RESEARCH AT ALPHA VENTUS

Offshore Wind R&D 2015

AN AREVA GAMESA COMPANY

Long-term experience at alpha ventus – Model and measurement based life time estimation

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Introduction

Adwen – an AREVA GAMESA company

Adwen has 126 wind turbines in operation in the German North Sea

- **6 alpha ventus**
- **40 Trianel Wind Farm Borkum**
- **80 Global Tech I**

19.4% market share during the first semester of 2015 **(according to EWEA statistics)**

Trianel Wind Farm Borkum (Source: http://www.adwenoffshore.com)

Overview

"Long-term experience at alpha ventus"

– Model and measurement based life time estimation –

Topics:

- **Lumping approach – an innovative consideration of wind and wave data for an integral load analysis**
- **Dynamic Wake Meandering (DWM) Model – Validation of fatigue loads based on long-term measurements at alpha ventus**
- **State Observer – automatized life time estimation of support structures based on measured loading**

This work is related to Adwen's current RAVE projects

- **OWEA Loads**
- **GIGAWIND*life***

Lumping approach

An innovative consideration of wind and wave data for an integral load analysis

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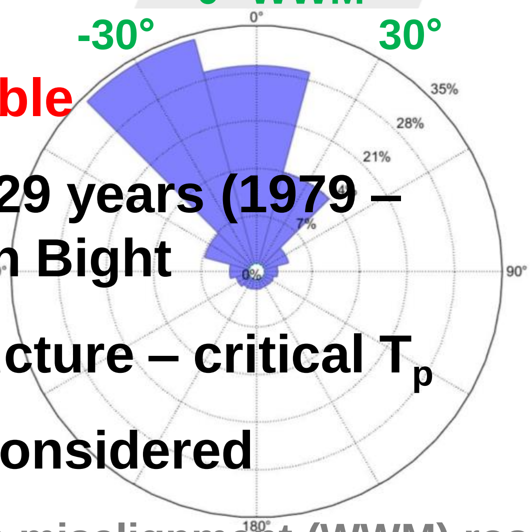
Lumping Approach

Classical Analysis and New Approach

- **Scatter matrices of hub wind speed (V_{hub}), significant wave height (H_s) and peak period (T_p) data form the basis for the classical analysis.**
- **From data correlation functions H_s (V_{hub}) and T_p (H_s) are derived**
- **<u>Classical fatigue load cases</u> defined using 30° WWM steps are *too conservative for monopile structures***

  ➔ **More realistic representation is preferable**

- **New <u>Lumping approach</u> was developed using 29 years (1979 – 2007) DHI model data representative of German Bight**
- **Specific consideration: Eigenfrequency of structure – critical T_p**
- **Wind-wave misalignment (WWM) is explicitly considered**



