SWE Stuttgart Wind Energy @ Institute of Aircraft Design

RAVE RESEARCH AT ALPHA VENTUS
Eine Forschungsinitiative des Bundesumweltministeriums

Evaluation of the extreme and fatigue load measurements at alpha ventus

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Stuttgart Wind Energy (SWE), University of Stuttgart

Rave International Conference 2015, Bremerhaven

Gefördert auf Grund eines Beschlusses des Deutschen Bundestages

Projektträger

Koordination

Bundesministerium für Wirtschaft und Energie

Projektträger Jülich Forschungszentrum Jülich

Fraunhofer IWES

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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

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Presentation Content

Extrapolation

1. What are the procedures for extrapolation of ultimate loads from measurements?

Fatigue in Wake

2. What is the deviation measured in the fatigue loads of two turbines in a wind park?

IEC Simulations

3. What are the effects of the stochastic environmental conditions which are not considered in the design guidelines?

Part 1

Extrapolation

1. What are the procedures for extrapolation of ultimate loads from measurements?

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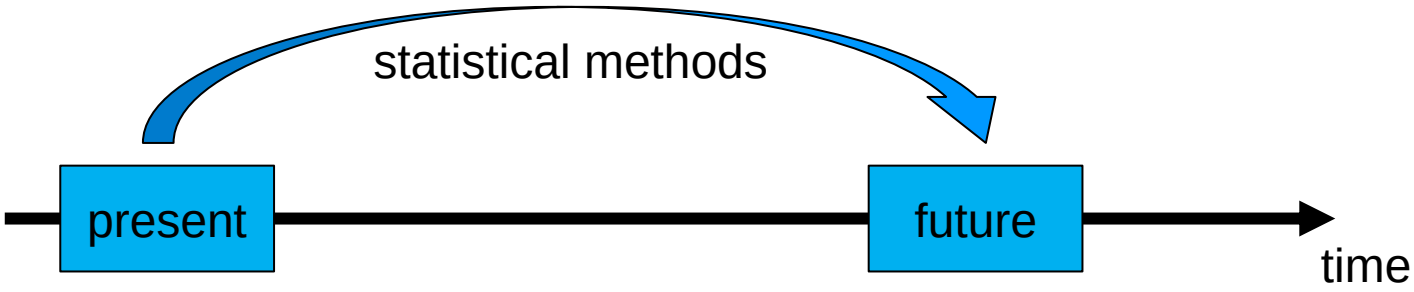
General Idea of Extreme Load Extrapolation



Extract from IEC 61400-1 ed.3: Wind Turbine - Part 1: Design requirements

For DLC 1.1 the characteristic value of load shall be determined by a statistical load extrapolation and correspond to an exceedance probability, for the largest value in any 10-min period, of less than or equal to $3{,}8 \times 10^{-7}$, (i.e. a 50-year recurrence period) for normal design situations. For guidance see Annex F.

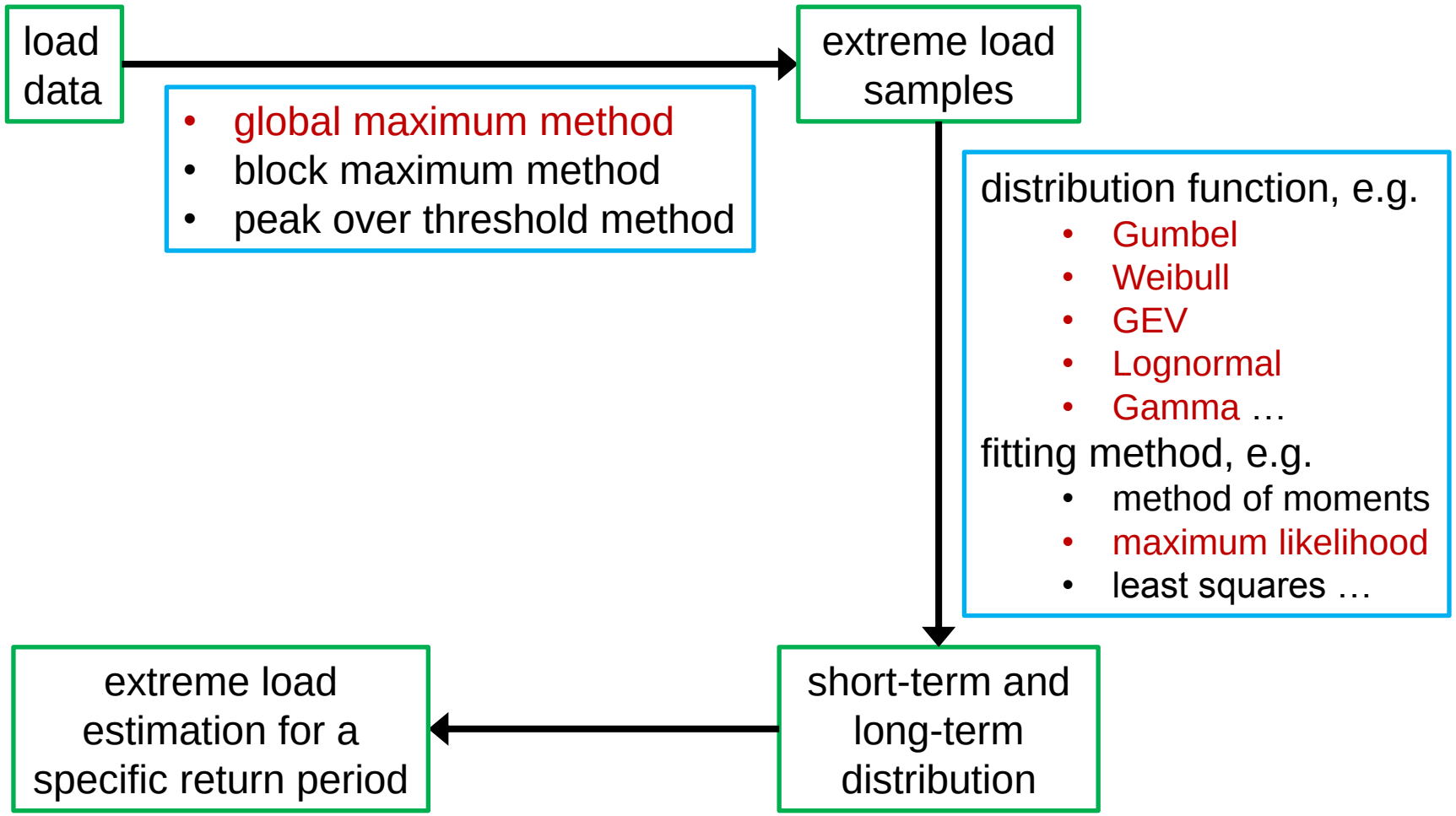
No detailed information about the extrapolation procedure is given

