Enhanced design basis for offshore wind farm load calculations based on met-ocean data from a floating LiDAR system

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Outline

- Background and motivation
- Methodology
- Results
- Conclusions and outlook

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Background and motivation

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Background and motivation

- Design Basis for planning and development of offshore wind farms
- Design Basis includes
  - Local environmental conditions
  - Soil conditions
  - Ect.
- Basis for load calculations
- Basis for final wind turbine system and structure design
- Guidelines: IEC 61400-1, IEC 61400-3

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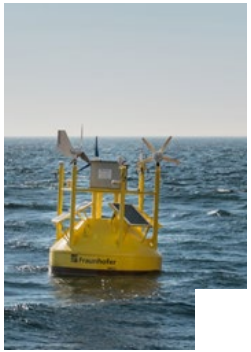
Background and motivation

Research project OptiDesign* (2016-2020)

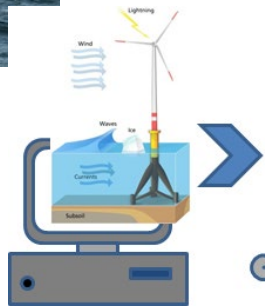


Local measurements with a Floating LiDAR System (FLS)

Site specific and advanced Design Basis for load simulations

Cost reduction for structure designs

Risk minimization for large rotor blades



Optimized Design

€ Cost reduction

* OptiDesign (2016-2020, FKZ 0324043A) is funded by the German Federal Ministry for Economic Affairs and Energy on the basis of a decision by the German Bundestag and project management Projektträger Jülich.

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Methodology

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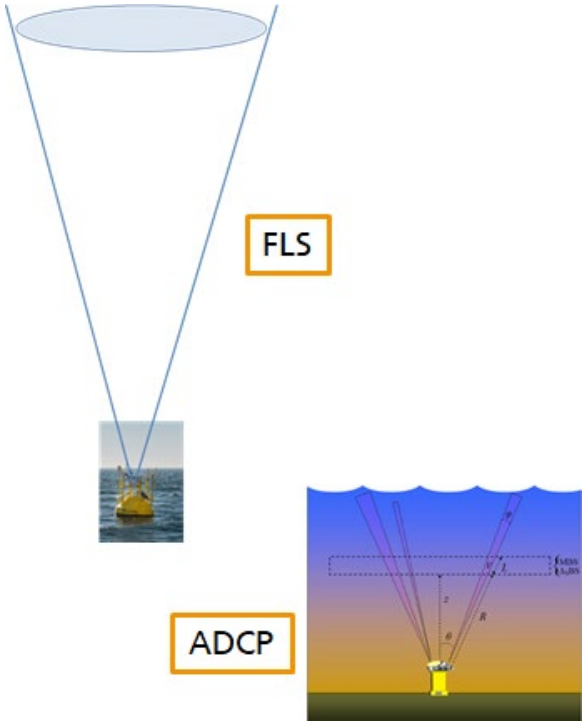
Enhanced Design Basis

Procedure

- Site specific met-ocean data of an FLS and ADCP*
  - Determining all basic parameters
  - Method to correct motion-affected turbulence intensity (TI)
- Assessment of advanced parameters (deviating from the standard recommendations)
  - Different wind shear and current profiles
  - Advanced analyses of wind-wave-correlations