Exemplarily wind-wave misalignment (WWM) rose

Lumping Approach

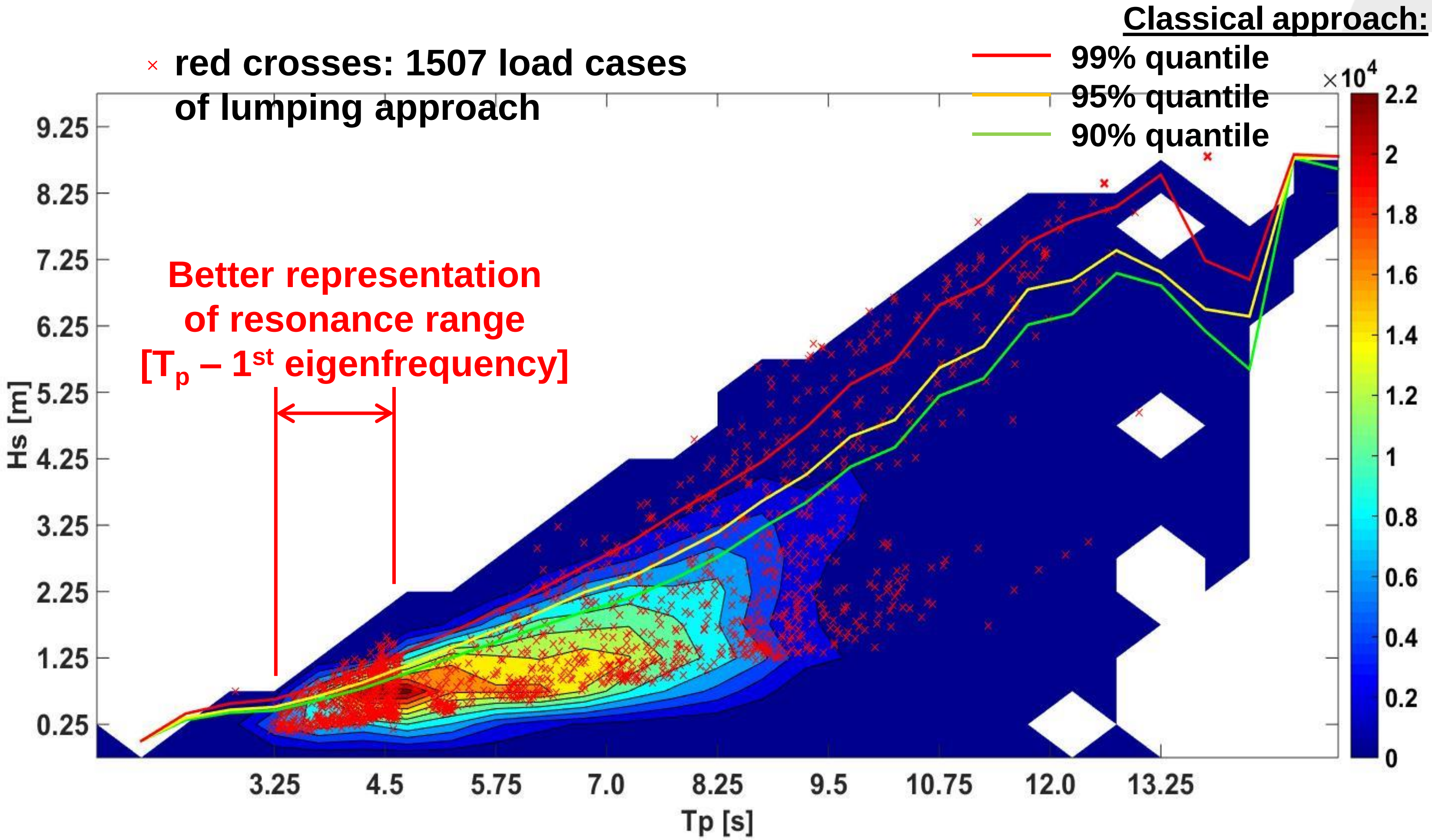
Analysis Method

- **Classification of (V_{hub}, WWM) for all events according to (T_p, H_s) → Basis of a representative load case set**
- **Critical: Peak spectral periods close to 1st eigenfrequency of the structure → higher resolution in critical range of T_p**
  - **For T_p > critical period: 4 sub-groups per (V_{hub}, WWM) combination specified**
  - **For T_p < critical period: 9 sub-groups per (V_{hub}, WWM) combination specified**
- **Results in ~1500 fatigue load cases for DLC1.1 / 6.4 acc. to GL 2012 (compared to 1300 in classic approach), but much more realistic**
- **Probability of occurrence for each load case assigned**

→ **Accepted by DNV GL for definition of load case groups DLC1.1 and 6.4**

Lumping Approach

Lumped (H_s, T_p) data compared to classical scatter data



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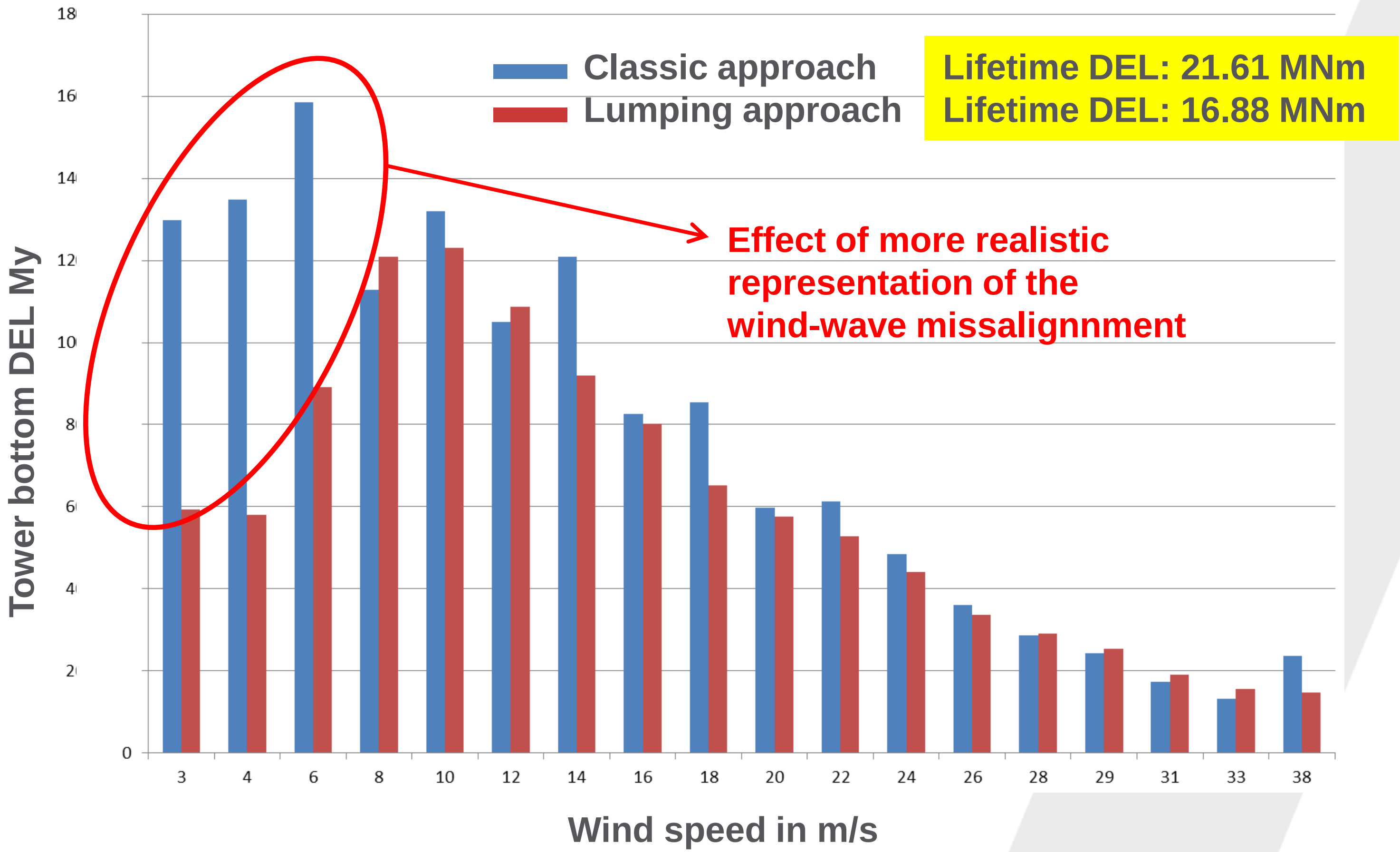
Lumping Approach

