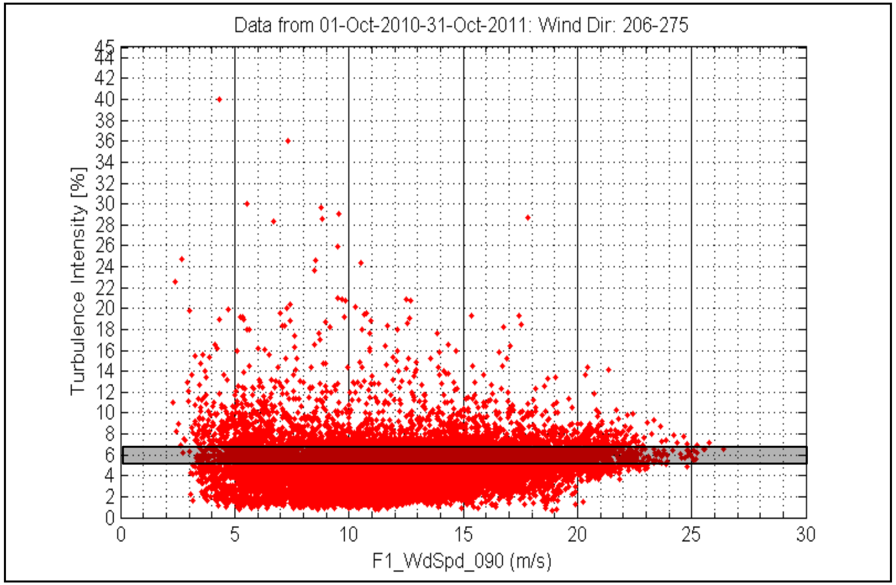
Screened Statistical Data Comparison Method

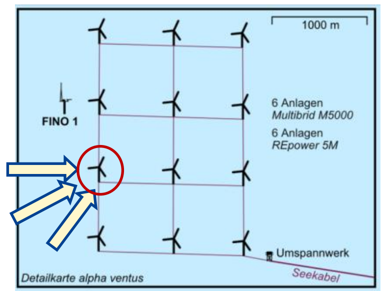
1st step: examples of screening of measured data