* Acoustic Doppler Current Profiler

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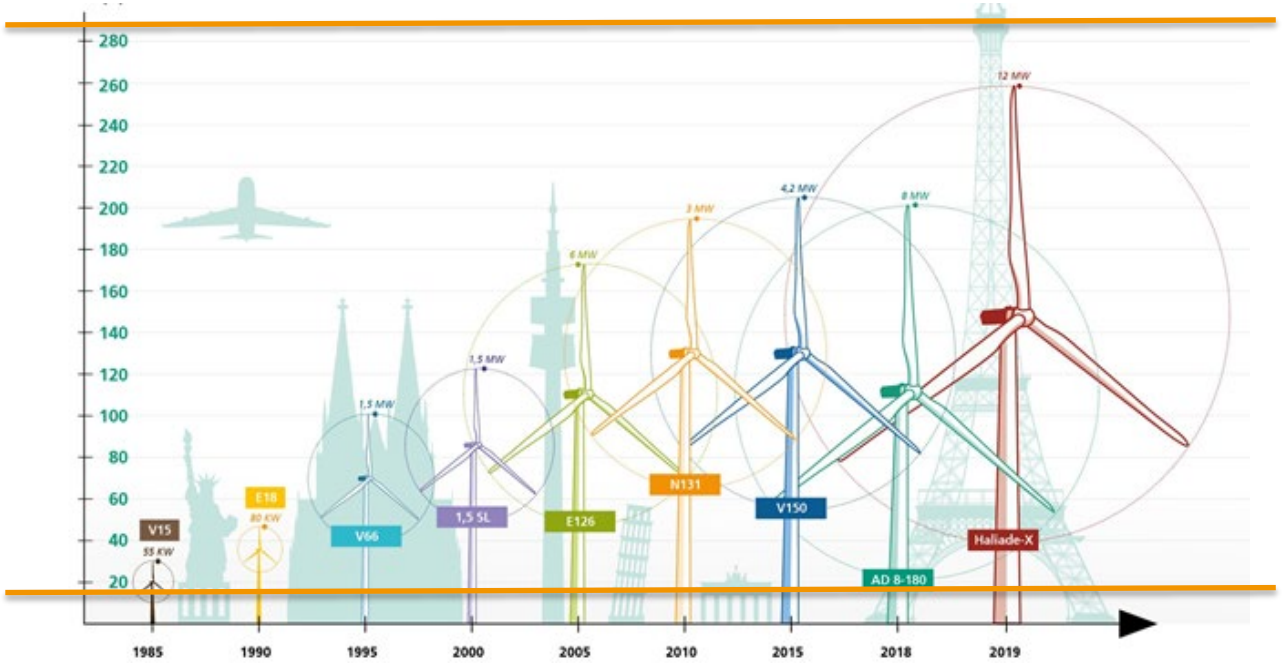
Measurement campaign

Wind measurements with floating LiDAR system

- Measurement heights of LiDAR system
  - 11 heights
  - From 15 m up to 285 m
- Wind measurements
  - Speed
  - Direction



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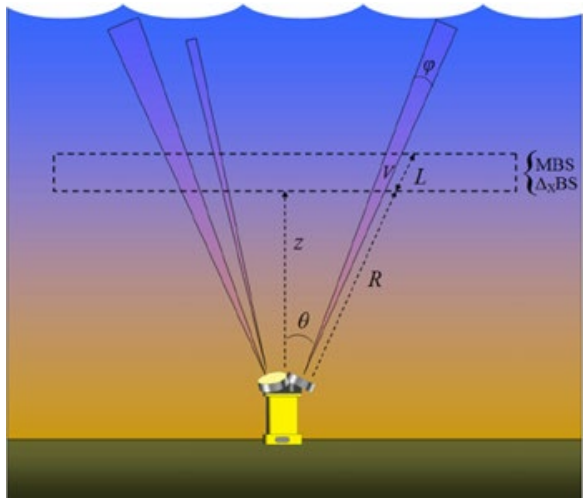
Measurement campaign

Wave and current measurements with an ADCP mounted in a frame on the sea bottom

- Wave measurements
  - Significant wave height H_s
  - Peak wave period T_p
  - Wave direction
- Current measurements
  - Profile (5 m steps)
  - Current speed and direction