→ room for interpretation

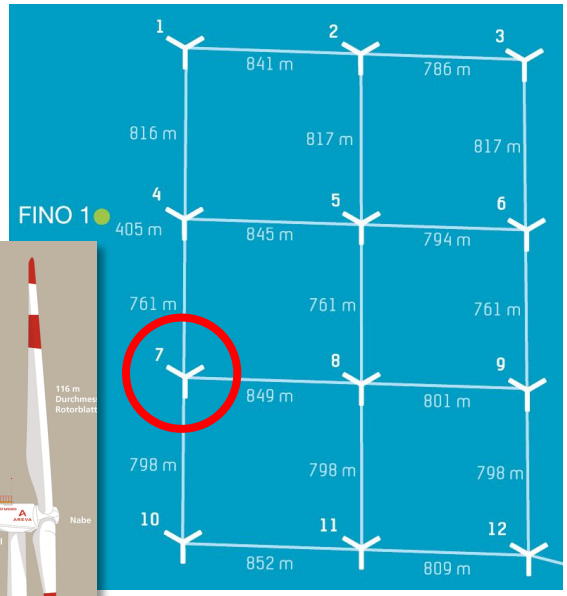
Methods were developed for simulation data

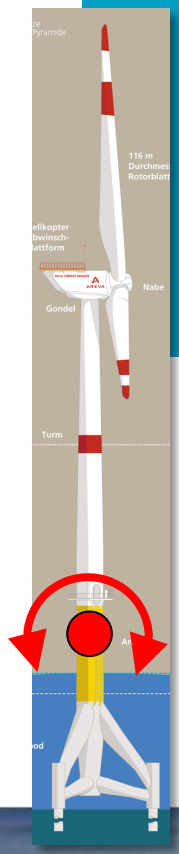
→ unique opportunity to apply the methods to offshore measurement data

Load Extrapolation Procedure



Database for Extrapolation





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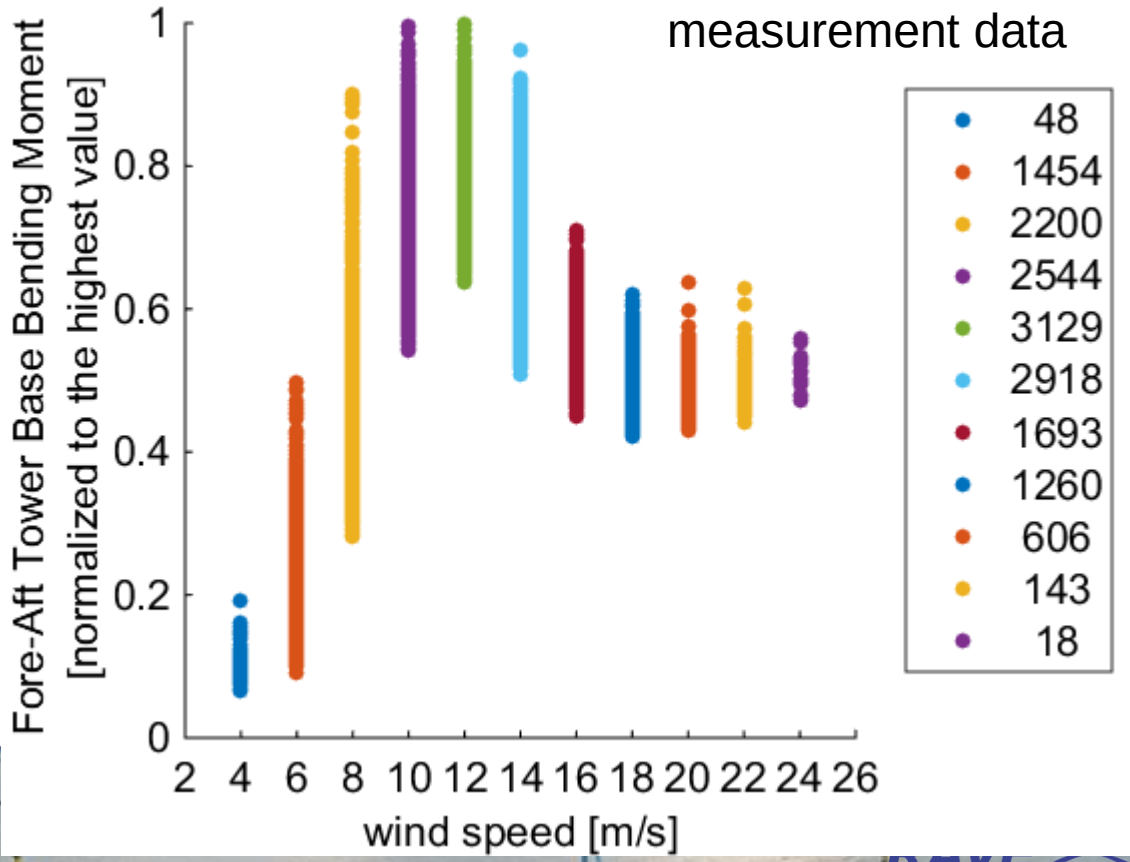
5MW wind turbine
AD 5-116

Restrictions:

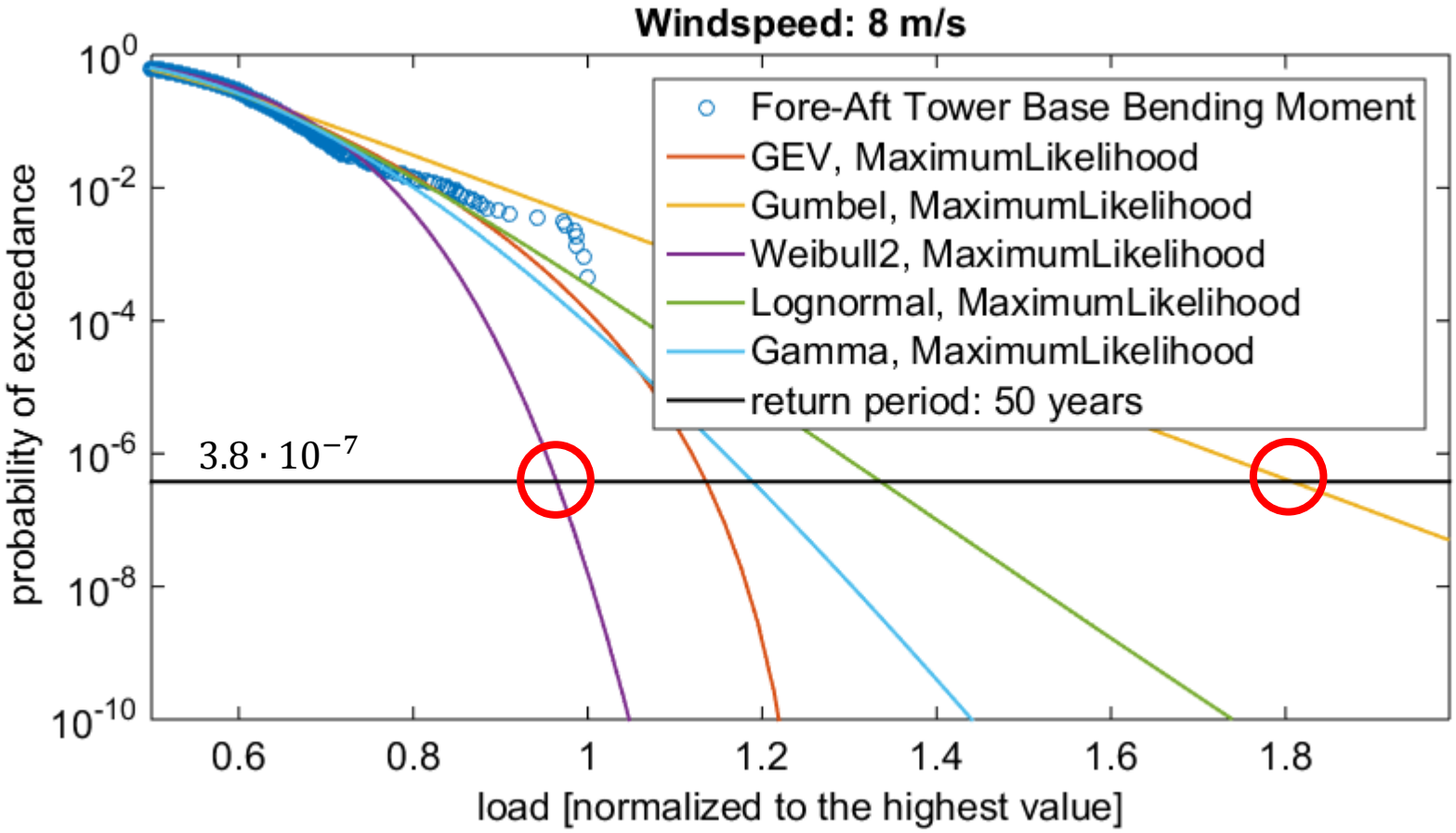
- Status signal: Production, Power > 200kW
- Freestream