- Wave height



- Turbulence Intensity





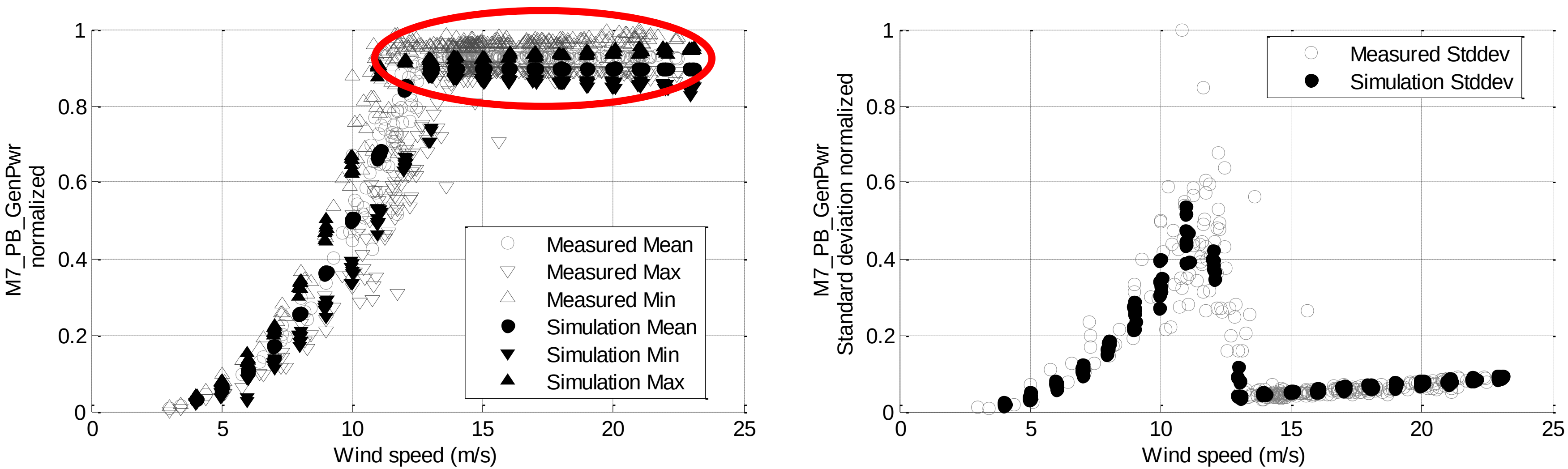
- Free flow sector

Example from alpha ventus

	Parameters	Constraint or Binning	Values for data screening	Value for simulations	Seeds
Wind condition	Wind direction	Free stream	207-275 degrees	270 degrees	-
	Mean hub wind speed	1m/s bins	3.5-23.5m/s	4-23m/s	-
	Turbulence intensity	Constrained	5.5%-6.5%	6%	9 turbulent seeds / wind bin
	Wind shear	Not binned or constrained	none	0.14 power law exponent	-
Wave conditions	Significant wave height	Constrained as function of wind speed	Bin is defined as a function of the fitting curve of significant wave height vs wind speed. The bin will be +/- 0.5 m of the fitted significant wave height value for a given wind speed	For each wind speed bin, a significant wave height value is given by the best fit curve	-
	Peak spectral period	Constrained	6-8 seconds	7 seconds	-
Wind and wave	Misalignment	Constrained	-30 to +30 degrees	-30,0, +30 degrees	3
Sea currents	Current velocity	Not binned or constrained	None	0 m/s	-
	Direction	Not binned or constrained	None	-	-
Water level	Mean sea level	Not binned or constrained	None	27m design basis	-
Air Properties	Density	Not binned or constrained	None	1.225 kg/m^3	-
Marine growth	Thickness	Not binned or constrained	None	0.05 m	-
	Density	Not binned or constrained	None	1325 kg/m^3	-
Wind/Yaw	Misalignment	Not binned or constrained	None	-5,0,+5 degrees	3
Soil parameters	Scour	Not binned or constrained	Not available	None	-
	Stiffness and Damping	Not binned or constrained	Not available	Provided by manufacturer	-

