GIGAWIND *alpha ventus*

ForWind
Zentrum für Windenergieforschung
Bremen Hannover Oldenburg

Global and Local Monitoring of System Dynamics and Grouted Joint Displacements at the Tripod Support Structure in *alpha ventus*

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IfB Institut für Baustoffe

ISD INSTITUT FÜR STATIK UND DYNAMIK

Fraunhofer IWES

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

PtJ Projektträger Jülich Forschungszentrum Jülich

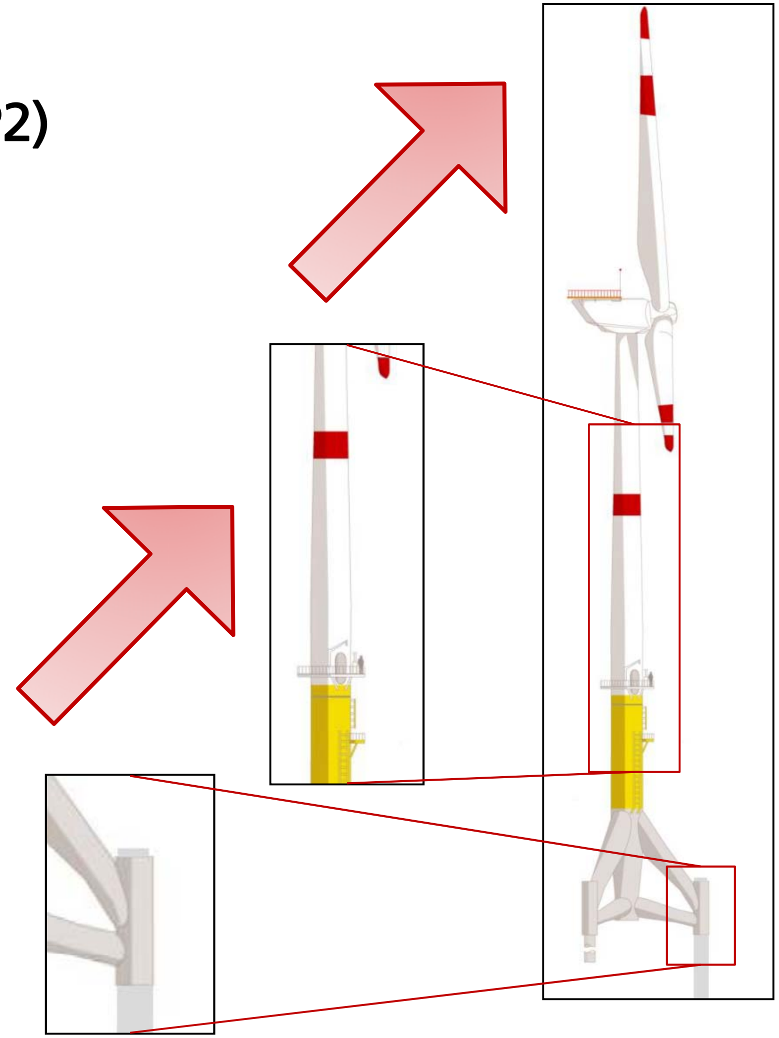
RAVE RESEARCH AT ALPHA VENTUS

Fraunhofer IWES

Leibniz Universität Hannover

Content

- I. **Monitoring of Grouted Joint (WP2)**
  - Motivation
  - Concept and Prototype
  - Recorded Data
- II. **Local Monitoring (WP4)**
  - Data Assistant
  - Fatigue estimation
- III. **Global Monitoring (WP4)**
  - Concept & Data basis
  - Modal Analysis
  - Condition Indicators



MONITORING OF GROUTED JOINT

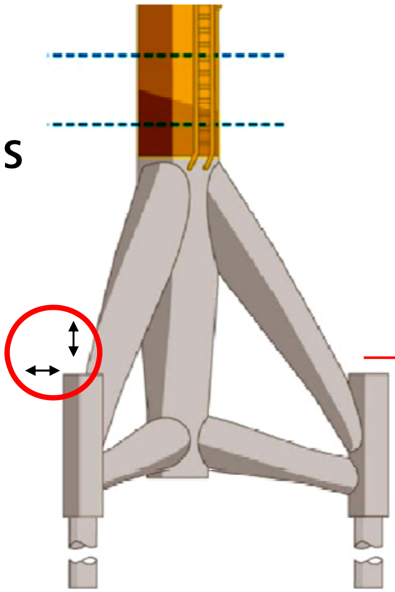
Local monitoring at the Grouted Connection

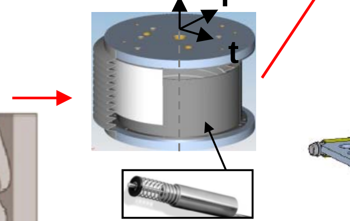
- The **Stiffness behavior** of Grouted Connections is of high interest
- **Displacements between pile and sleeve** are needed to describe the stiffness behavior
- **No existing measuring system** is suitable for this field of application

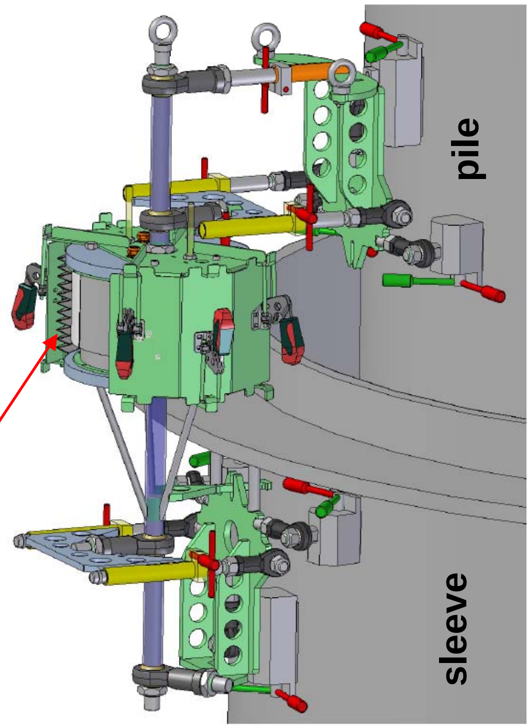
➢ A **new conception** was created:

– Sensor protection by an oil-filling

– Flexible magnetically adaptable fixing structure







Manufacturing and Application

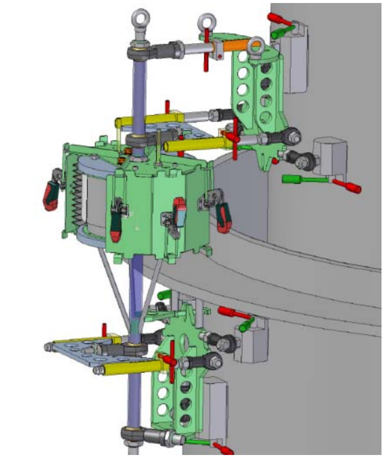
Installed measurement equipment:

- 4 Inductive displacement transducers (2 vertical, 2 horizontal)
- 2 dummy displacement transducers with constant measurement signals
- 1 temperature sensor
- 1 leakage measurement

Application offshore:
11th August 2010

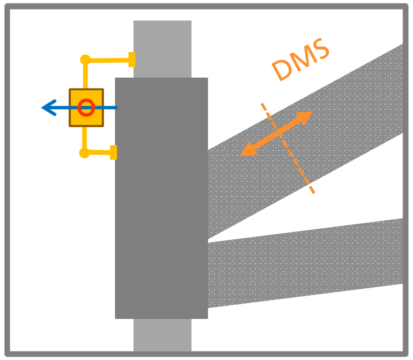
Start of data transmission:
2nd November 2010

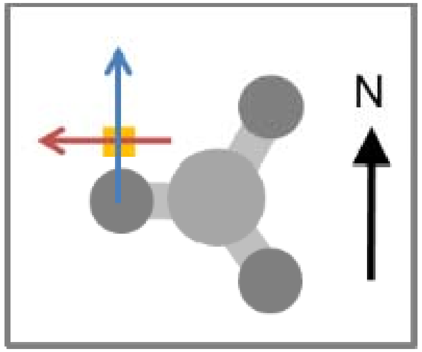


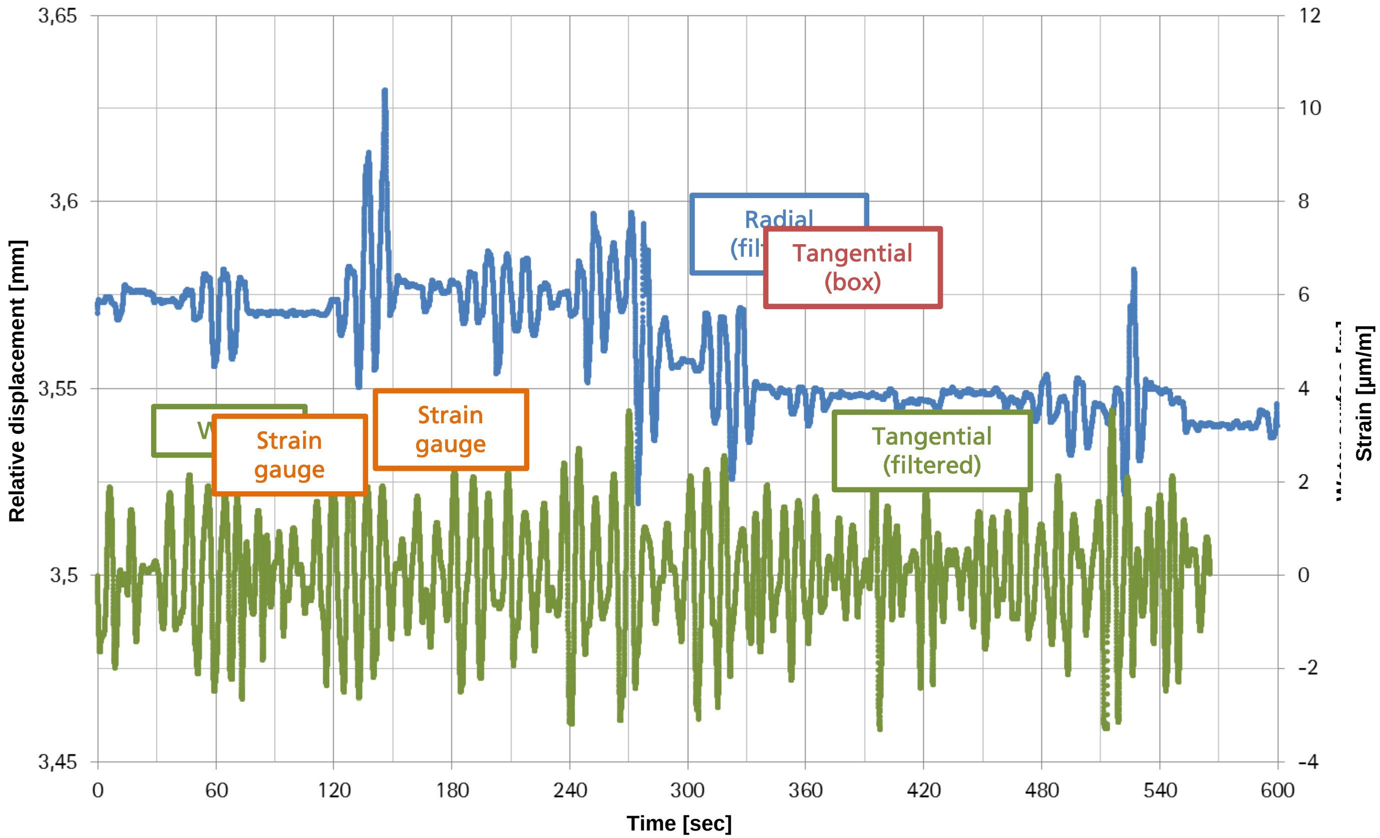
Measurement Data

5th February 2011
Wind: SW, 26 m/s





There is correlation between relative displacement signal and structural response as well as wave height.