3 years of measurement data



[Figure1: http://www.alpha-ventus.de
Figure2: http://www.trianel-borkum.de/typo3temp/pics/ed103a7723.gif]

Exemplary Short-Term Extrapolation

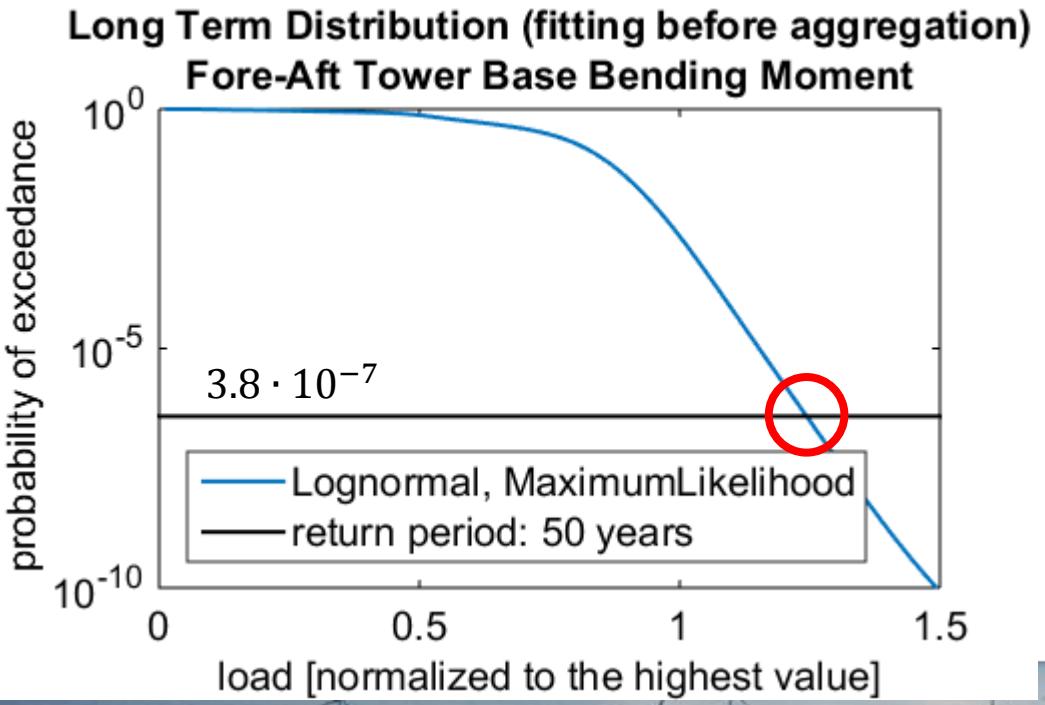


The estimated extreme load essentially depends on the choice of the distribution function.

Conclusion and Outlook

Which distribution function fits the evaluated measurement data best?

Goodness of fit tests for all wind bins
→ Lognormal distribution



Conclusion:

- Load extrapolation with measurement data results in plausible extreme loads.
- Lots of processing of the data is necessary.

Outlook:

- Further investigation of different extrapolation methods.
- Comparison to simulation data.