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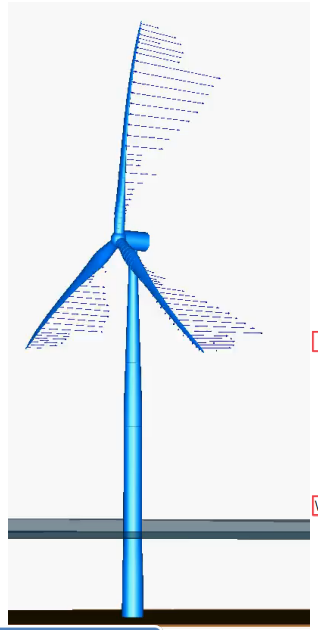
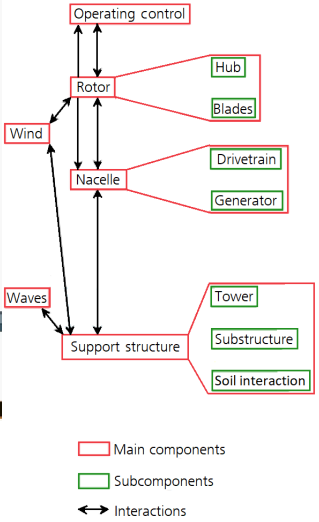
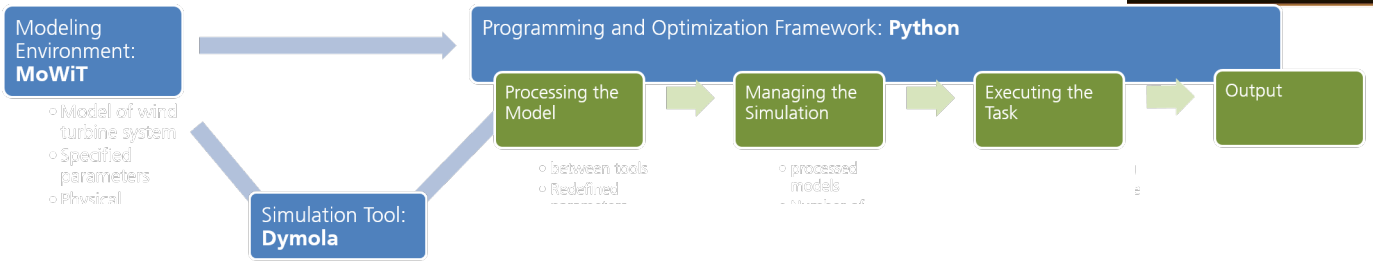
Load simulations

Toolchain for automated fully coupled simulations

- Computational model for wind turbine load calculations
  - Using MoWiT (**Mo**delica® library for **Wi**nd **T**urbines)
  - Component-based modeling
  - Aero-hydro-servo-elastic simulations
- Framework for automated simulation







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Load simulations

Selected design load cases (DLCs)

- According to IEC 61400-3 ed. 1

	DLC	Condition	Wind	Waves	Directionality wind/waves	Current
Fatigue	1.2	Operation	Normal turbulence model	Normal sea state	codirectional, multidirectional	No current
	2.4	Operation + fault	Normal turbulence model	Normal sea state	codirectional, multidirectional	No current
	6.4	Parked	Normal turbulence model	Normal sea state	codirectional, multidirectional	No current
Ultimate loads	1.3	Operation	Extreme turbulence model	Normal sea state	codirectional, unidirectional	Normal current model
	2.1	Operation + fault	Normal turbulence model	Normal sea state	codirectional, unidirectional	Normal current model
	5.1	Emergency stop	Normal turbulence model	Normal sea state	codirectional, unidirectional	Normal current model
	6.1a	Parked	Extreme wind speed	Extreme sea state	shifted, multidirectional	Extreme current model
	6.2a	Parked + fault	Extreme wind speed	Extreme sea state	shifted, multidirectional	Extreme current model

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Results

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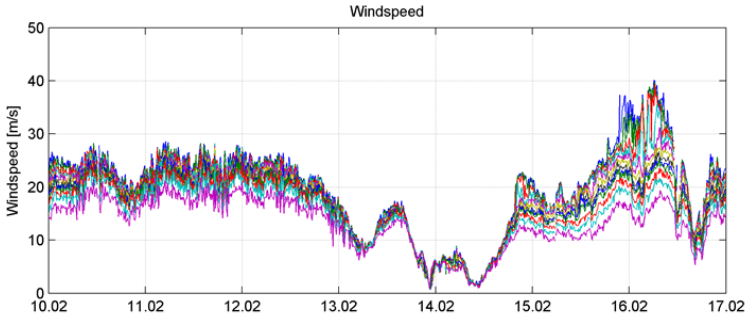
Measurement campaign