Example Results

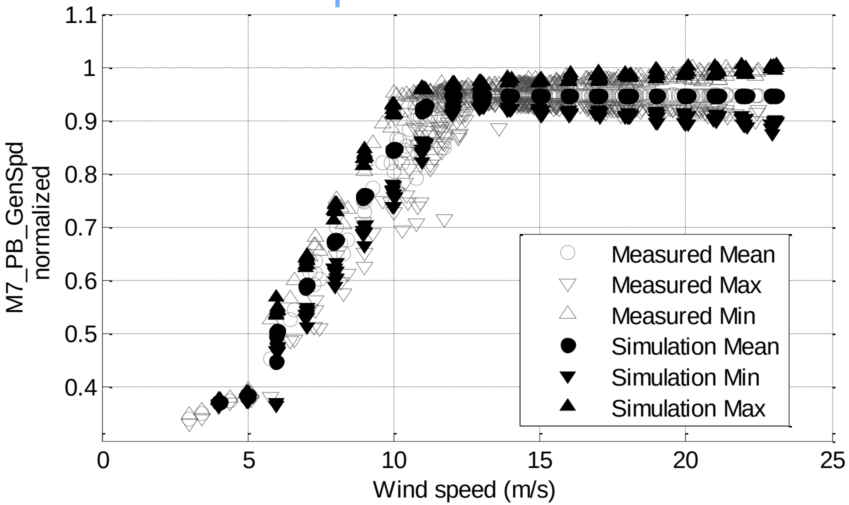
Power production

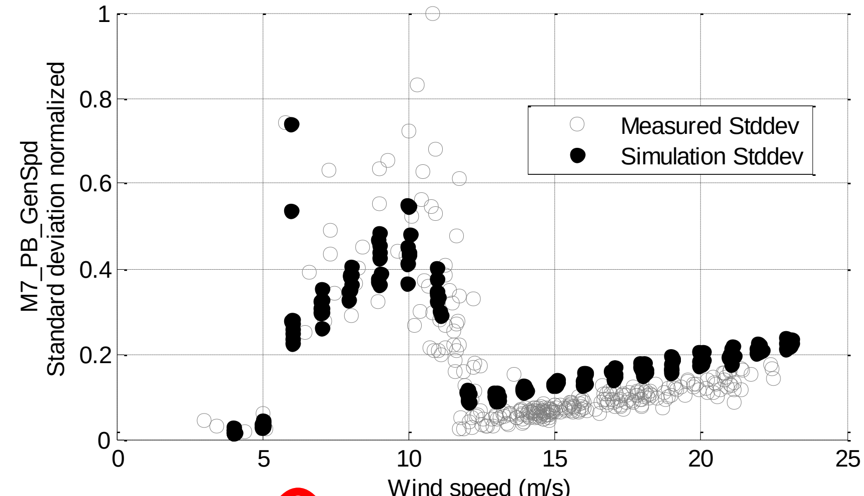


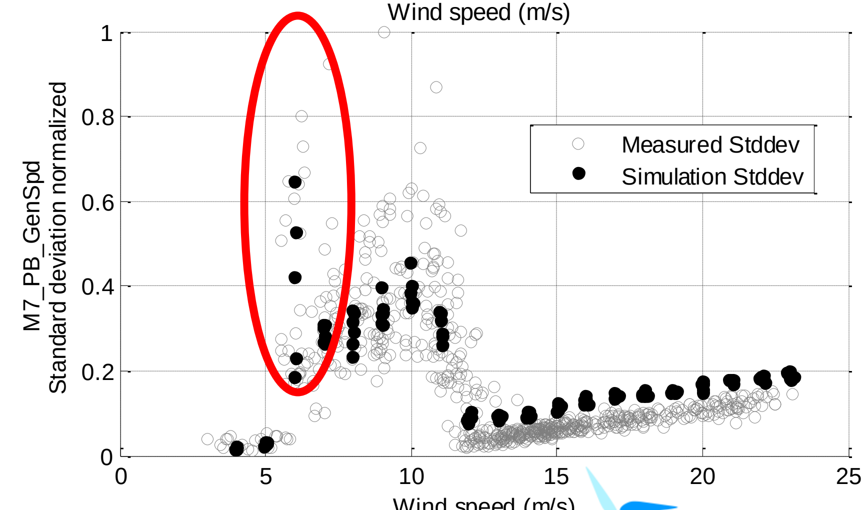
Losses dependant on location of measurement point