Part 2

Extrapolation

1. What are the procedures for extrapolation of ultimate loads from measurements?

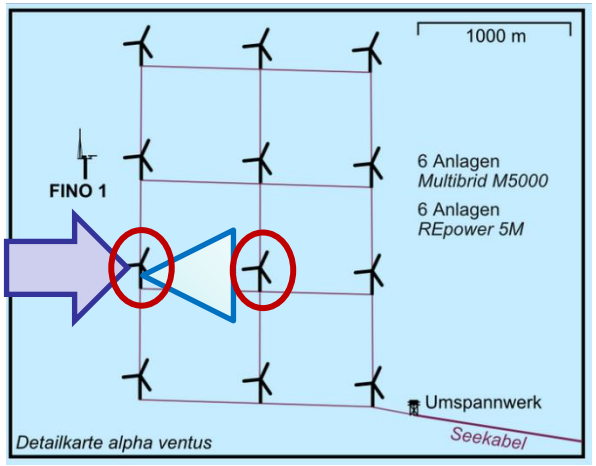
Fatigue in Wake

2. What is the deviation measured in the fatigue loads of two turbines in a wind park?

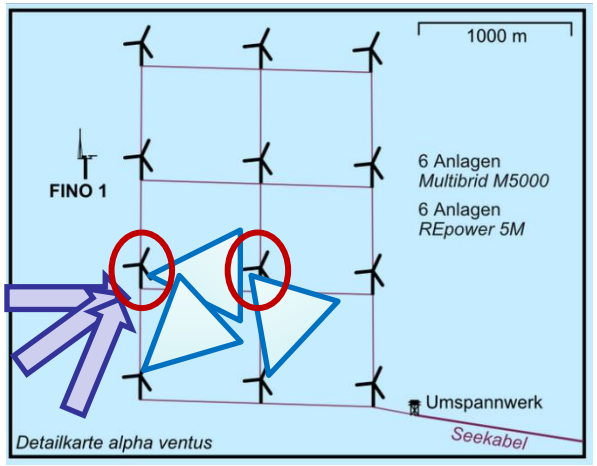
IEC Simulations

3. What are the effects of the stochastic environmental conditions which are not considered in the design guidelines?

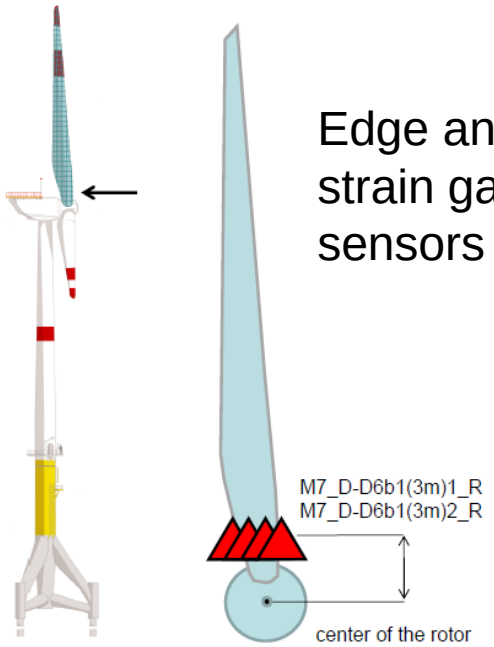
Two cases can be analysed



Case A
AV8 in wake of AV7

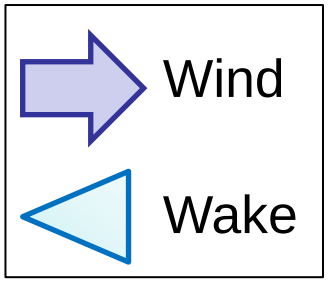


Case B
AV7 in freestream



Edge and flap strain gauge sensors

Adwen 5MW
AD 5-116

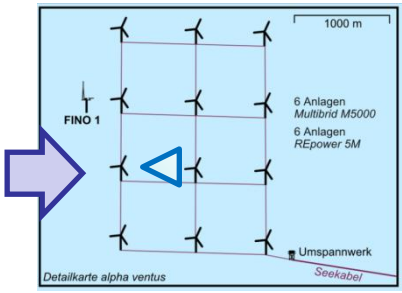


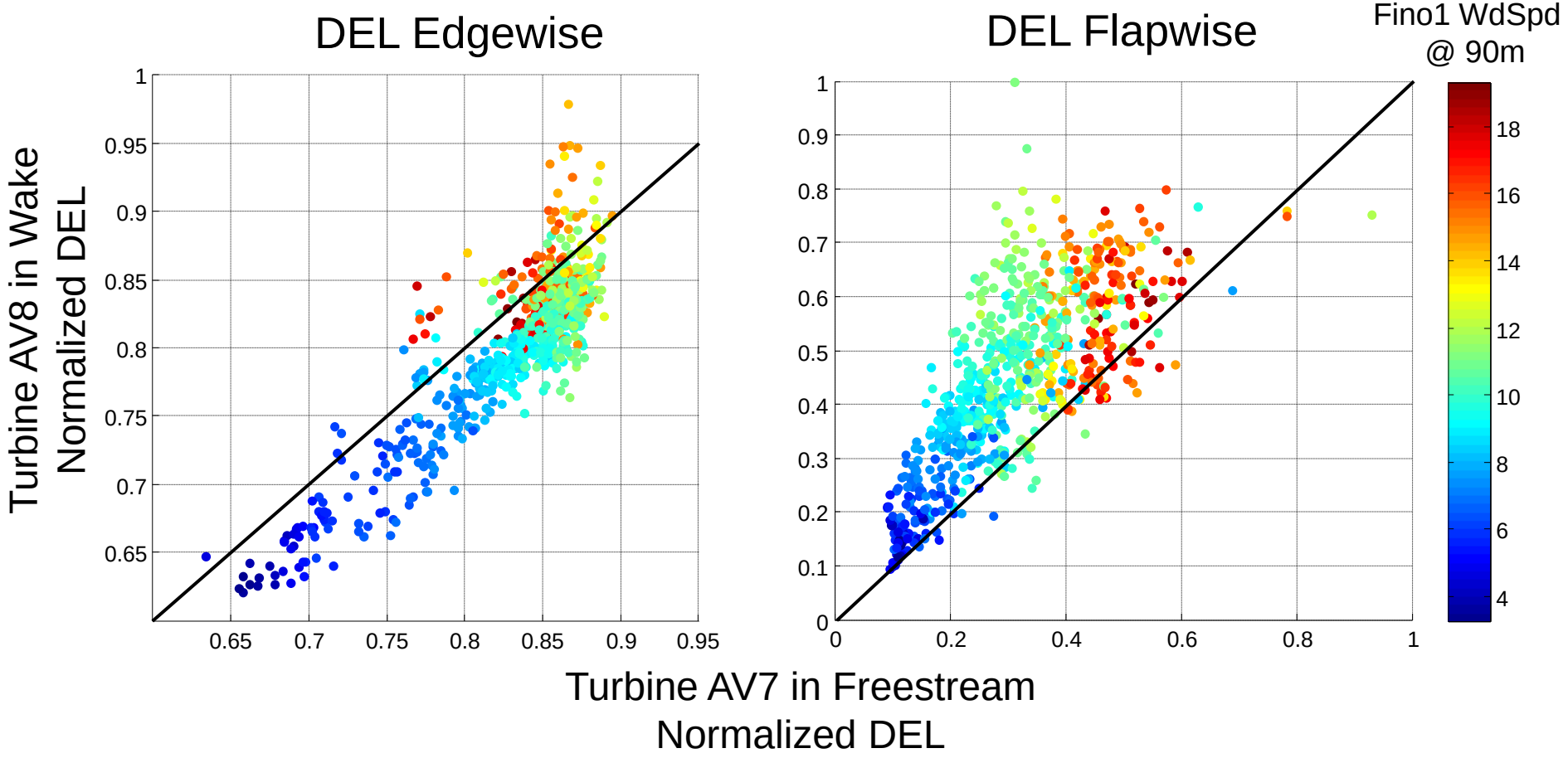
Data sorting

- 13 Months – Data from 01-Oct-2010 to 31-Oct-2011
- 10 min time series
- Power production
- No curtailment

[Figure1: Adaptation from wikipedia.com / Lencer
Figure2: http://www.trianel-borkum.de/typo3temp/pics/ed103a7723.gif]

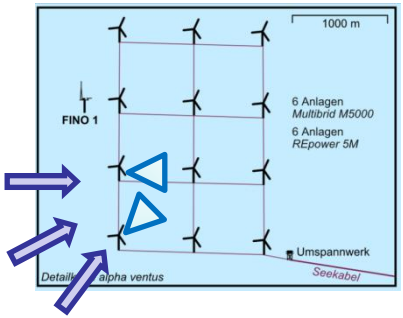
Case A: AV8 in Wake
Damage equivalent loads (DEL) on the blades