Overview

- Close to wind farm "Meerwind Süd | Ost" of project partner WindMW Service GmbH
- Period: 01/2020 - 04/2020
- Very stormy measurement period (storm Sabine)

max. wind speed	42.7 m/s in 285 m
max. sign. wave height	7.7 m
max. indiv. wave height	10.6 m (12.02.2020)



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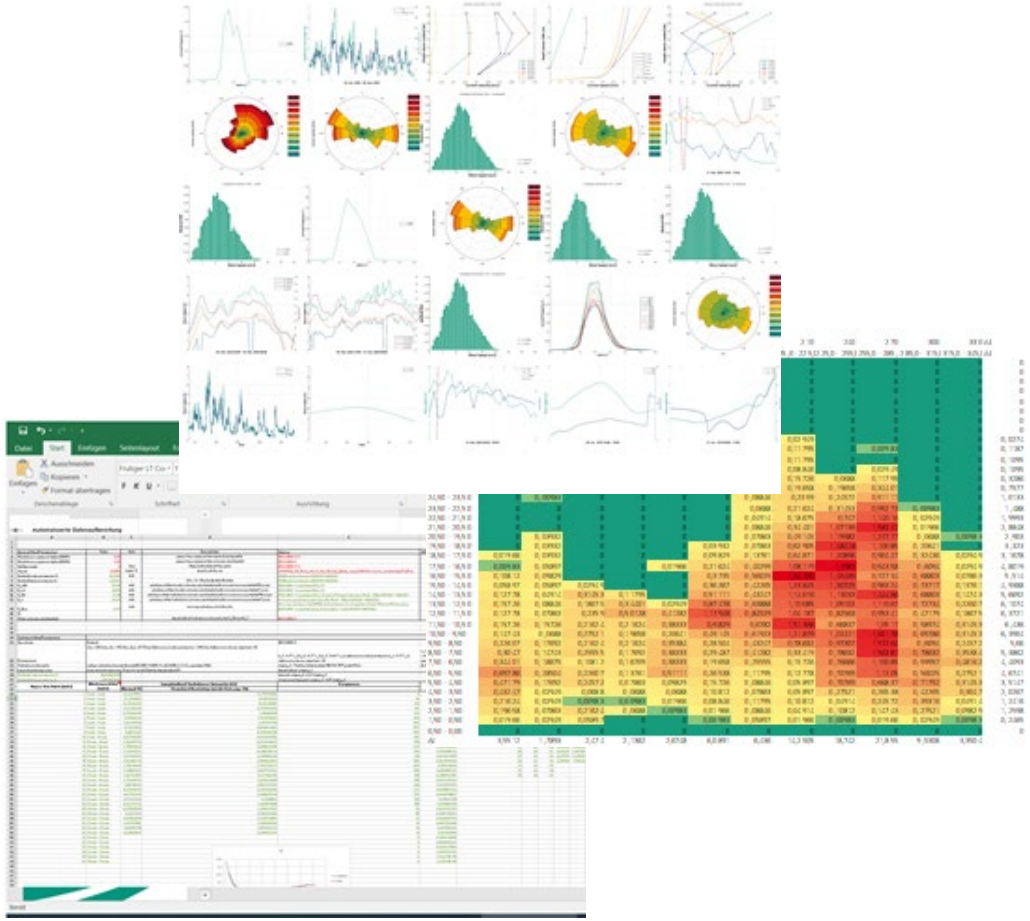
Measurement campaign

Results for enhanced Design Basis

- Developed MATLAB-based tool for automatically determining all basic and advanced environmental parameters
  - Scatter tables and diagrams, plots
  - Output in Excel-table for load simulations



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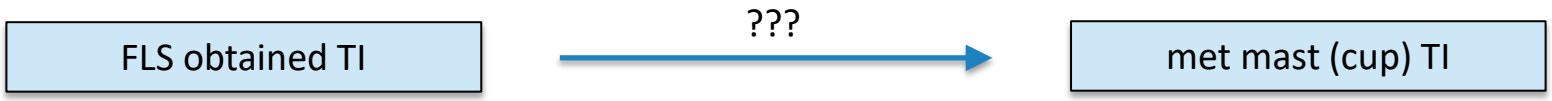
Turbulence intensity from FLS measurements

