

Probabilistic Fatigue Damage Extrapolation Based on Strain Measurements – First Alpha Ventus Results

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C. Hübler, T. Grießmann, R. Rolfes

Institute for Structural Analysis - Leibniz University Hanover/ForWind - c.huebler@isd.uni-hannover.de

- General idea
- Previous work on measurement-based fatigue damage extrapolation
- Raw data
- Short term damage
- Long term damage
- Next steps

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Remaining fatigue lifetime based on strain measurements

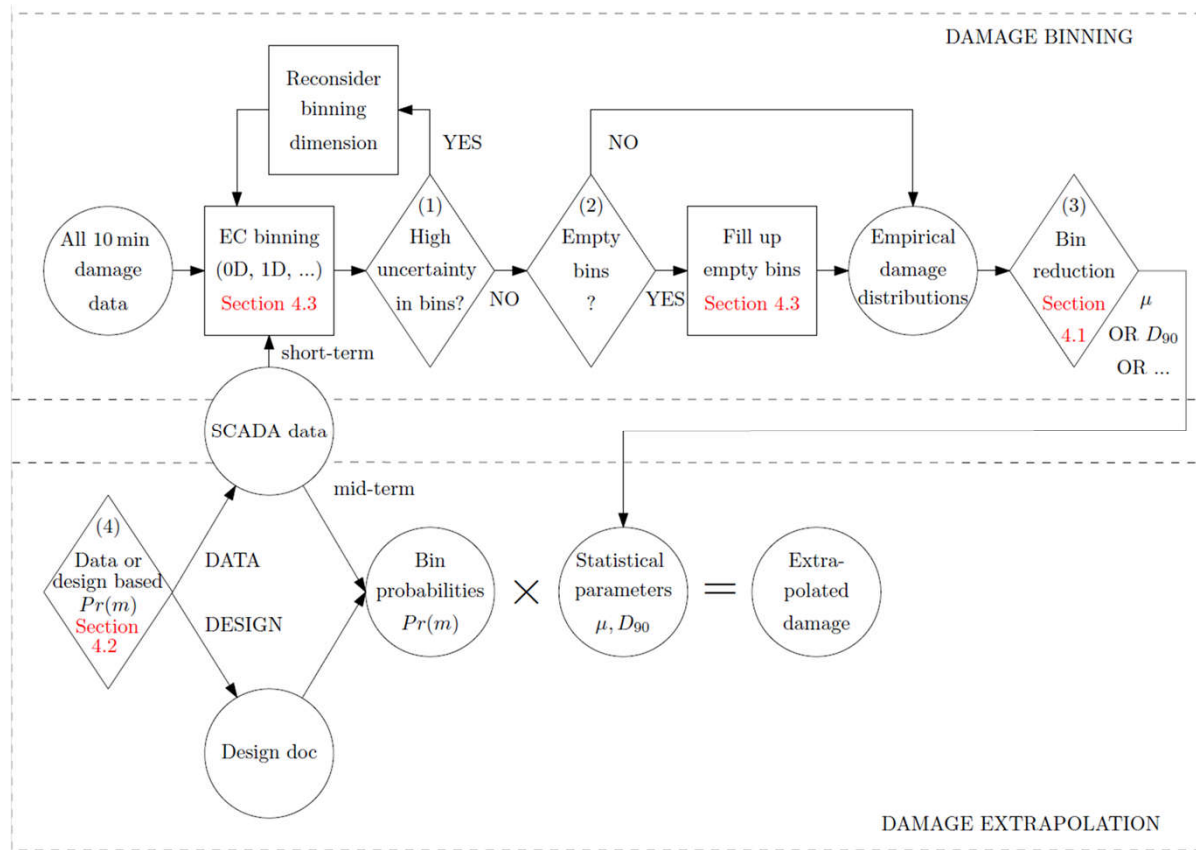
Approximation of the remaining fatigue lifetime based on strain measurements and extrapolations

- Reasons:
 - Fatigue calculations based on simulations always feature a significant amount of model uncertainty
 - Measurement-based approaches take real offshore conditions of the precise site and time period into account
 - Fatigue extrapolation can be done using (always available) SCADA-data. Only a limited amount of strain data is required to achieve relatively good extrapolated results
- Challenges:
 - (Spatial) extrapolation to hot spots where no measurement data is available
 - Data quality
 - **Accurate fatigue damage extrapolation methods (extrapolation in time)**