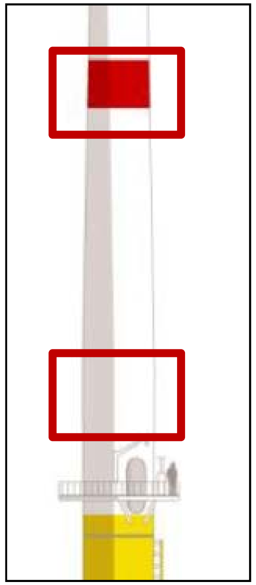


LOCAL MONITORING

Measurement Data Assistant

- Goals:
  - **Classify and categorize** raw data from RAVE data archive
  - Provide a **search function** for certain **load events**
  - Provide a **means** to directly use measurement data in data analysis software without having to download them first
- Setup:
  - **Server-based solution**
  - Measurement data and search indexes are stored in **efficient directory structure**
  - **Stateless Access** via HTTP (searches are traceable)
  - **Data is streamed** to the client, no preparation of downloads necessary
  - All data are exchanged in **structured plain** text (CSV, JSON)

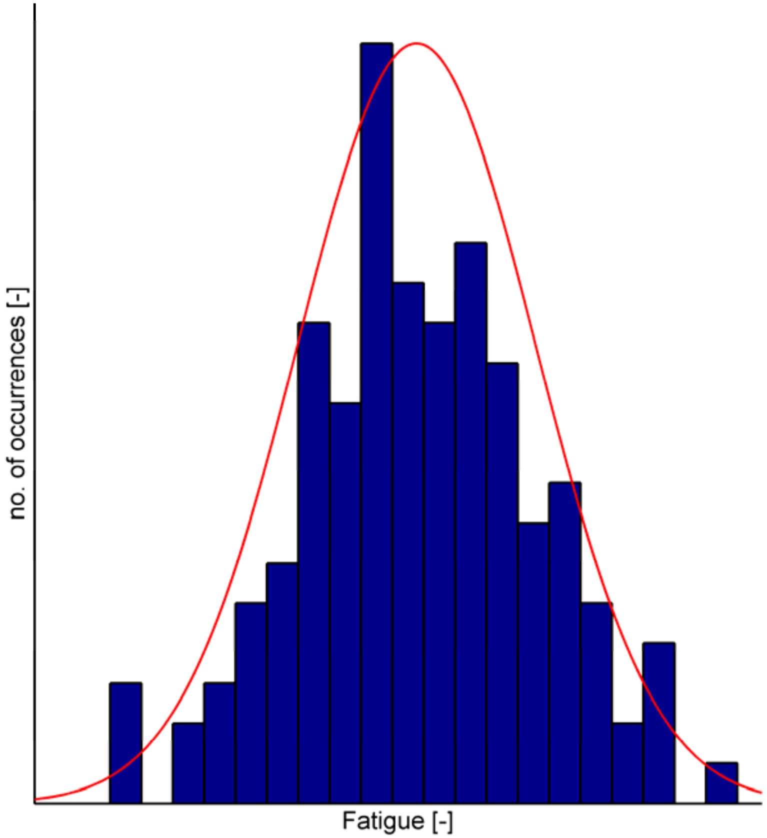
Fatigue approximation



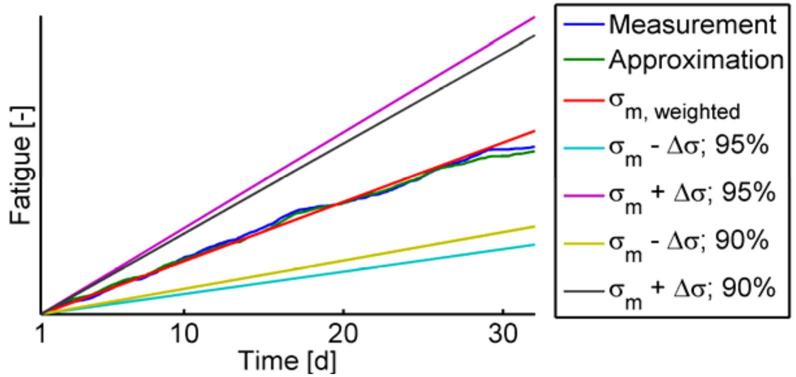
- Fatigue depends on external parameters
  - External parameters **depend on each other**
  - Fatigue must be considered depending on **combination of external parameters**
- Goal: Approximation of fatigue for three cases
  1. **Known parameters** of time period in question
  2. Approximation for **neighbouring turbine** in same period
  3. **Prognosis** of the future
- Method: Fatigue approximation with a Monte Carlo approach
  - Determination of **per-class distribution** of fatigue (Rainflow, Palmgren-Miner)
  - Classification of parameters of **base period** and **period in question**
  - **Approx. without strain measurements: Monte Carlo simulation** of fatigue using computed distributions with classified parameters in question
  - **For prognosis**: distribution of parameter classes for base period and their sequence (Markov chain), simulation of possible **future parameters** using a **Markov-chain-Monte-Carlo method**

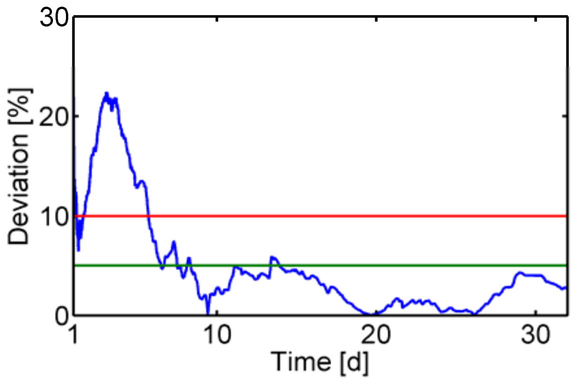
Fatigue approximation, results

Fatigue distribution for example class
- All external parameters have the same value