Tower bottom side-side DELs: Classic vs. Lumping



Dynamic Wake Meandering Model

Validation of fatigue loads based on long-term measurements at alpha ventus

In cooperation with B. Schmidt[1], S. Lott[2]

[1] 8.2 Consulting AG
[2] Stuttgart Wind Energy (SWE), University of Stuttgart, Germany

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8.2 AG Die Sachverständigen für Erneuerbare Energien The Experts in Renewable Energies

SWE

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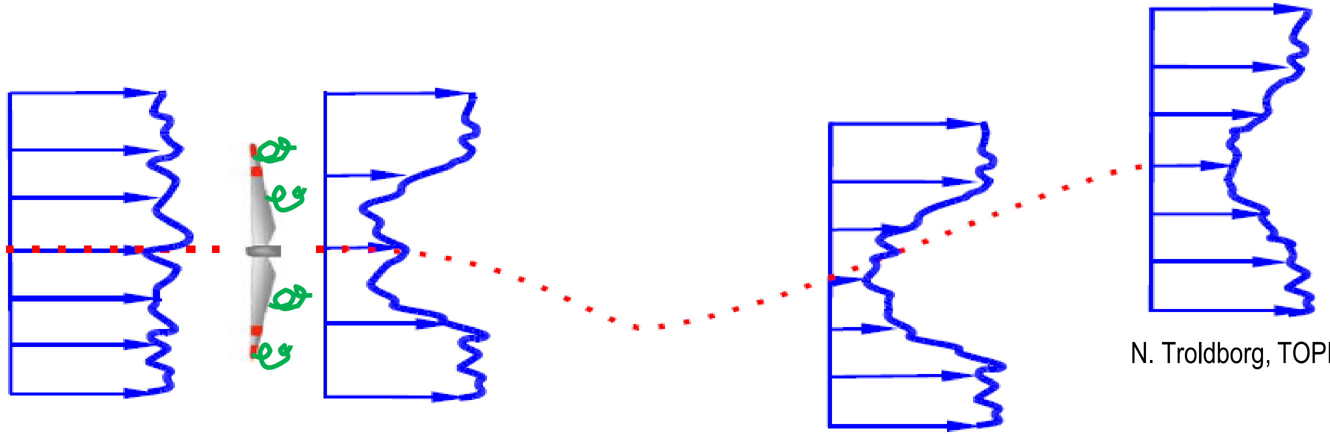
DWM Model

The Dynamic Wake Meander (DWM) model consists of, primary:

Velocity deficit | **Meandering** | **Added Turbulence**



N. Troldborg, TOPFARM, 2009

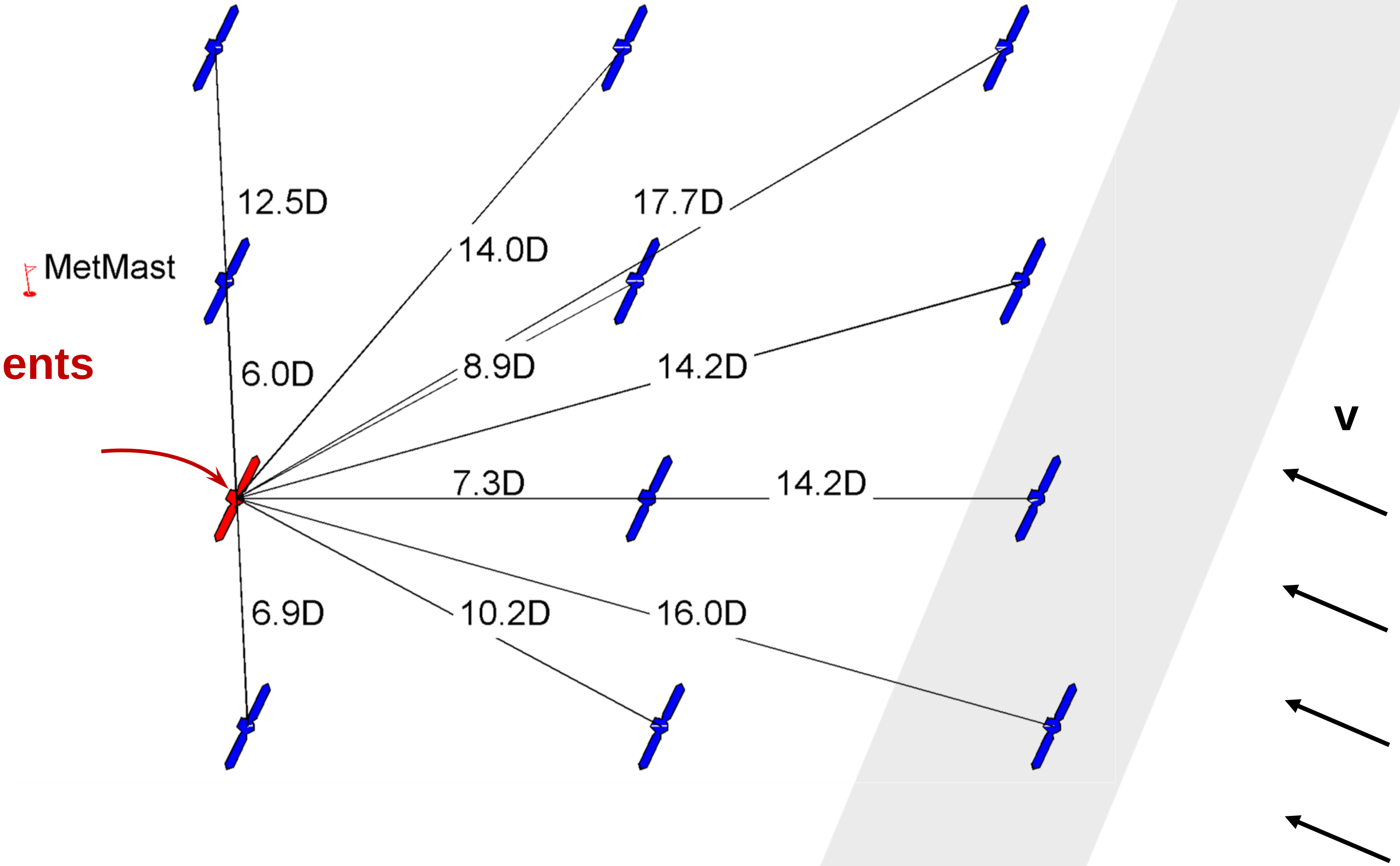
1) **Velocity deficit:** Extraction of kinetic energy reduces wind speed