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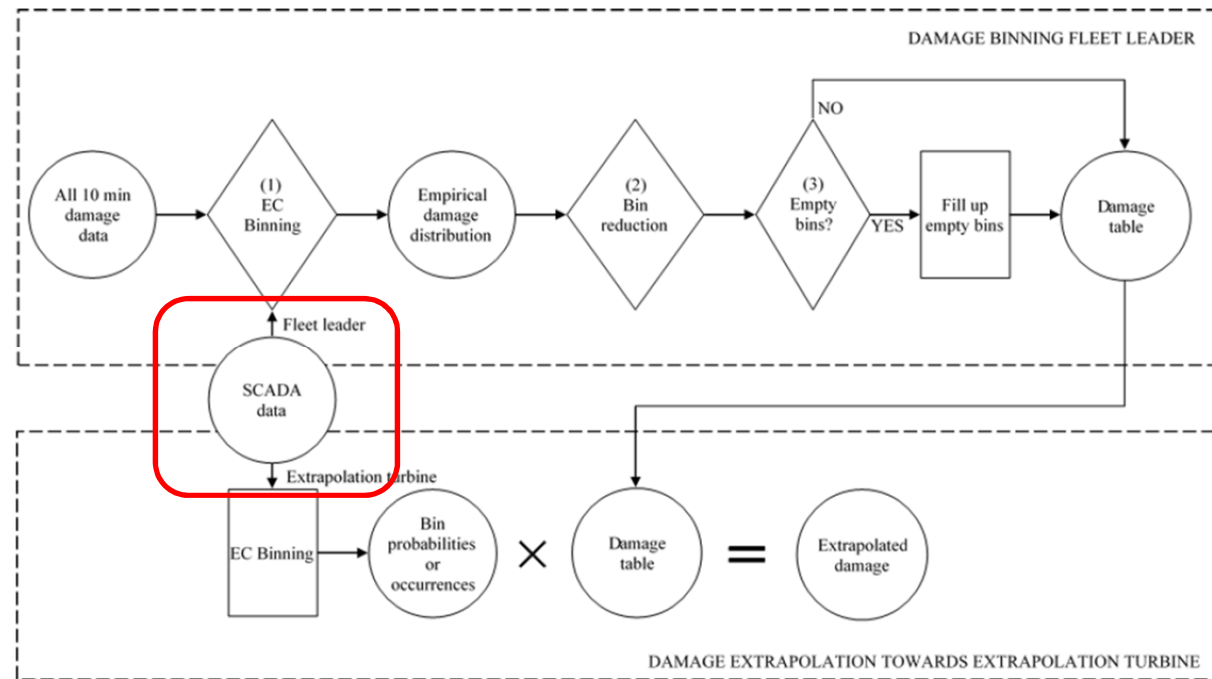
Reliability analysis of fatigue damage extrapolations of wind turbines using offshore strain measurements

- Various approaches possible (partly very different results)
- Which environmental conditions should be used for the extrapolation?
- Design or data-based bin probabilities for extrapolation
- Mean damage or 90th percentile



Validated extrapolation of measured damage within an offshore wind farm using instrumented fleet leaders

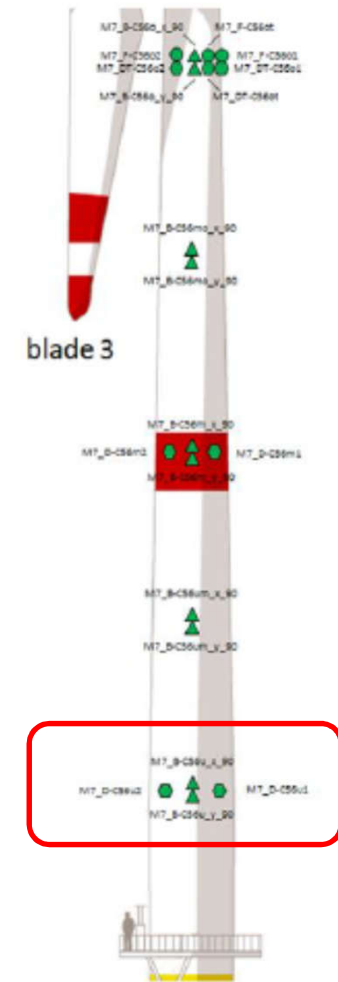
- Similar approach, but extrapolation to other turbine in the same wind farm
- Relative errors of less than 5% on damage