Procedure



- Motion correction versus em empirical solution
- Sensitivity analysis for TI
  - Sensitivities for observed wind speed and TI

$$TI_{Optimized} = x_1 * TI_{FLS}^{Observed} + x_2 * U_{FLS}^{Observed} + Offset$$

- Calibration based on a 6-month verification campaign using FINO1

$$= 1.1556 * TI_{FLS}^{Observed} - 0.2405 * U_{FLS}^{Observed} - 8.4146$$

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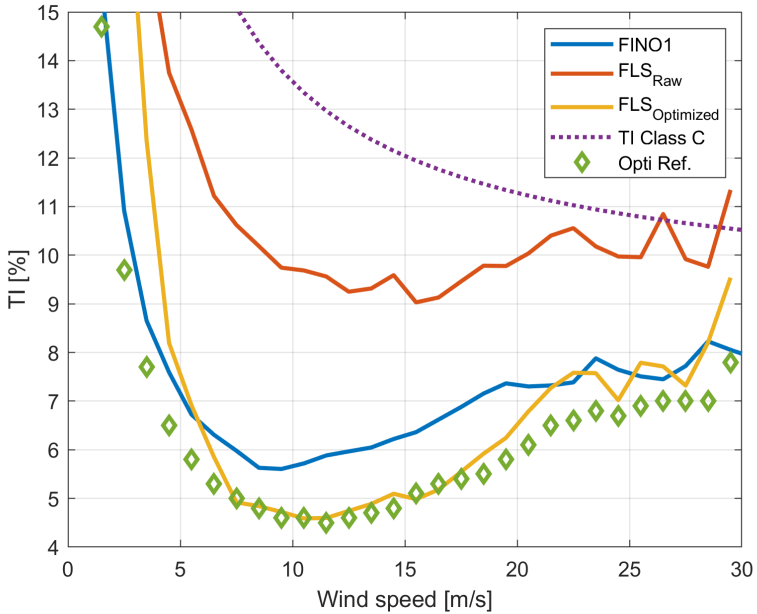
Turbulence intensity from FLS measurements

Results

- Verification: good TI agreement for measurements in Irish and North Sea (FINO3)
- OptiDesign measurement campaign
  - Was too short for improving TI assessment
  - But it's worth to compare existing TI values and FLS TI
  - ➢ Optimized FLS TI values match the existing TI values!



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Load simulation scenarios

Design Bases of different levels of advancement

- Design Basis 1 (DB 1)
  - IEC standard recommendations
  - “Meerwind Süd|Ost” data, supplemented by CoastDat for wind-wave-correlation data
- Design Basis 2 (DB 2)
  - Replacement of selected data in DB 1 through data from measurement campaign
  - Supplemented by ERA 5 data set for long-term data
- Design Basis 3 (DB 3)
  - DB 2 extended by wind speed, wind direction, and current speed profiles