2) **Meandering:** Wind speed deficit moves in space

3) **Added turbulence:** Blades and hub create vortices that add turbulence

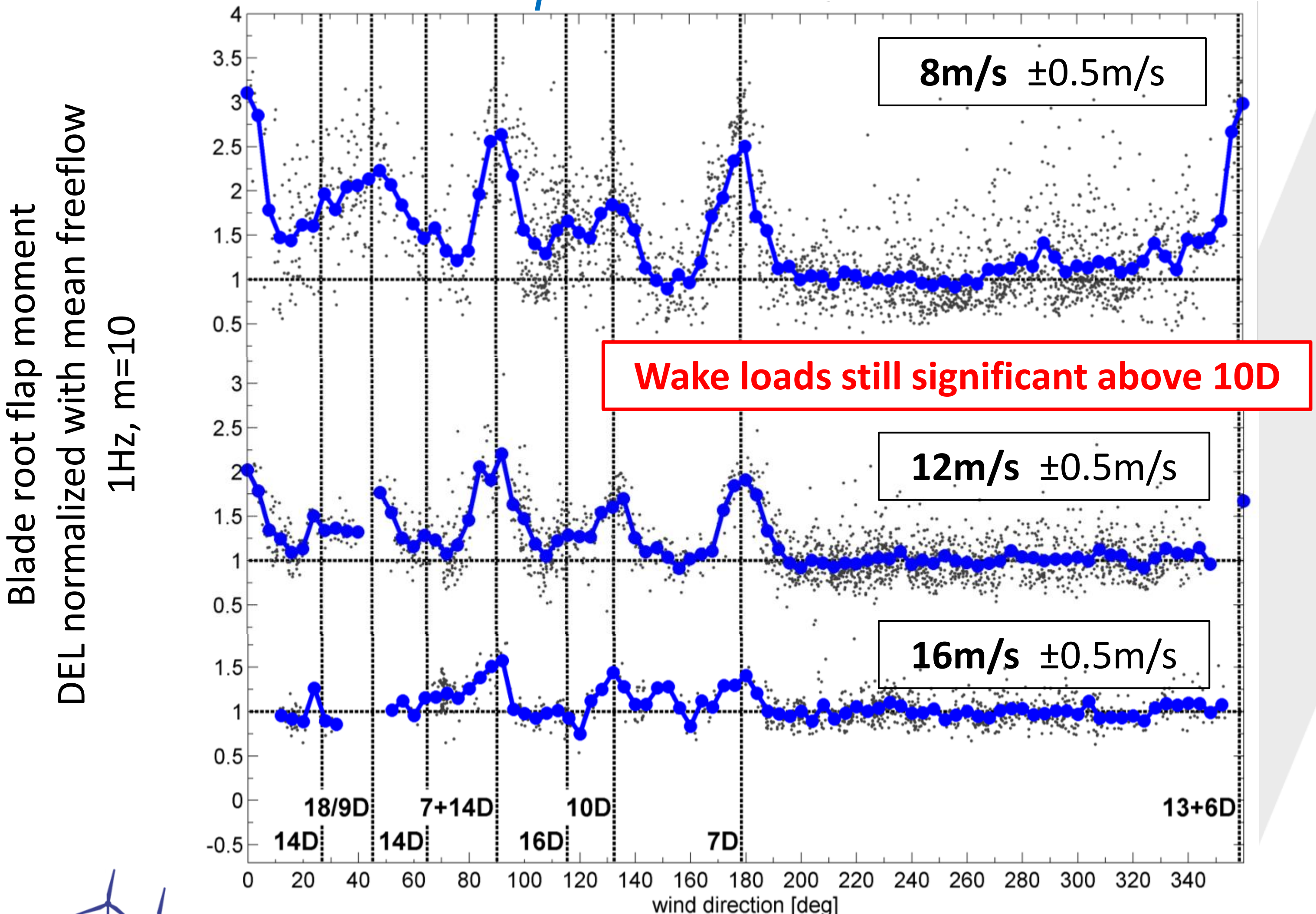
DWM Model

Alpha Ventus park layout with wake distances



DWM Model

Evaluation of alpha ventus measurement data

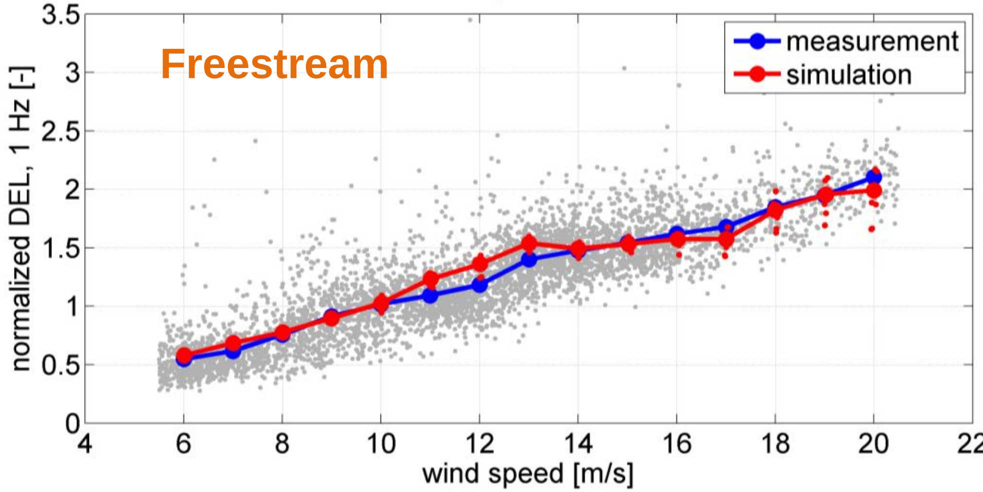


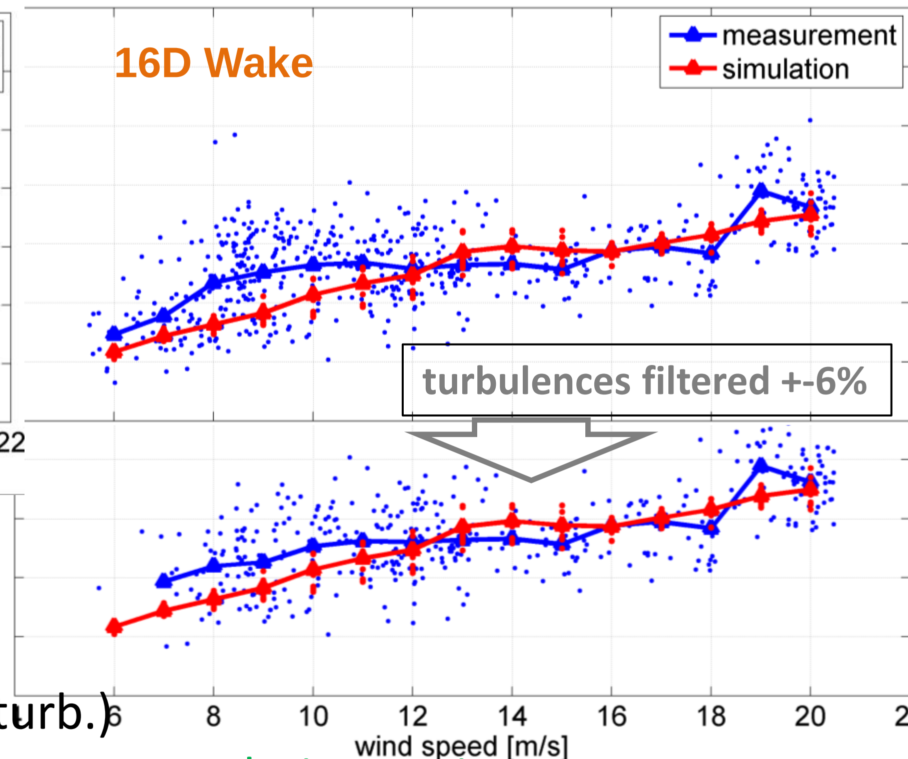
DWM Model

*Note: Presented loads are **not design loads**, only valid for this comparison!*

Blade Load validation with Bladed 4.3 DWM model