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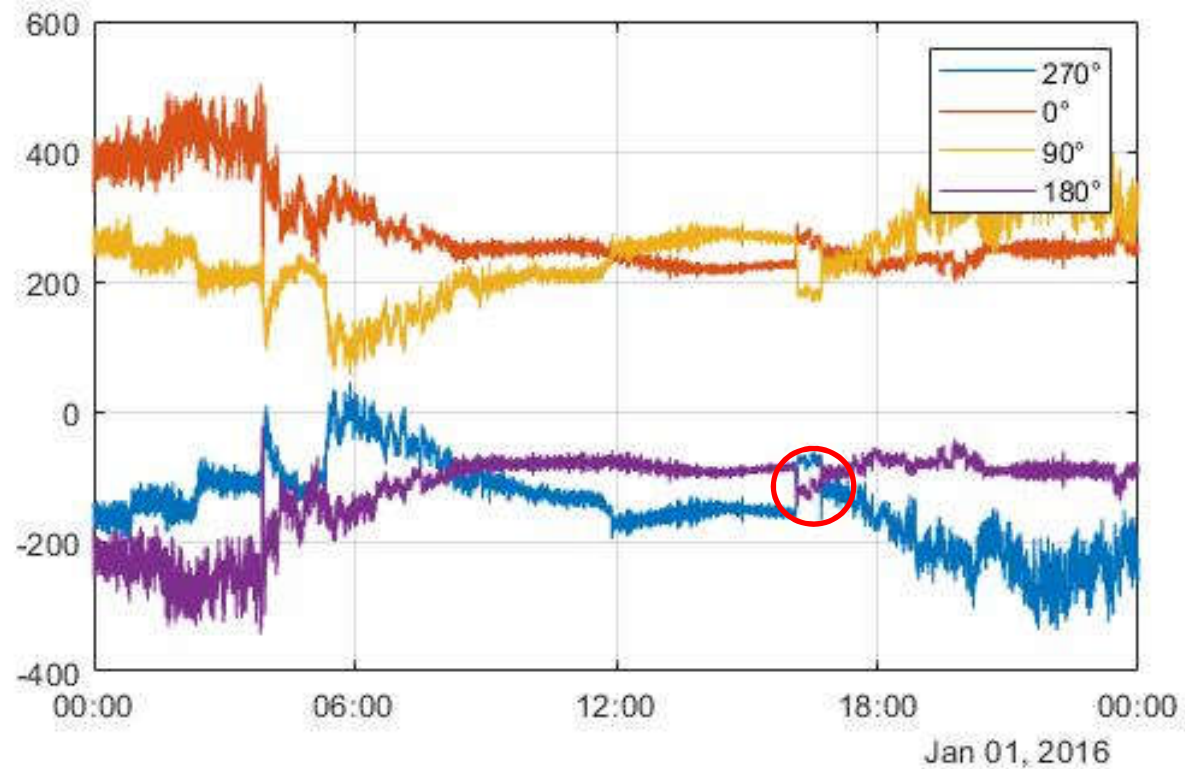
Alpha Ventus - AV07 Adwen-Tripod

- Strain data (50 Hz)
 - A single location at the tower
 - Four strain gauges around the tower
- SCADA and FINO 1 data (10min mean values)
 - Wind speed, wind direction, turbulence intensity, wave height, wave direction, wave period, turbine operating status
- Measurement period of several years
 - Data quality is not sufficient over the entire time, but three complete years of sufficient data quality
 - So far only data of two months are used, as data postprocessing still goes on