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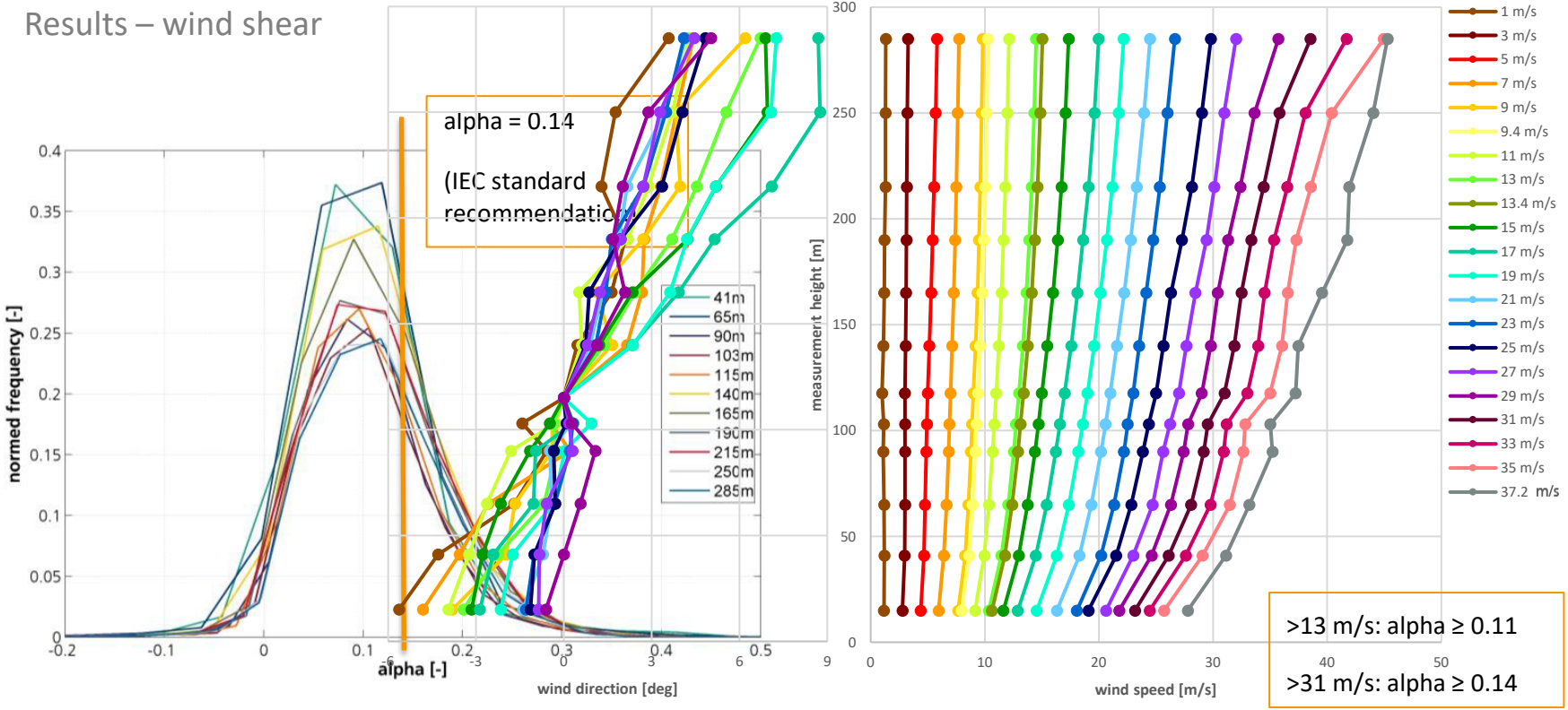
Measurement campaign