For example: Blade root flapwise moment, DEL m=10,





Blade root flapwise moment:

- Good agreement for Freestream
- Good agreement for 16D Wake (filtered turb.)
  → measurement data base enlarged to **4 years**, analysis ongoing

DWM model has also been validated for tower bottom fore-aft moment.

State Observer

automatized life time estimation of support structures based on measured loading

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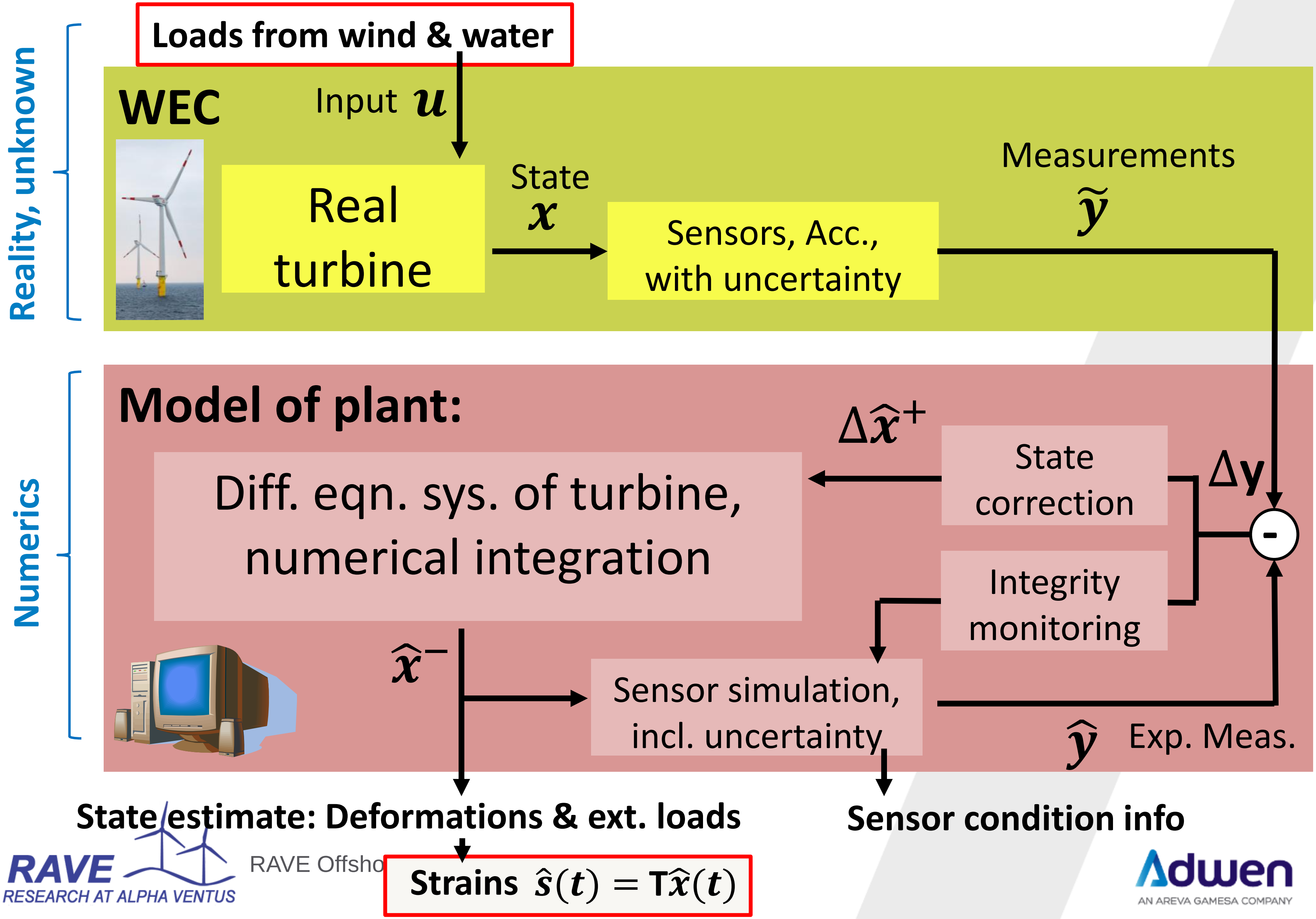
State Observer