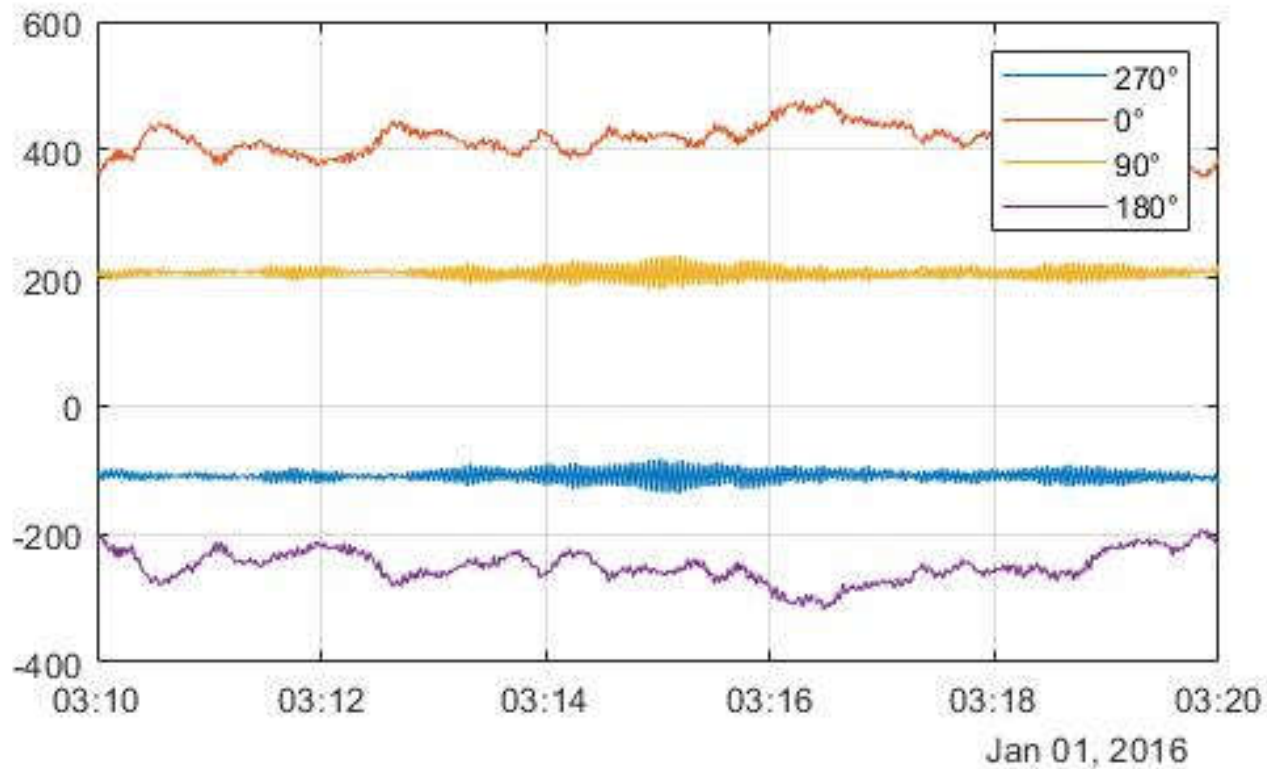
Some exemplary data

Strain measurements – 24h



Some exemplary data

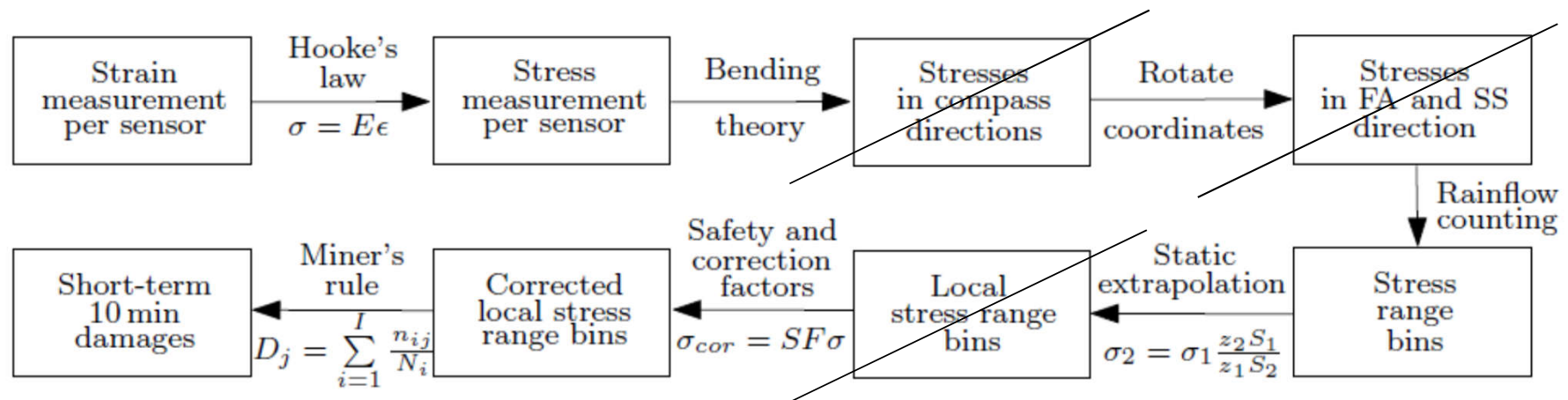
Strain measurements - 10min data set



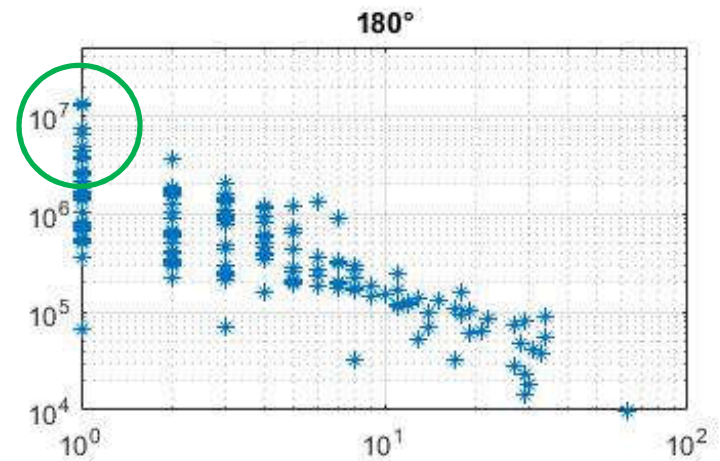
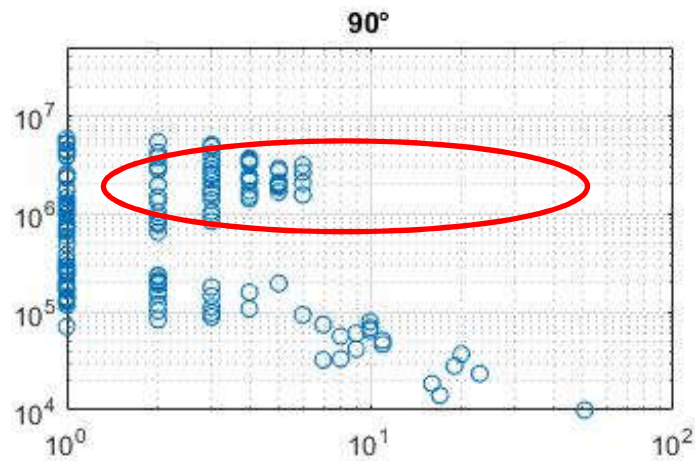
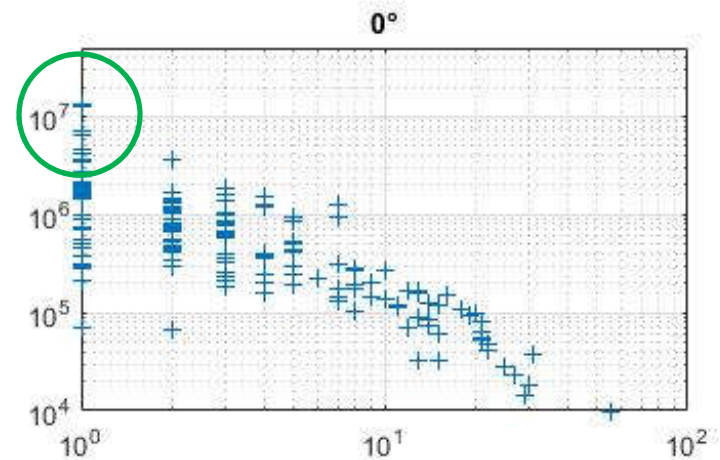
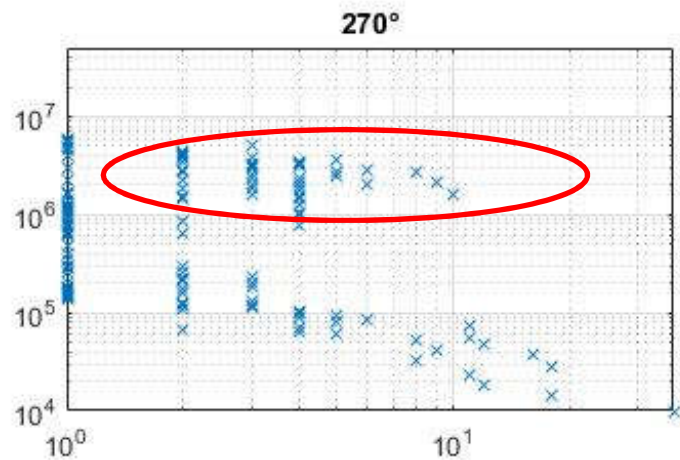
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Calculation using standard approach