Example Results

Generator speed



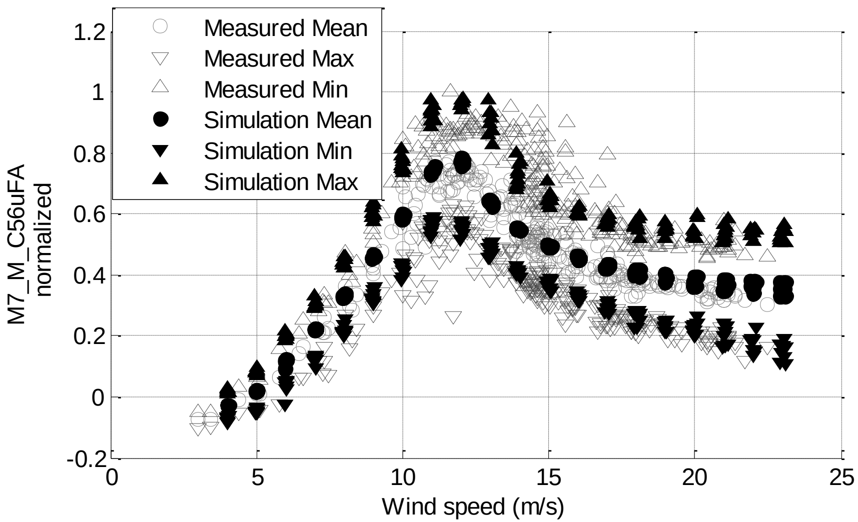


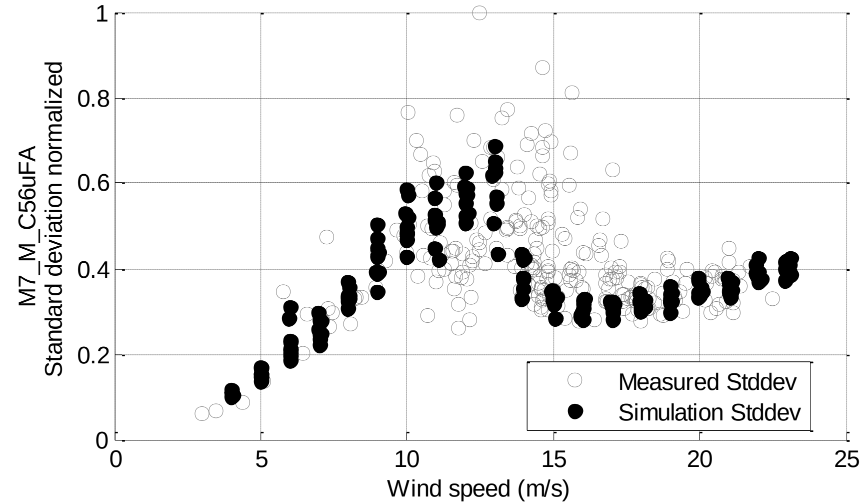


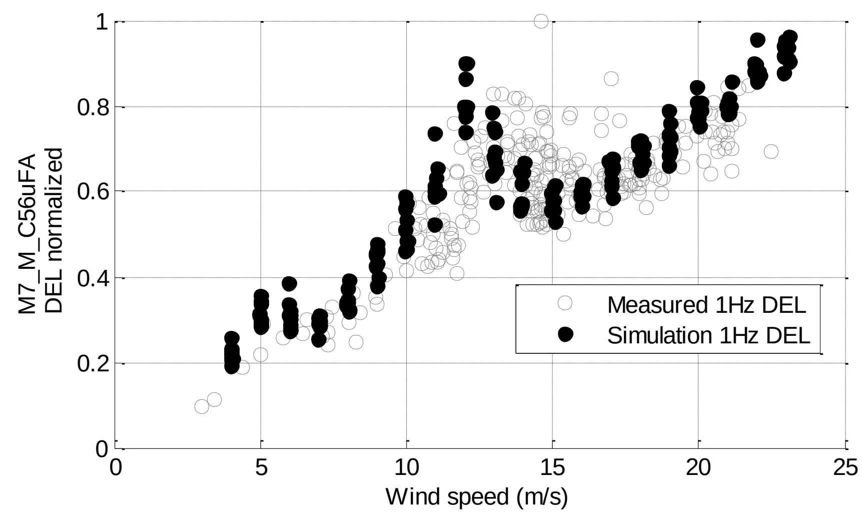
Screening without wave period restriction