Concept for monitoring of fatigue loads

- ***Simulated*** **fatigue loads of OWECs may contain several uncertainties → significant potential expected by knowledge of *real* fatigue loads**
- ***Therefore measured*** **fatigue loads and *real* lifetime estimation needs continuous evaluation of strains at critical points**
- **Strain sensors have insufficient lifetime → Accelerometers do better**
- **Not trivial to calculate deflections / strains from accelerometers due to summation of sensor errors. → Model based Kalman Filter yields optimal estimates**
- **Benefits of Kalman Filter:**
  - **Considering all available (mixed) sensor information to improve accuracy**
  - **Realtime state estimate (deflection, forces) for advanced control**
  - **Realtime Sensor Integrity Monitoring**

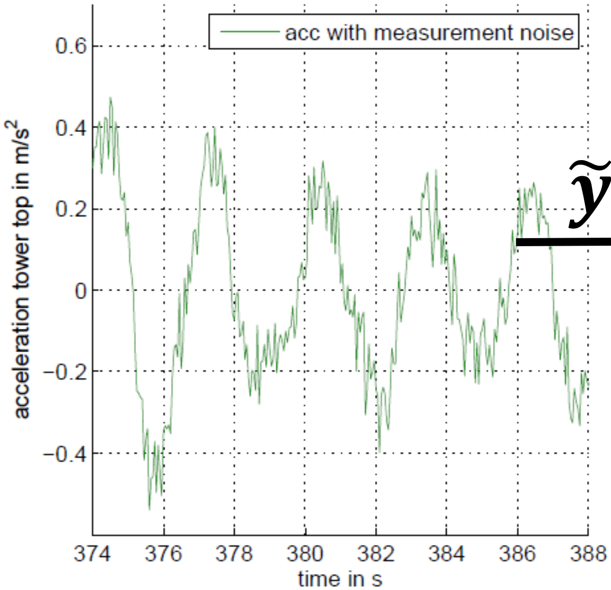
State Observer (Kalman Filter)



State Observer

Simplified example

Measurements

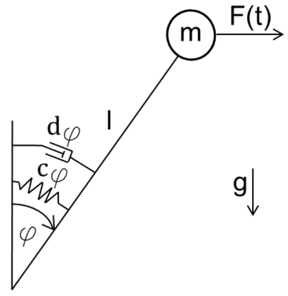


$\tilde{y}$

Kalman Filter

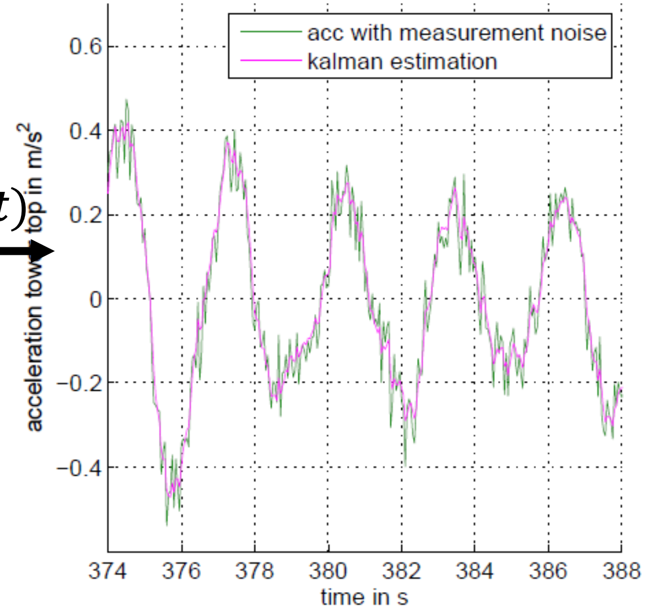
- **Time Update (“Predict”)**
- **Measurement Update (“Correct”)**