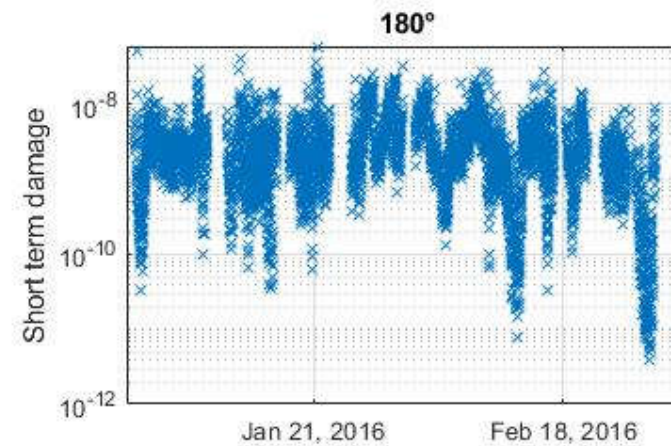
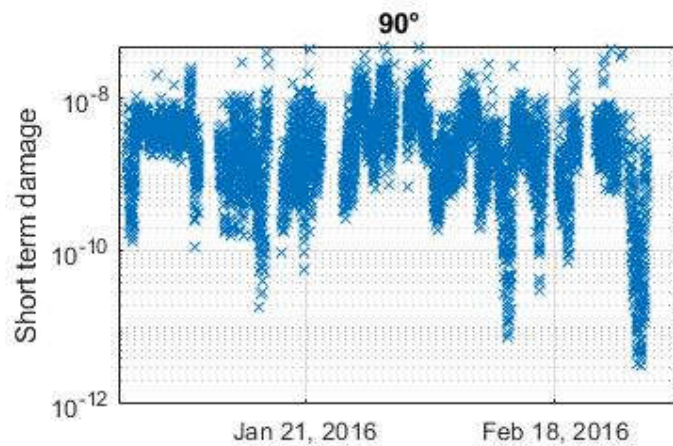
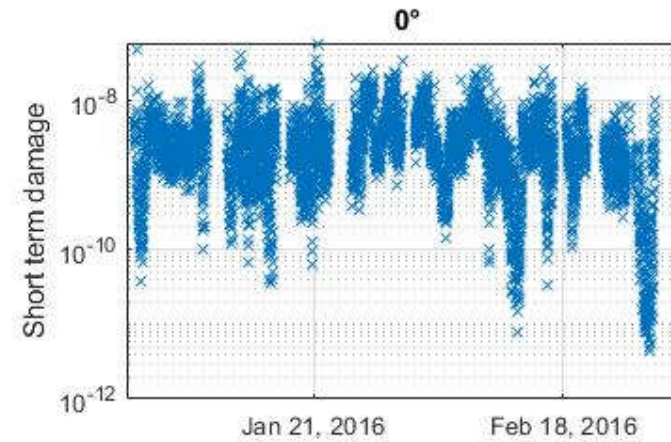
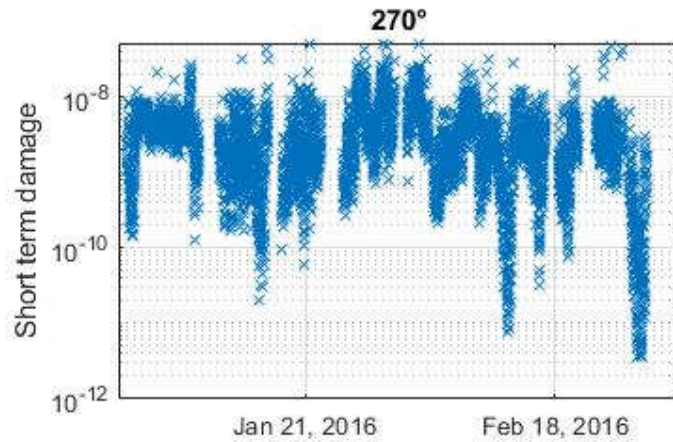
- Calculation of stresses (no spatial extrapolation, no calculation of bending moments, etc.)
- Rainflow counting
- Safety factors (MSF = 1,0, SCF = 1,0; but weld with regular inspections)
- S-N curve D in air