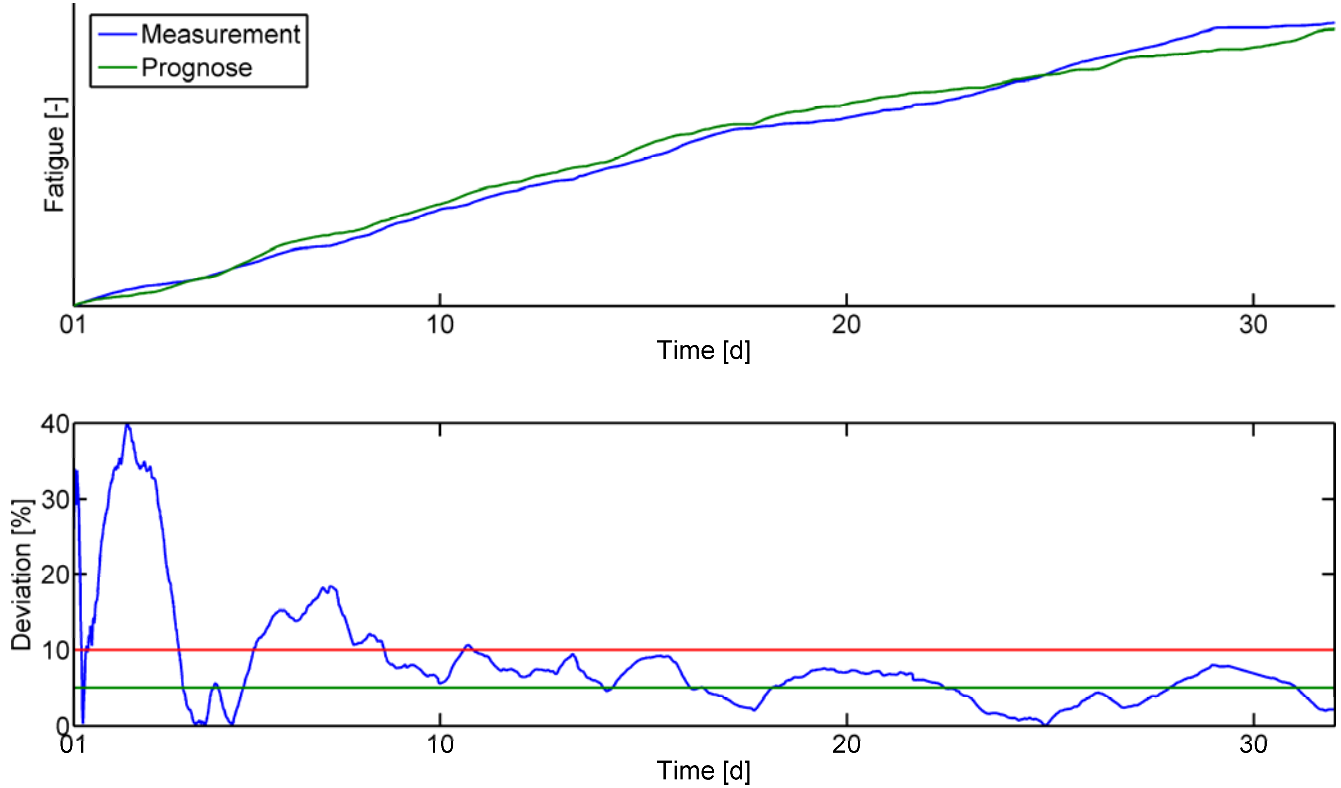


Approximation result for known parameters
- Dez.10 learned, Jan.11 approximated by external parameters and compared to measured strain (fatigue)





Approximation result for unknown parameters



- Fatigue prognose with MCMC simulation of external parameters
- Dez.10 learned, Jan.11 approximated without external parameters and
  compared to measured strain (fatigue)

GLOBAL MONITORING

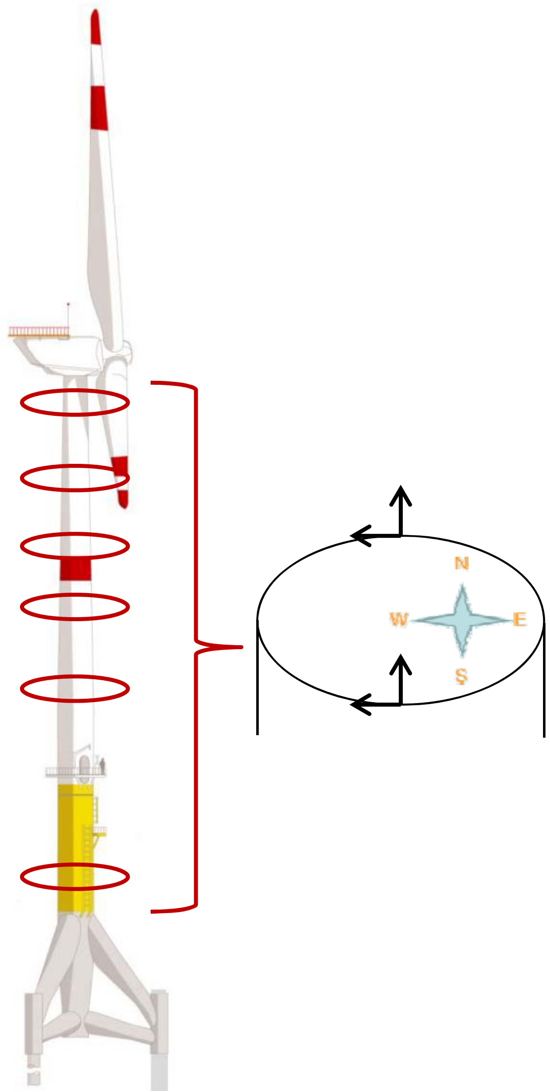
Concept to analyze the huge data basis

Goals:

- Extraction of **modal parameters** for damage localization and quantification
- Extraction of **condition parameters** (damage existence)

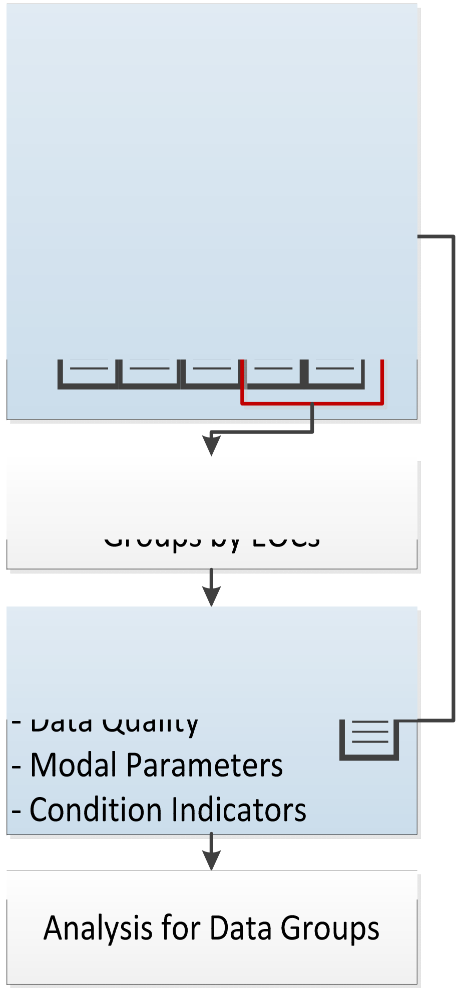
Data pool from *alpha ventus*:

- Period: February 2010 – June 2011 / 17 Month
- Volume: **1000 GB in binary .mat files**
- **48.000 Datasets** of 10 min length each holding
  - 50Hz data of 44 Acceleration sensors and 4 Strain gauges
  - plus **Environmental and Operational Conditions** (EOCs)



Concept to analyze the huge data basis

Concept:



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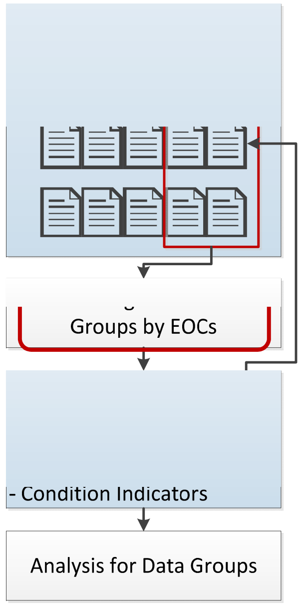
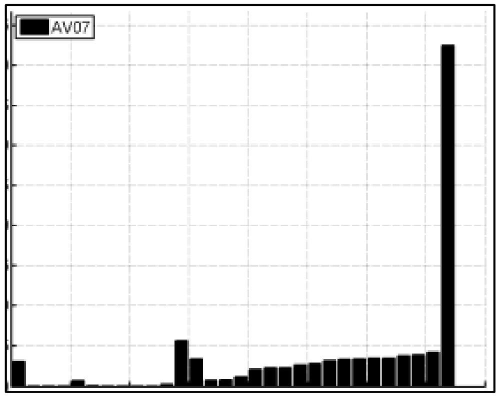
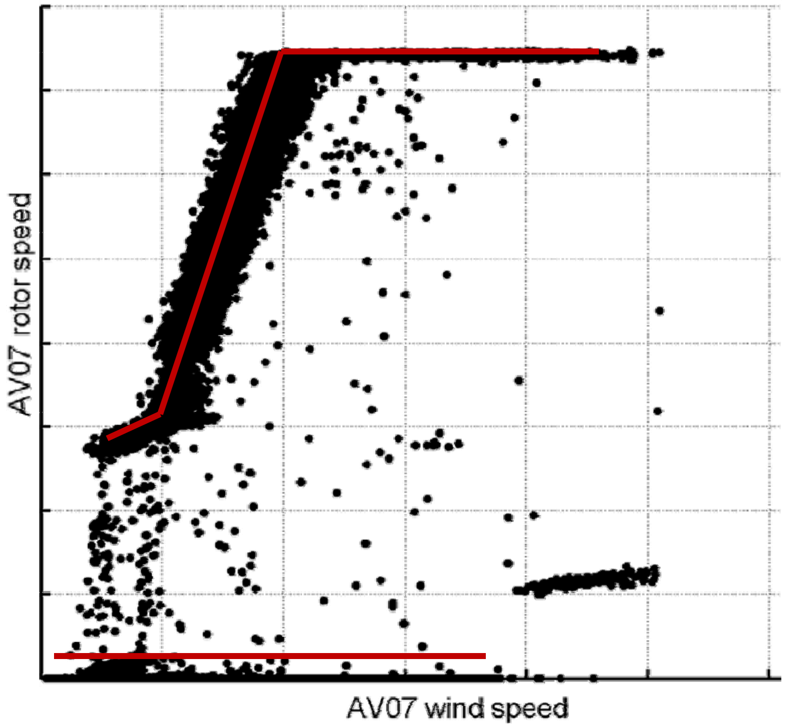
Grouping all data sets by EOCs



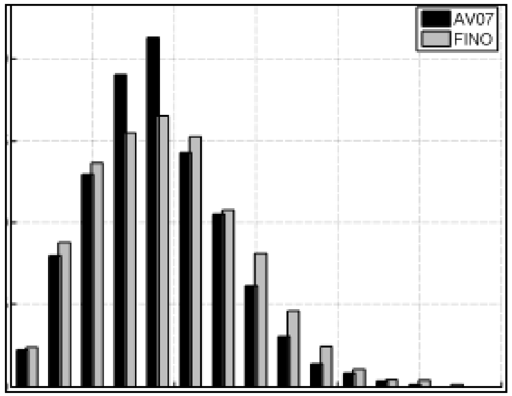
- Here exemplarily EOCs: **Rotor speed** and **wind speed**
- **Occurrence** important for combining **data sets to Groups**