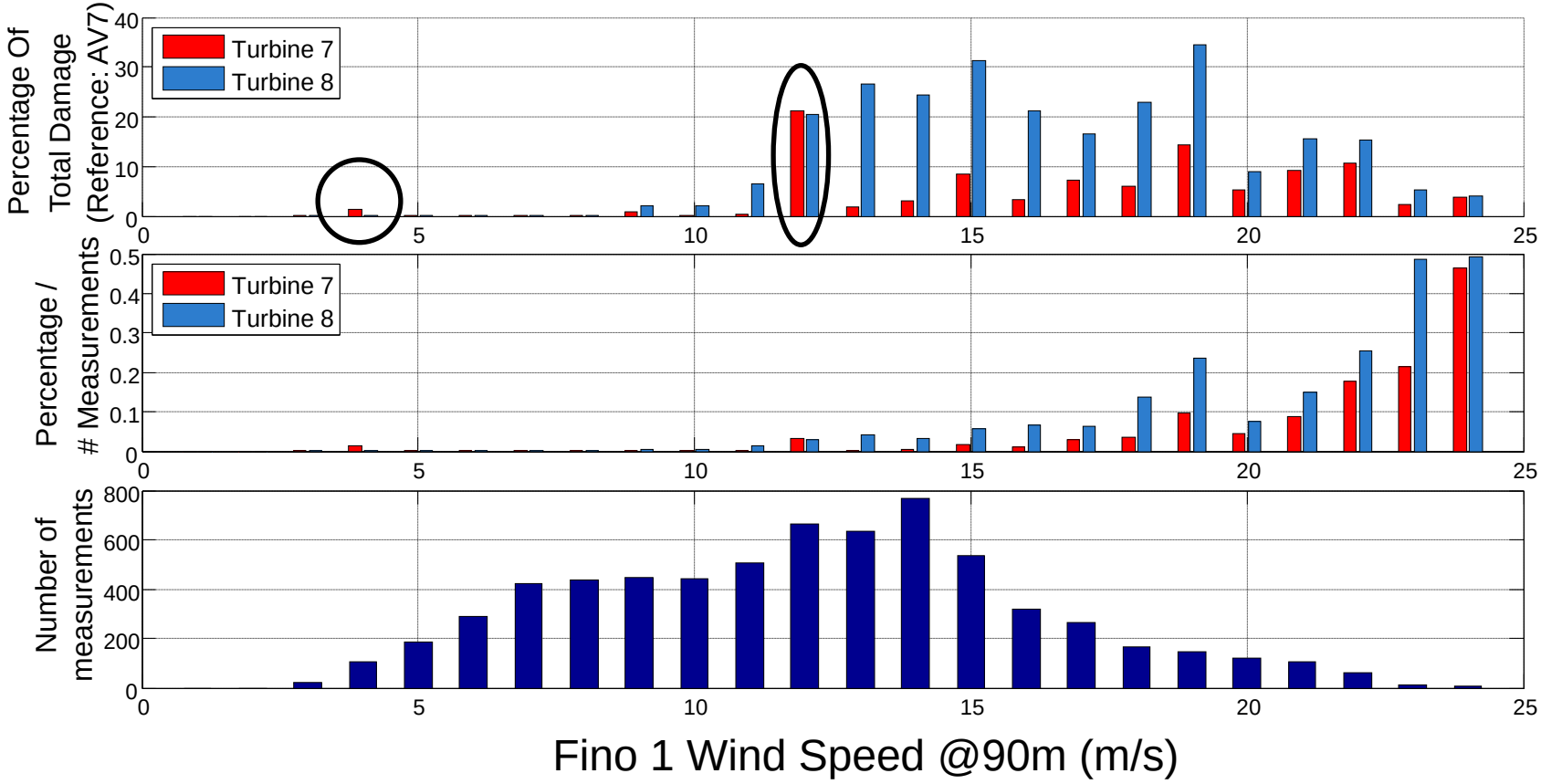




Comparing the damage on the blades based on linear damage accumulation and the Palmgren-Miner Rule

Case B: Freestream vs Wake
Comparing Damage of **Flap Measurements**





Turbine AV7 in freestream
Turbine AV8 in wake

Rated wind speed
= 12.4m/s

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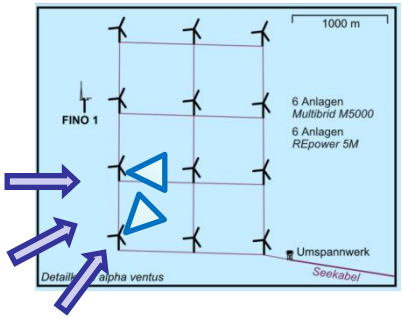
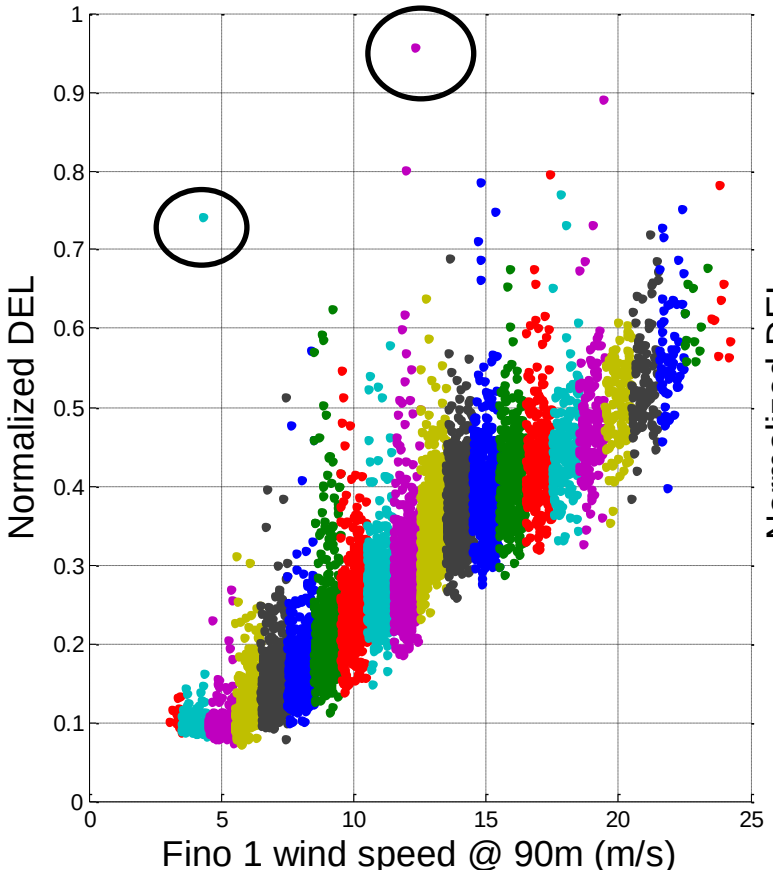
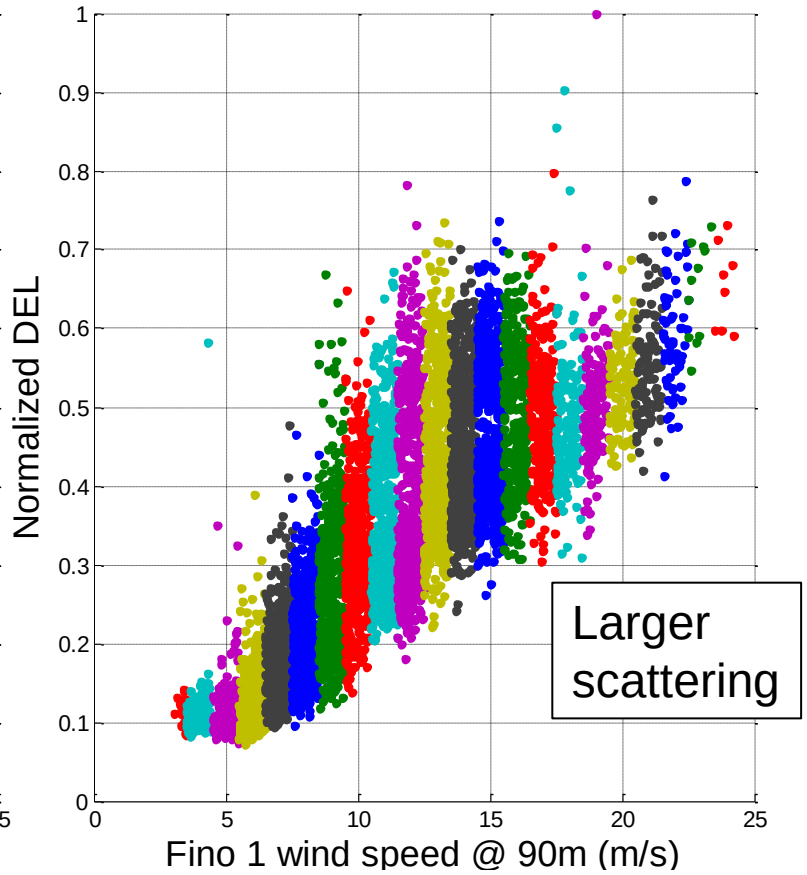
Case B: Freestream vs Wake
Outliers for flap sensors