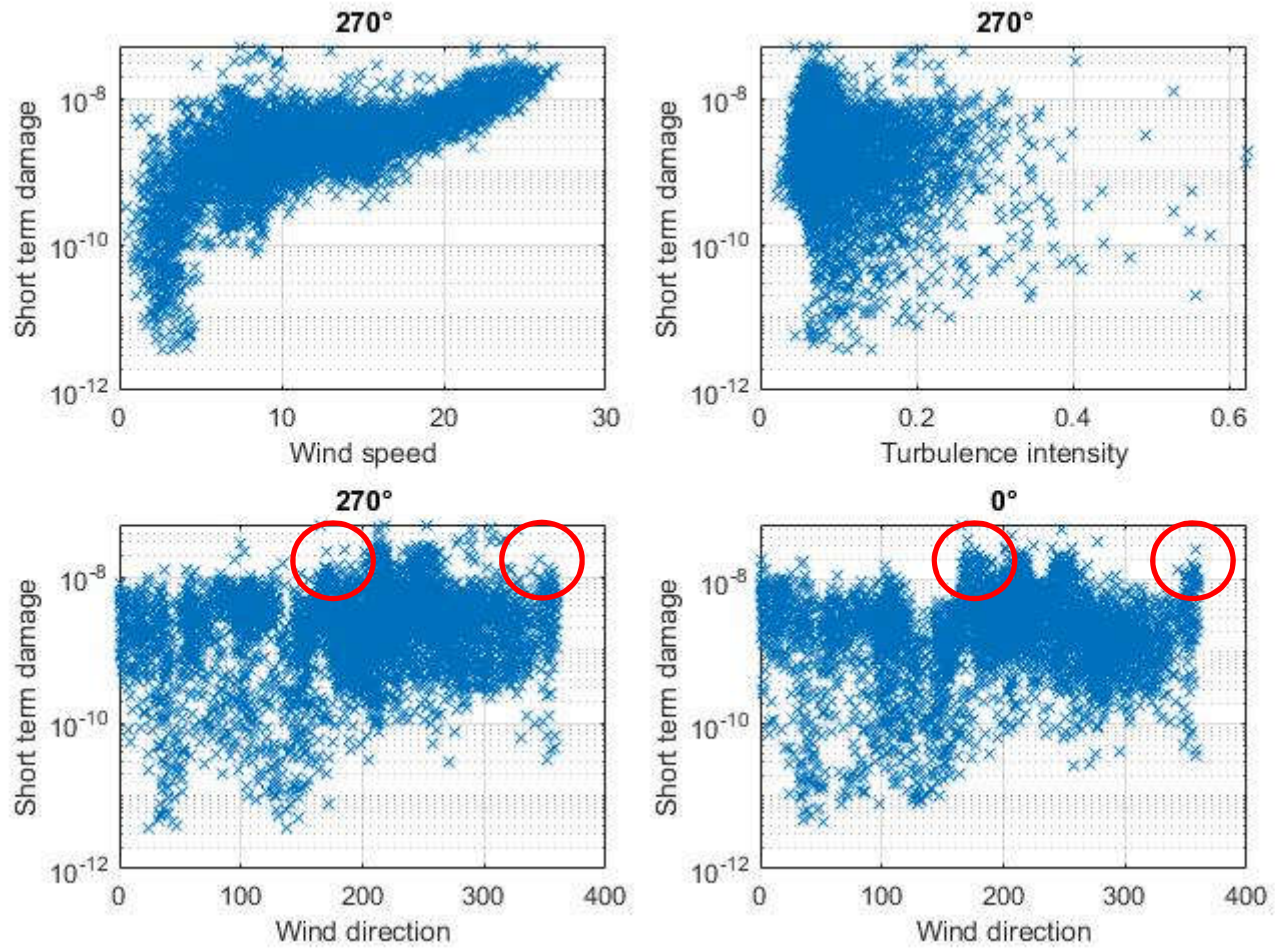
Cycle count data



Short-term damage data



Correlations between damage and environmental conditions



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Different approaches to extrapolate fatigue damage data

Simple approaches

- **Deterministic**
 - Calculate the mean damage of all 10min intervals (measurement period)
 - Multiply the mean damage by the overall number of 10min intervals (full period)
- **Probabilistic**
 - Calculate short-term damages of all 10min intervals (measurement period)
 - Draw N random samples (with replacement) from the short-term damages, where N is the number of 10min intervals in the measurement period
 - Calculate the mean damage of all drawn samples
 - Repeat this process n times to determine the statistical uncertainty in this process