Rotor speed

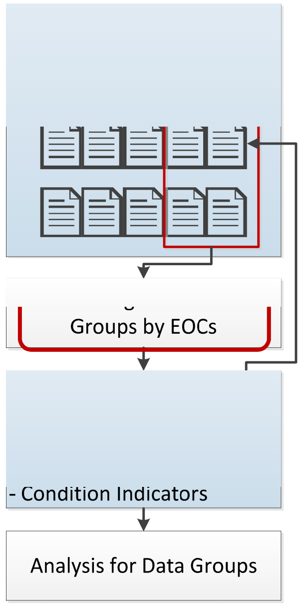




Wind speed

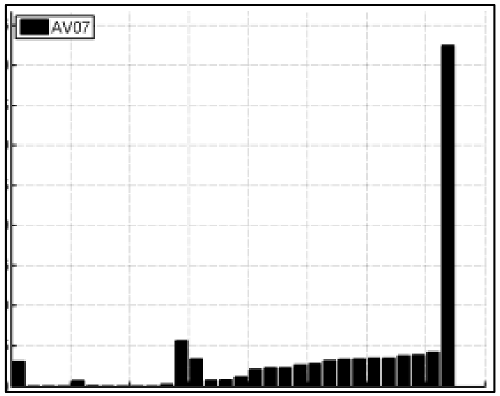


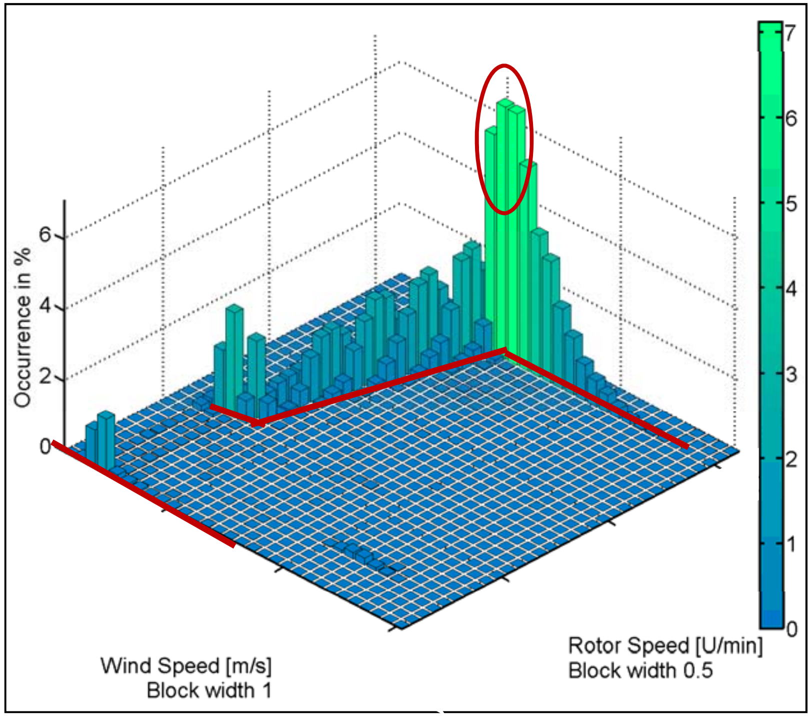
Grouping all data sets by EOCs



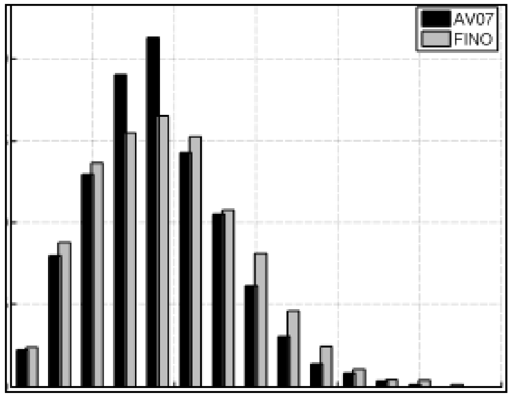
- Here exemplarily EOCs: Rotor speed and wind speed
- Occurrence important for Selection of sets to Groups
- In the following slides: **One Group with 1596 sets**

Rotor speed



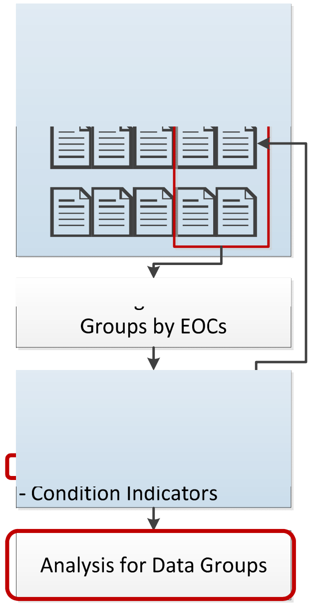


Wind speed

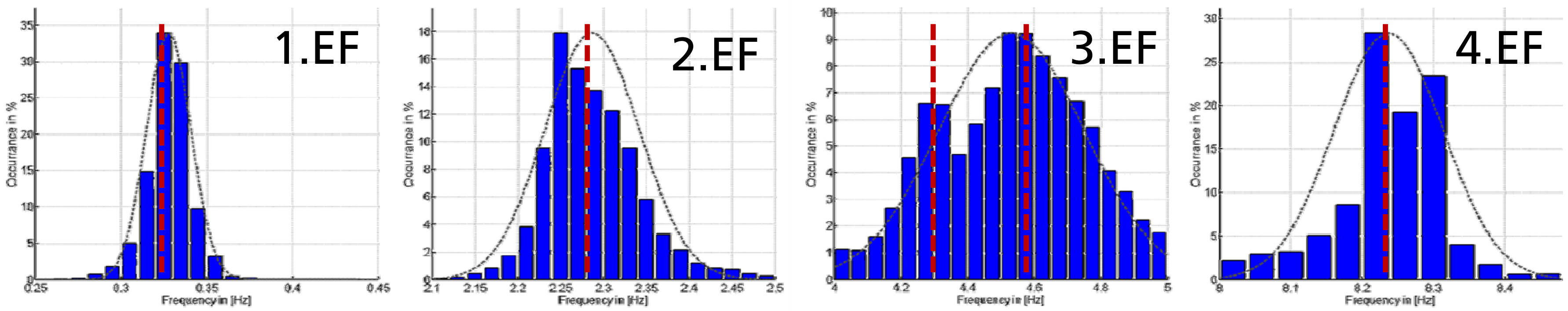


Modal Analysis for selected data group

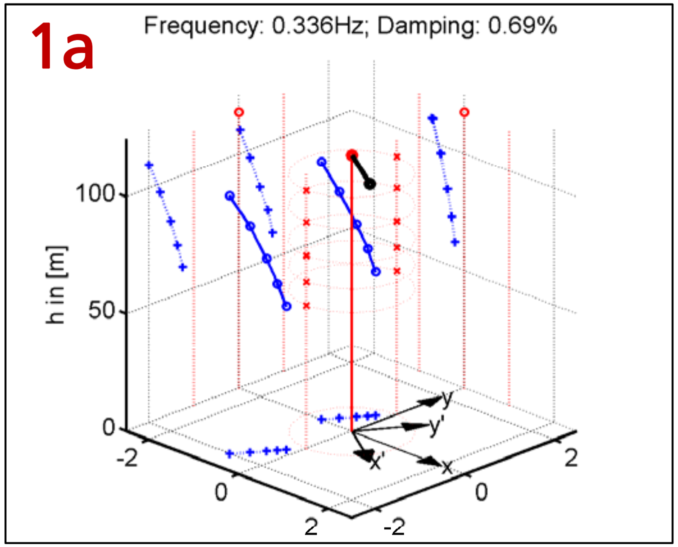
-1596 sets

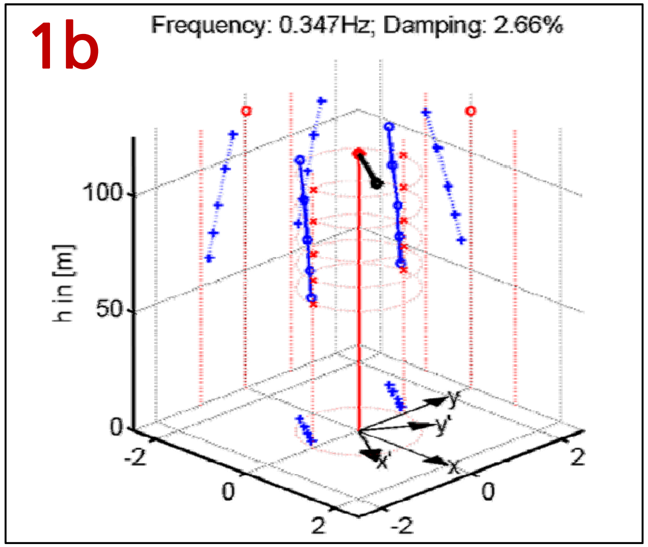


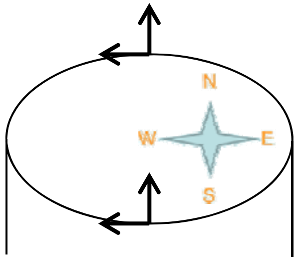
- **Eigenfrequencies** and **mode shapes** are important values for **Damage detection** and **model validation**
- In total: **20 Channels** at **five** different **levels** were used
- Used Method: **Data driven Stochastic Subspace Identification** (SSI) for several model orders. Hence, more solutions than phys. modes; a distinction between mathematical and physical solution is needed
- **3d mode shapes** can be calculated
  - Projection into nacelle KOS supports interpretation