Freestream



Wake



Conclusion:

- A better understanding of outliers is needed to properly characterize damage and fatigue of measurement data

Part 3

Extrapolation

1. What are the procedures for extrapolation of ultimate loads from measurements?

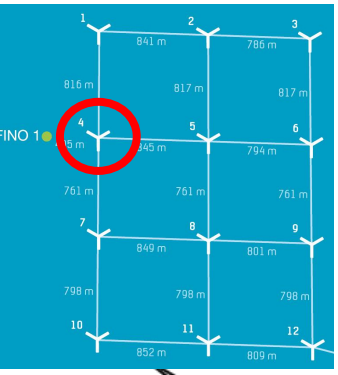
Fatigue in Wake

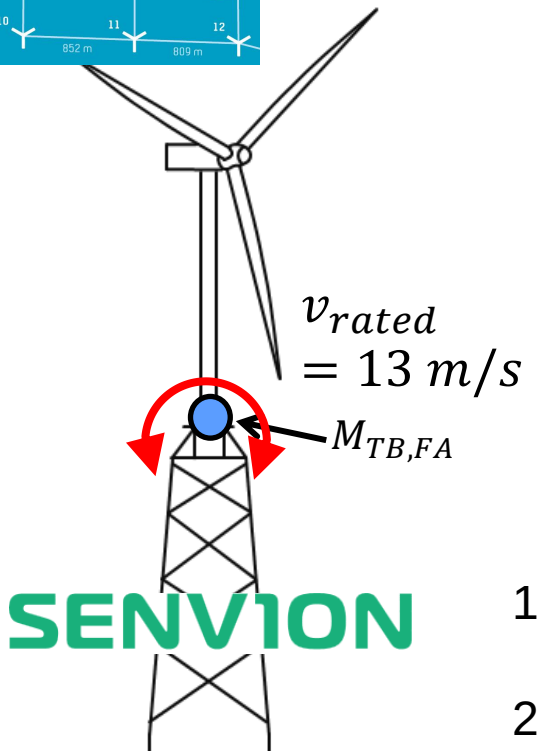
2. What is the deviation measured in the fatigue loads of two turbines in a wind park?

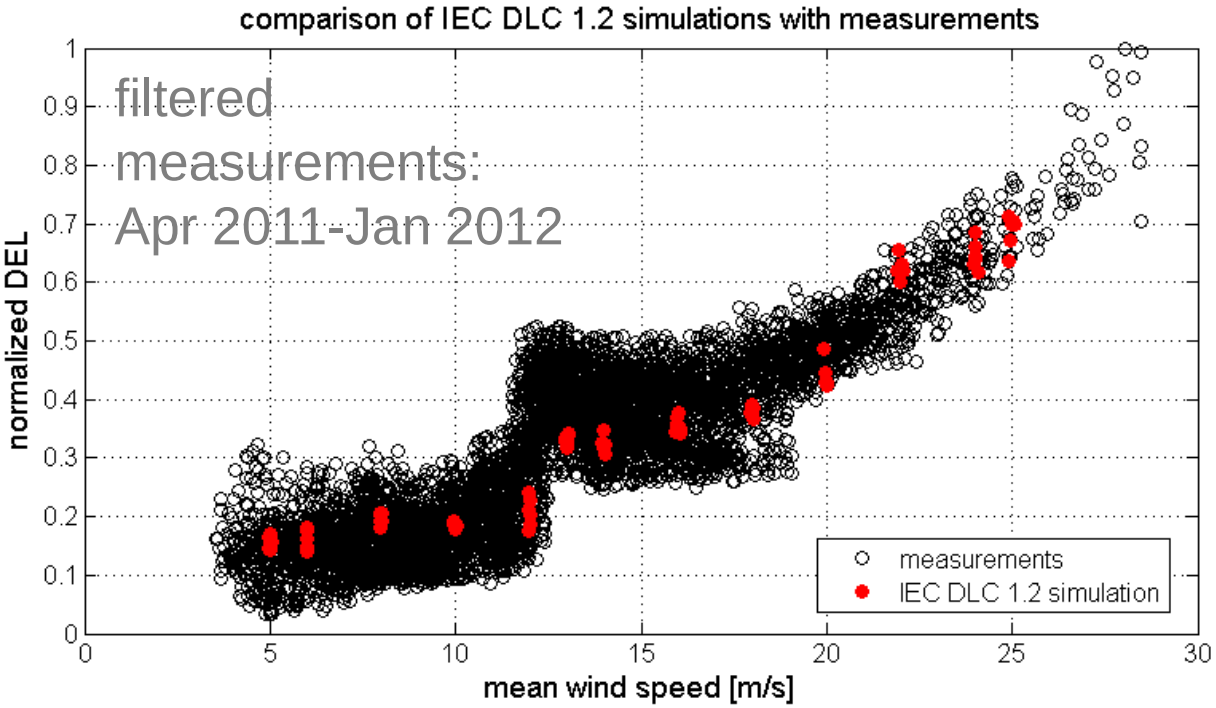
IEC Simulations

3. What are the effects of the stochastic environmental conditions which are not considered in the design guidelines?

Validation of IEC 61400-3: DLC 1.2 (fatigue + production)