Different approaches to extrapolate fatigue damage data

Advanced approaches considering environmental conditions

- **Deterministic**

- Sort all short-term damages of all 10min intervals (measurement period) into bins of environmental conditions (here: wind speed)
- Calculate the mean damage of all 10min intervals in each bin
- Multiply the mean damage of each bin with the occurrence probability of this bin during the full period and the overall number of 10min intervals (full period)

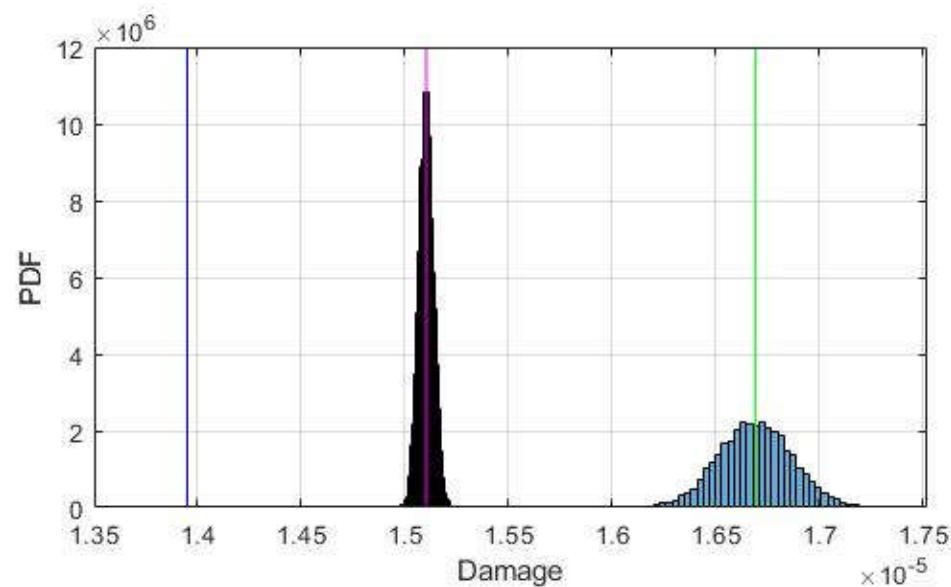
- **Probabilistic**

- Just like the deterministic approach, BUT do not calculate the mean value of each bin, but the mean value of N randomly drawn samples (with replacement) in each bin
- Repeat this process n times to determine the statistical uncertainty in this process

Results of long-term extrapolation

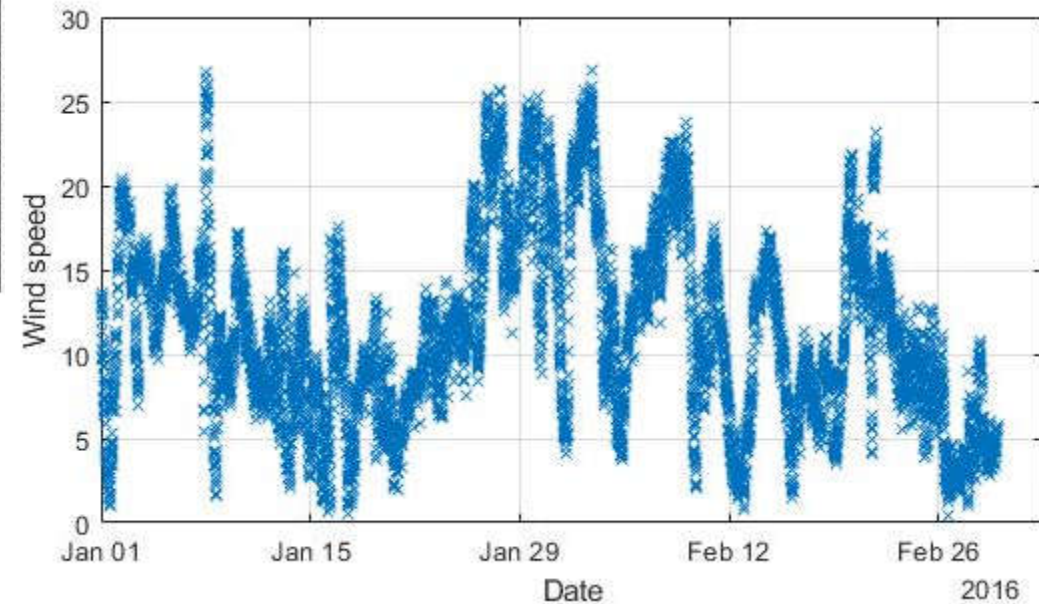
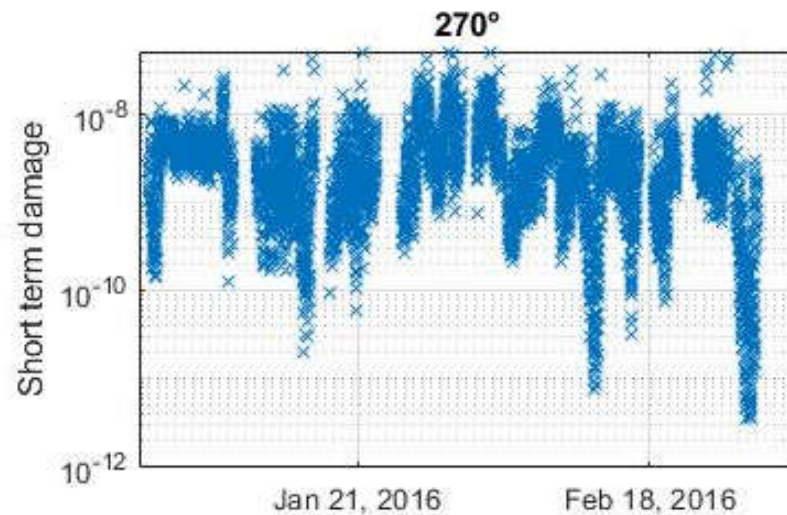
Extrapolation from January to February