Mechanical model



$\hat{x}(t)$

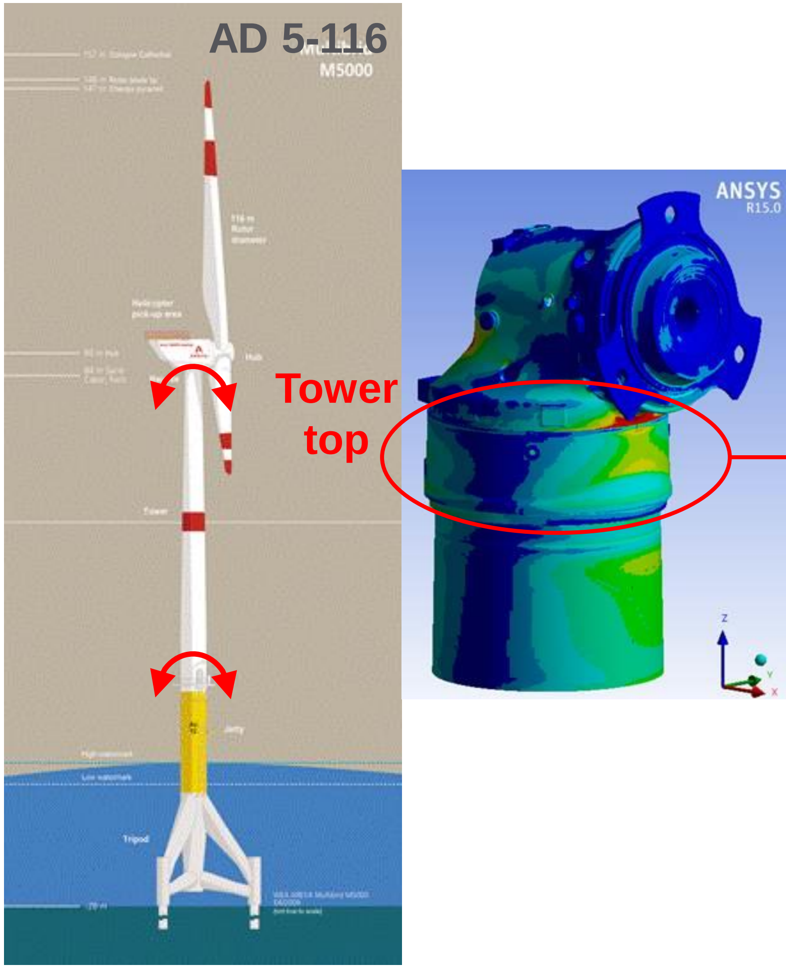
Plot of estimated acceleration



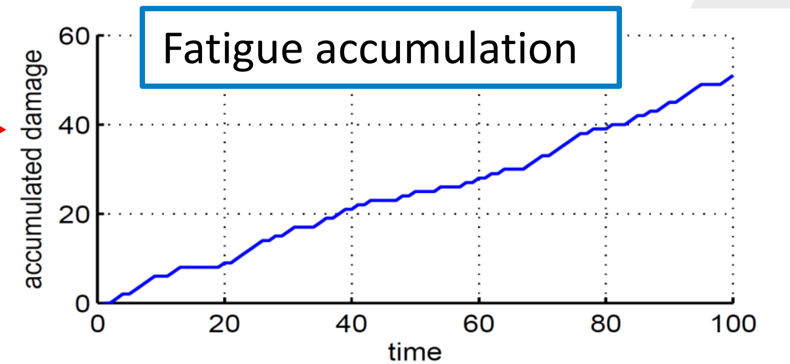
- **Result: Strain time series from estimated state** $\hat{s}(t) = \mathrm{T}\hat{x}(t)$
  - **Mean deflection (strain) poorly estimated despite excellent accelerometer. Observability problem → Additional information like „mean thrust“ will help**
  - **Lifetime estimation requires only amplitudes as long as mean stress values are small with respect to the measured amplitude**

State Observer

Perspective



- **With a sufficient state estimation, the accumulated damage can be calculated:**



➢ **Fatigue assessment possible for all points of the tower depending on the used model**

➢ **Remaining life time estimation**

Summary

Outlook

Summary / Outlook

Long-term experience at alpha ventus

Lumping approach — Load Simulation

- More realistic approach of applying environmental input for fatigue load calculation – *accepted by DNV GL*
- Benefit shown for monopile substructures

Dynamic Wake Meandering (DWM) model — Load Validation

- Wake effects shown from OWECs with more than 10D distance
- Implementation of DWM in Bladed and validation with RAVE data

→ further improvement using more than 4 years of AV measurement

State observer for fatigue monitoring — Load Prediction

- Realtime model + real measurements = real fatigue loads
- Functionality shown for simple model

→ Advancement planned for real-scaled structures, Validation @ AV

Thank you !