[Figure1: http://www.alpha-ventus.de, Figure 2,3: Kolja Mueller, SWE]

1. What is the scatter range of IEC simulations?
2. Can load scatter be captured with simulation model?

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Scatter range of loads from IEC simulations

SWE Computer Model

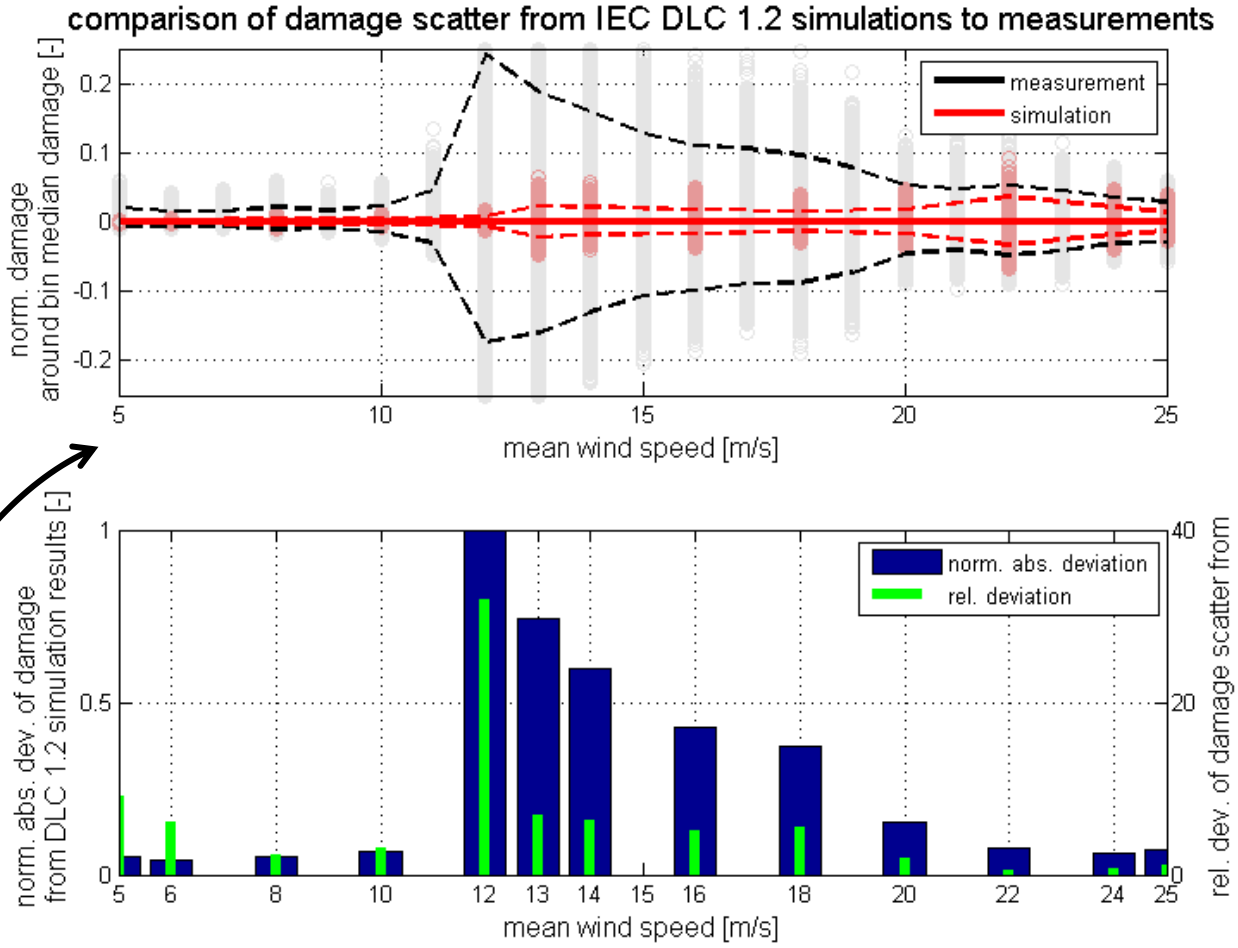
100 simulations
Per wind bin

Weibull
dist.

Take DEL of 6
simulations
per bin

Damage
Over lifetime
(20 yrs)

Repeat 10,000 times



➔scatter included in IEC assumptions low in comparison to measurements

➔damage scatter around rated wind critical

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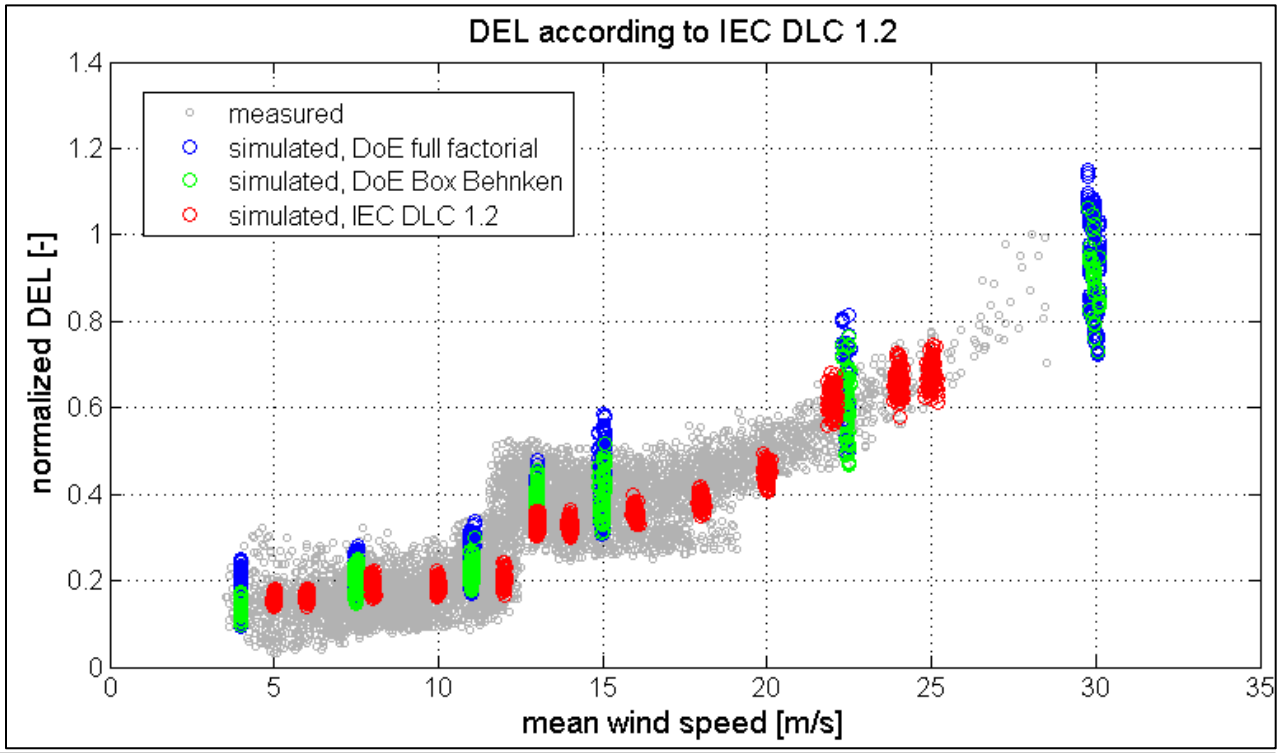
Capture load scatter through consideration of scatter of environmental conditions