Example Results

Fore-aft tower base bending moment



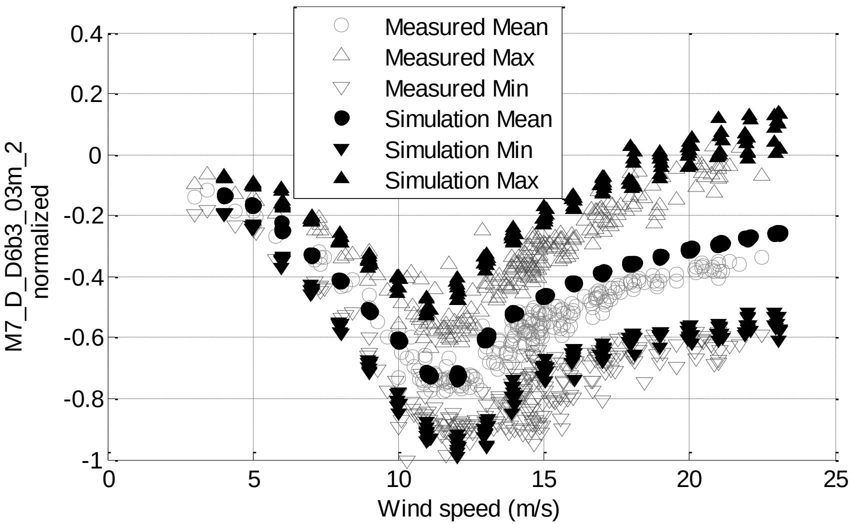


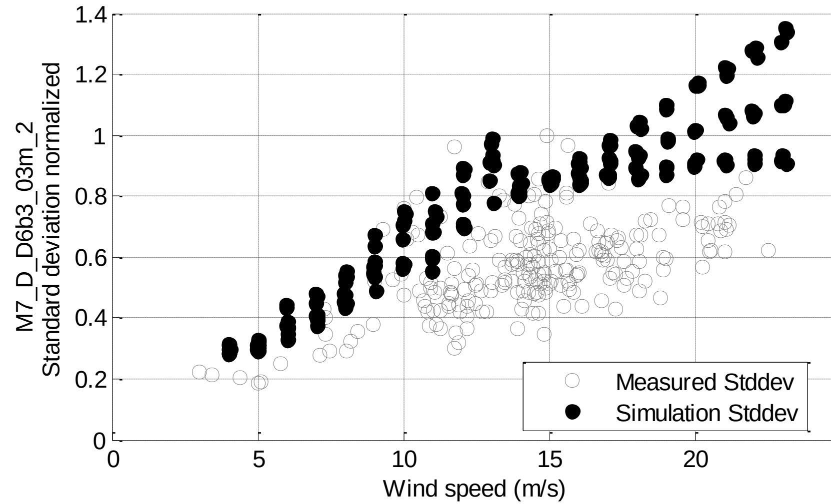


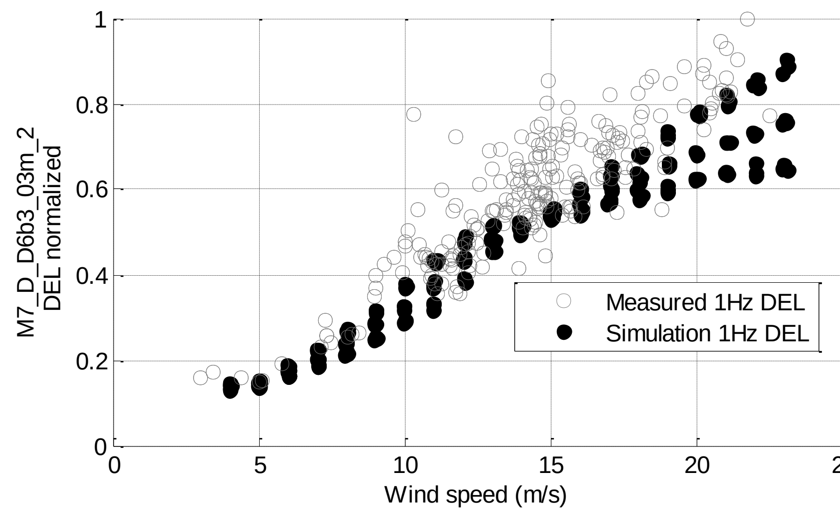
Good agreement of comparison

Example Results

Blade flapwise bending moments







Model dependant limitations of the standard deviation and DEL

Conclusions

- The simple methodology shows to be useful for the validation of statistical data

  ➡ The designer or validation engineer can therefore better understand the capabilities of the simulations

  Limits appearance of outliers and scattering when comparing data

- We need computer models we can trust but models themselves will always have limitation

  ➡ Careful interpretation of results necessary

Outlook

- **Importance of wake**: this also needs to be analysed as fatigue loading can be driven by this situation
  - but difficulty determining inflow wind speeds and turbulence intensities

- **Effects of other parameters**: by using the same *Screened Statistical Data Comparison Method* but changing the screening parameters, other effects can be investigated,
  - E.g. high turbulence intensities, hydrodynamic loads

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Thank you for your attention

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