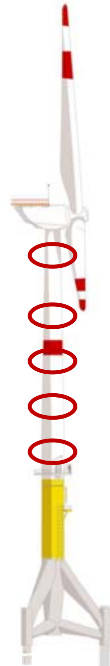


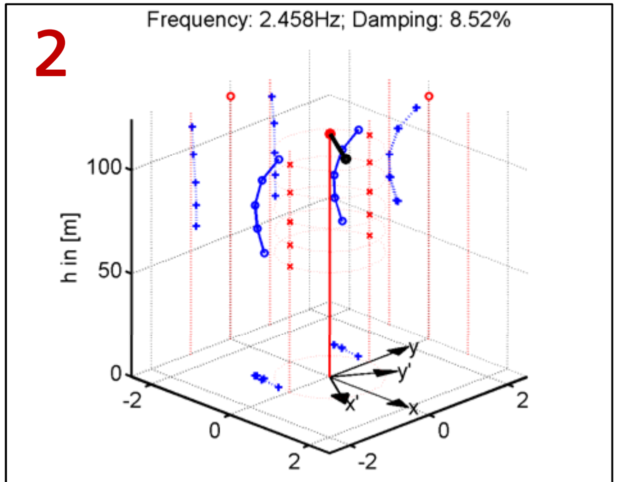
Modal Analysis for single data set

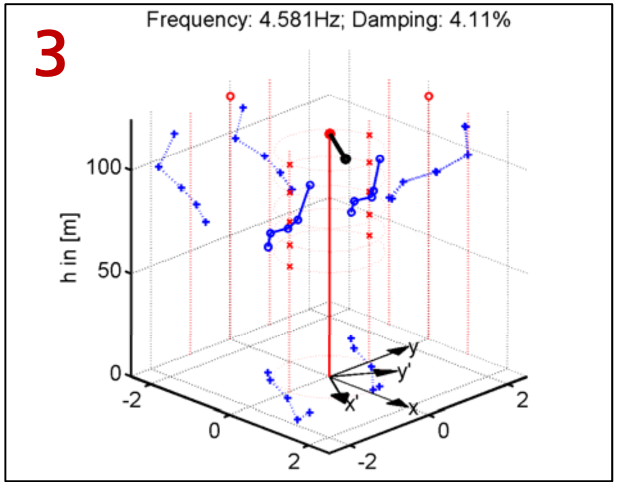


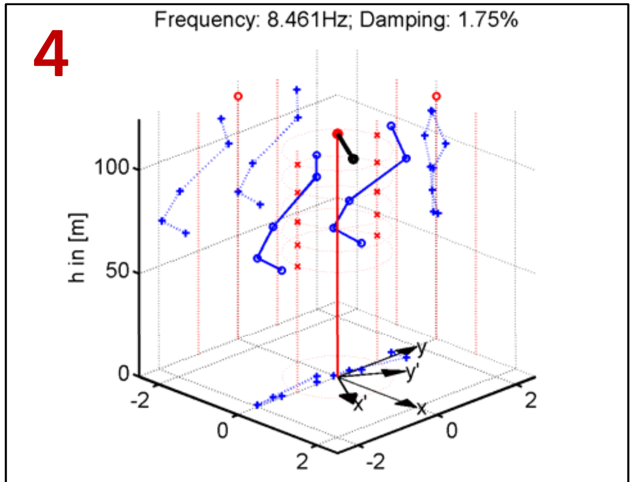




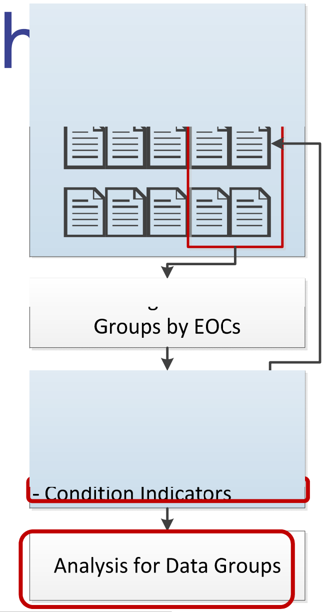




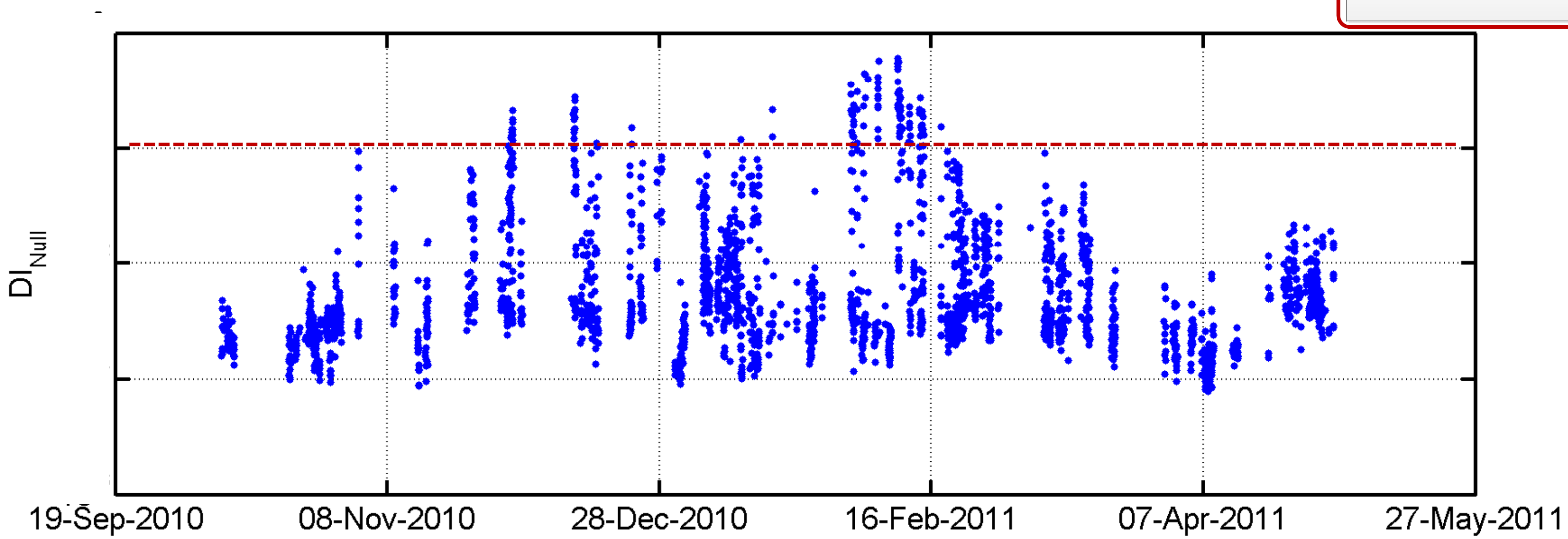




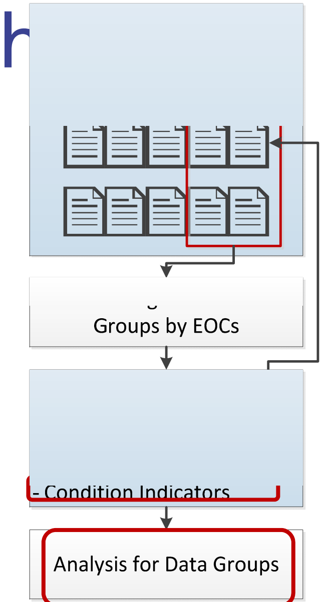
Condition Indicators give an idea about th structures state



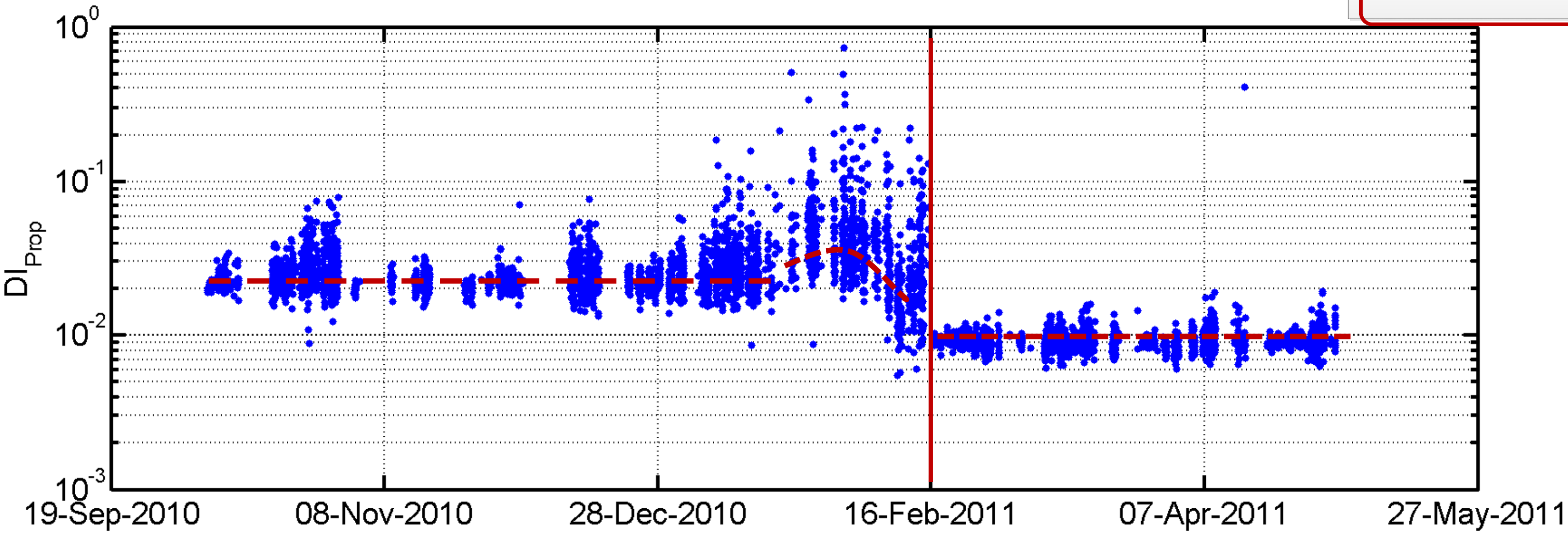
- DI_{Null}: Indicator from Covariance driven SSI. A **left Nulls pace** is calculated for the covariance Block-Hankel-Matrix and compared between reference set and further sets



Condition Indicators give an idea about the existence of damage

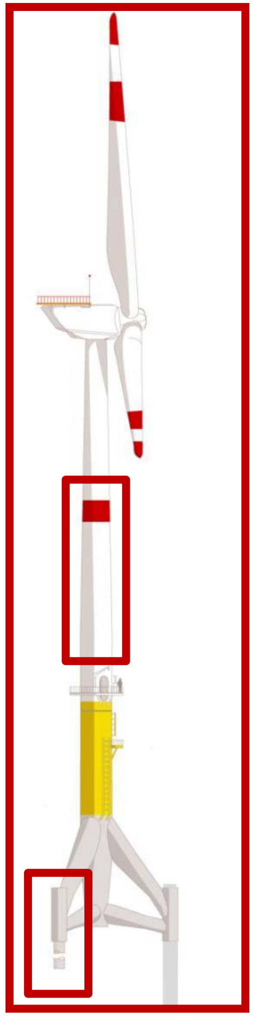


- DI_{Null}: Indicator from Covariance driven SSI. A **left Nulls pace** is calculated for the covariance Block-Hankel-Matrix and compared between reference set and further sets
- DI_{Prop}: **Proportionality indicator** for comparison of maximal strain level above Tripod and acceleration level below nacelle (both band-pass filtered for first bending mode)



Conclusions:

- **Grouted Joint**
  - Development of **prototype measuring** device for grouted joint displacements
  - Correlation between external loads (waves) and **grout-displacements**
- **Local Monitoring**
  - **Data assistant** for quick, local processing of measuring data
  - Calculation, approximation and forecast of **fatigue**
- **Global Monitoring**
  - Analysis of **global system dynamics** for model updating and later damage detection
  - Extraction of **condition parameters** to distinguish between healthy and unhealthy **system states**



Thank You for Your Attention !