Design of Experiment : 3 step, Full Factorial = 4374 simulations
Box Behnken = 738 simulations

Consider scatter of

- Wind speed
- Turbulence intensity
- Wind shear
- Wave height
- Wave period

Based on 5 year Fino1 data



[Figure: Kolja Mueller, Mario Reiber, SWE]

Conclusion:

➔ Stochastics of measured loads can be simulated when considering scatter of environmental conditions

➔ Turbulence intensity major contributor to scatter of DEL (MyTB)

Summary

- Extrapolation of measurements show how the extrapolated load depends heavily on the distribution function used
- Characteristic behaviour of fatigue on blades has been shown. While a better understanding of outliers is necessary to understand measurement of loads.
- Scattering of load measurements can be captured through consideration the stochastic environmental condition in the simulations

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Forschungszentrum Jülich

Fraunhofer
IWES

Thank you for your attention

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Supplemental slides

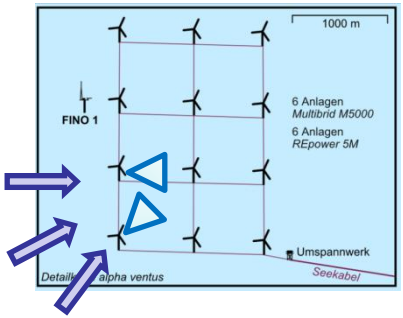
The damage caused by a load spectrum of n cycles with ranges Sr,i

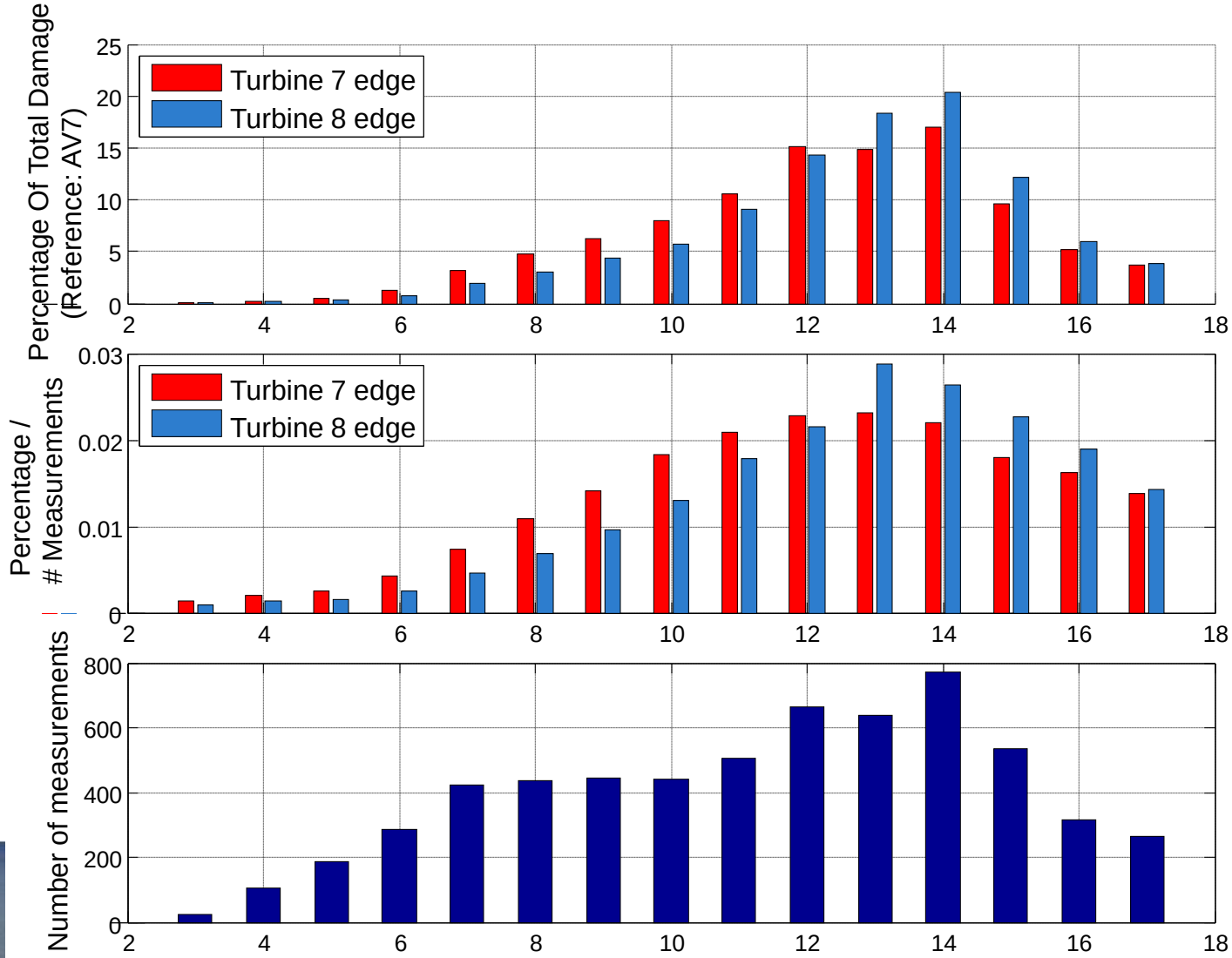
$$D = \sum_{i=1}^{n} \frac{1}{k \cdot S_{r,i}^{-m}}$$

Sr = is the range of a load cycle
-1/m = is the slope of the S-N line on log-log scale

http://www.ecn.nl/docs/library/report/1995/c95074.pdf

Case B: Freestream vs Wake
Comparative Damage **Edge** Sensors





AV7 in freestream
AV8 in wake

Rated wind speed = 12.4m/s

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