Results – wind shear



>13 m/s: alpha ≥ 0.11

>31 m/s: alpha ≥ 0.14

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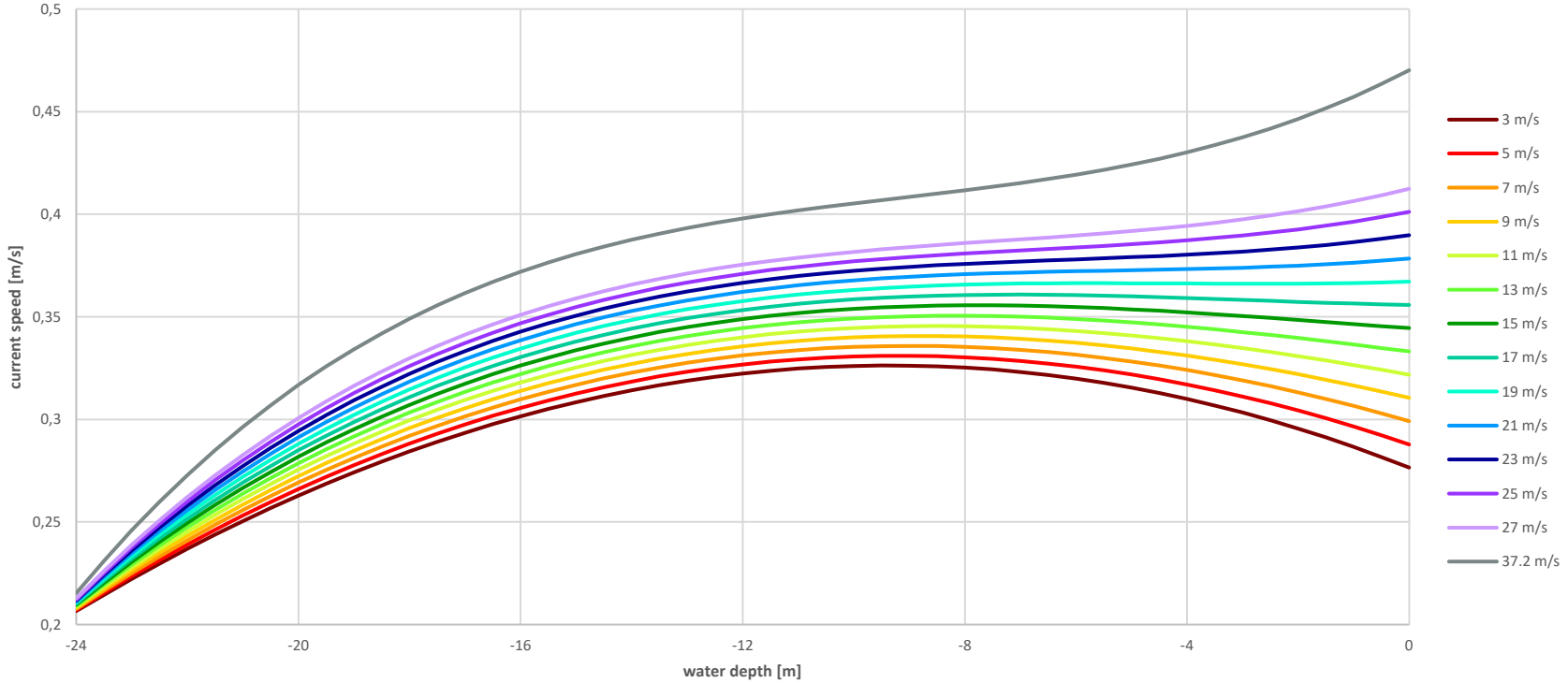
Measurement campaign

Results – current profiles



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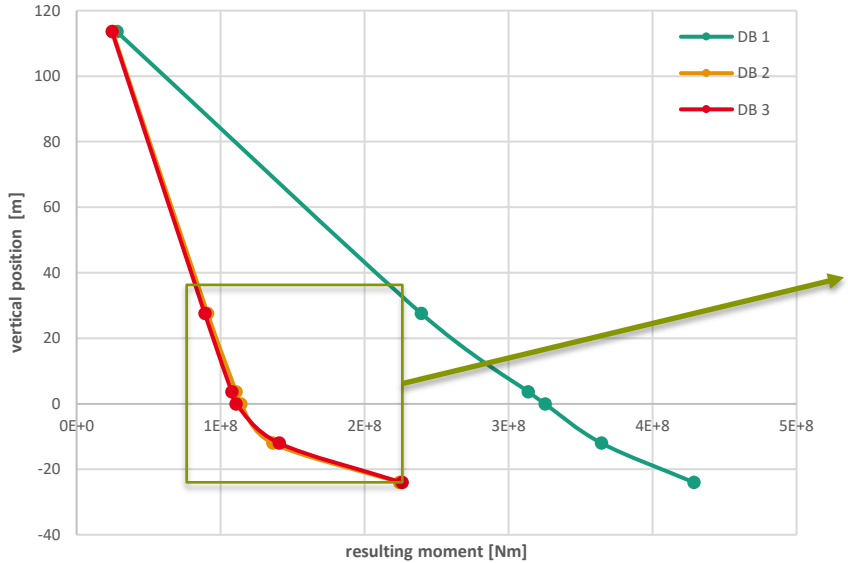
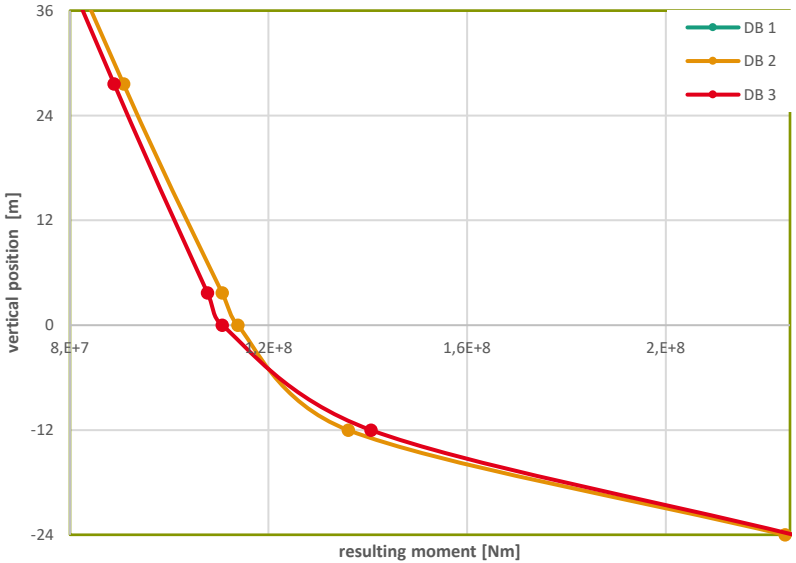
Load simulation scenarios