- Extrapolation is not yet sufficient
 - Not enough data (at least approx. 9 months required, c.f. Hübler et al. (2018))
 - All data is used (no differentiation between operating and non-operating data)
- Advanced extrapolation yields better results



Results of long-term extrapolation

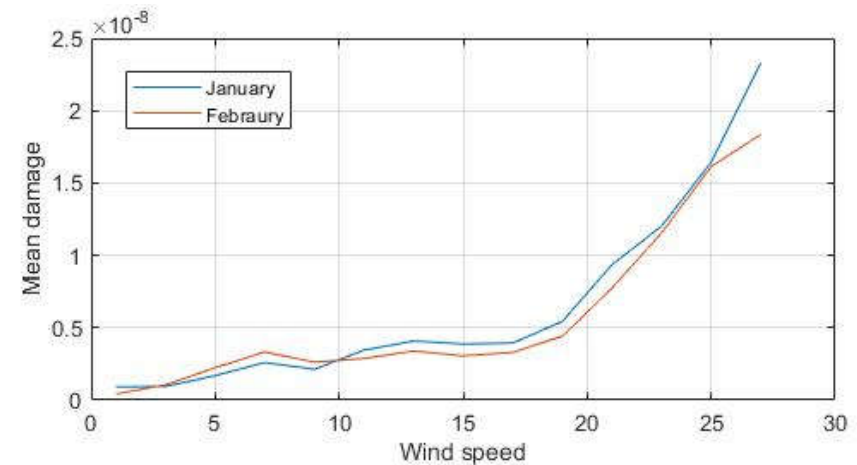
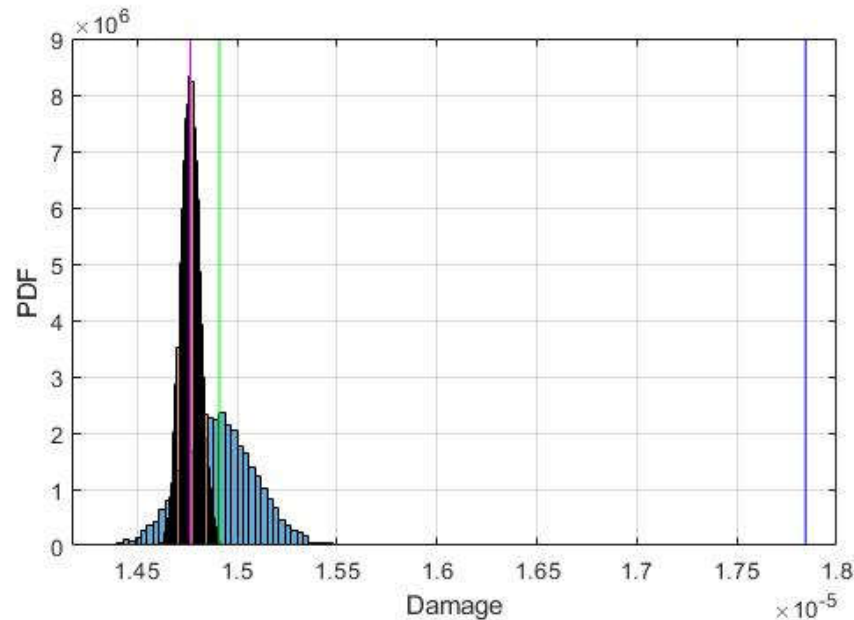
- Lower “measured” damages in February due to lower wind speed (11.8 m/s compared to 11.0 m/s)



Results of long-term extrapolation

Extrapolation from February to January

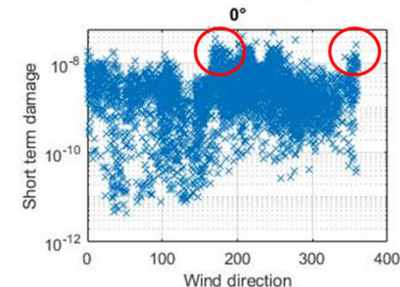
- Again, extrapolation is not yet sufficient
- Now, damages are underestimated
- The advanced approach does not yield an improvement



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Next steps

- Data of up to three years (e.g. 1 year of “training data” and 2 years for validation)
- Consider other environmental conditions within the damage extrapolation
- Consider operational and non-operational conditions separately
- Compare to approaches of other partners using precisely the same data sets and safety factors
- Pre-processed data sets of ISD can be directly shared in bilateral cooperation if NDA with BSH is signed



Thank you for your attention!

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