Resulting loads on the structure

- Based on the example of Fraunhofer's IWT-7.5-164 reference wind turbine on a monopile





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Conclusions and outlook

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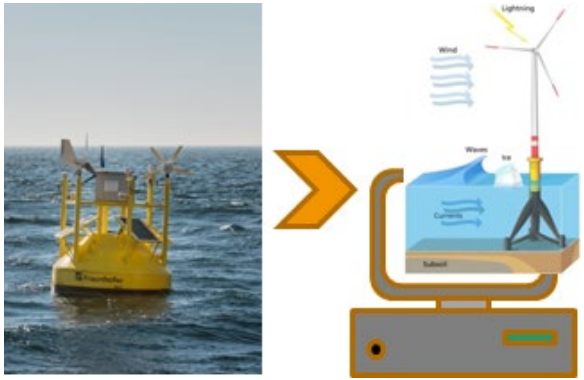
Conclusions

- FLS can be utilized as a more site specific solution for a Design Basis compared to model data
- Common standards recommend rather conservative values for environmental parameters and load design cases
- Advanced local parameters such as wind and current profiles can be implemented in load simulations
- Enhanced Design Basis allows potentially more cost effective offshore wind turbine system designs



➢ High potential in the development of new projects (large rotor blades)

➢ High potential in performance upgrades of old systems (service life extension)

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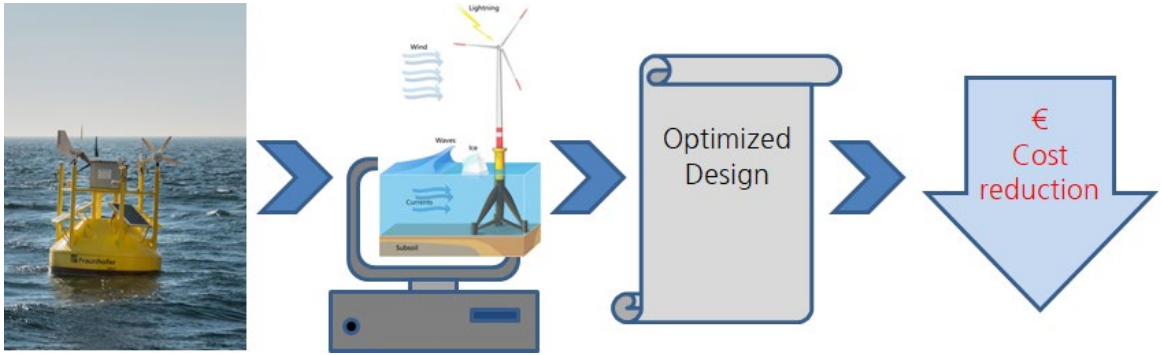
Outlook

- Measurement campaign of 1 year to obtain more accurate site specific data
- Complete load simulation with all load cases
- More precise estimation of a potential cost reduction



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