EERA DeepWind'2016 13th Deep Sea Offshore Wind R&D Conference

Probabilistic assessment of floating wind turbine access by catamaran vessel

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Operations and maintenance

Outline

- Motivation
  - Offshore wind energy trends
  - O&M challenges
- Methodology
  - Analysis of constrained multi-body system
  - Definition of access criteria
  - Calculation of short-term extreme response
- Case study: Aberdeen, Scotland
  - Evaluation of long-term accessibility
- Conclusions

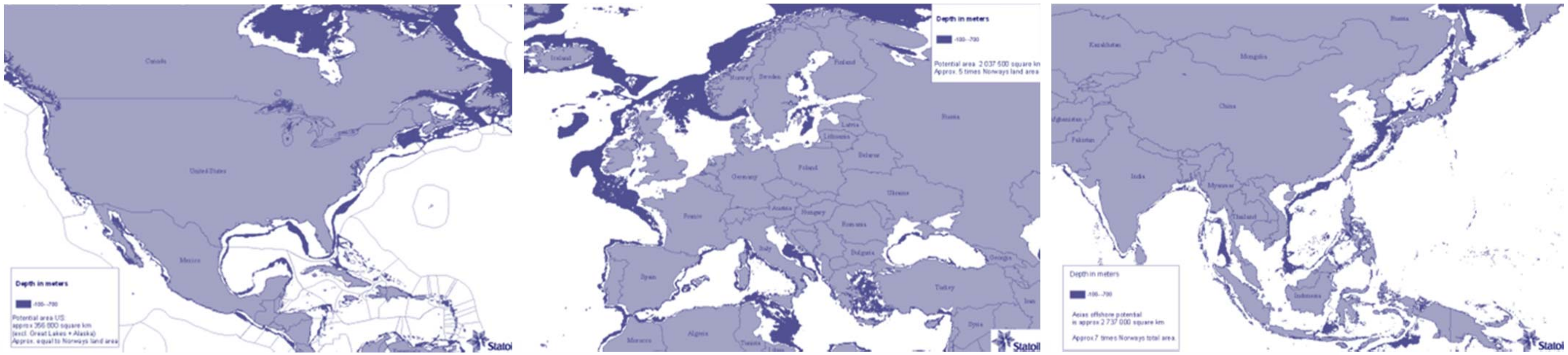
Motivation

Motivation/1

TRENDS
- Offshore wind market is rapidly increasing (EWEA 2015)
- **+111%/+70%** capacity/average investment in 2012-2014

LIMITATIONS
- Maximum water depth for fixed structures is **50 m** (EWEA 2013)
- Limited amount of available sites

ALTERNATIVES
- **Floating systems** for deeper waters (Hywind, WindFloat, Fukushima)
- Vast **potential market**



Water depth: 100-700 m

Source: Statoil

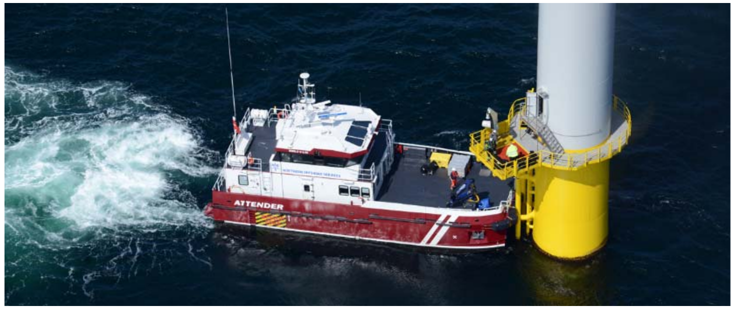
Motivation/2

CHALLENGES

- **Availability** (% of time wind turbine produces electricity)
- Reducing **downtimes**
- Inspection and maintenance has high cost **(25% of LCOE, GL 2015)**

ACCESS STRATEGIES

- Helicopter
- Relatively large access vessels with motion compensated gangway
- **Small and fast CTVs with fender**



Source: NOS, Windcat Workboats

QUESTIONS

- What is the **combined response** of floating platform/access vessel?
- What is the **long-term accessibility** for a chosen spot?

OBJECTIVES

- **Model the catamaran walk-to-work access of floating wind turbine**
- **Evaluate long-term accessibility in Aberdeen, Scotland**

Methodology

Methodology/1

Landing procedure on a floating platform

- The catamaran lands on the bumpers mounted on the platform. The platform displaces until the system reaches equilibrium

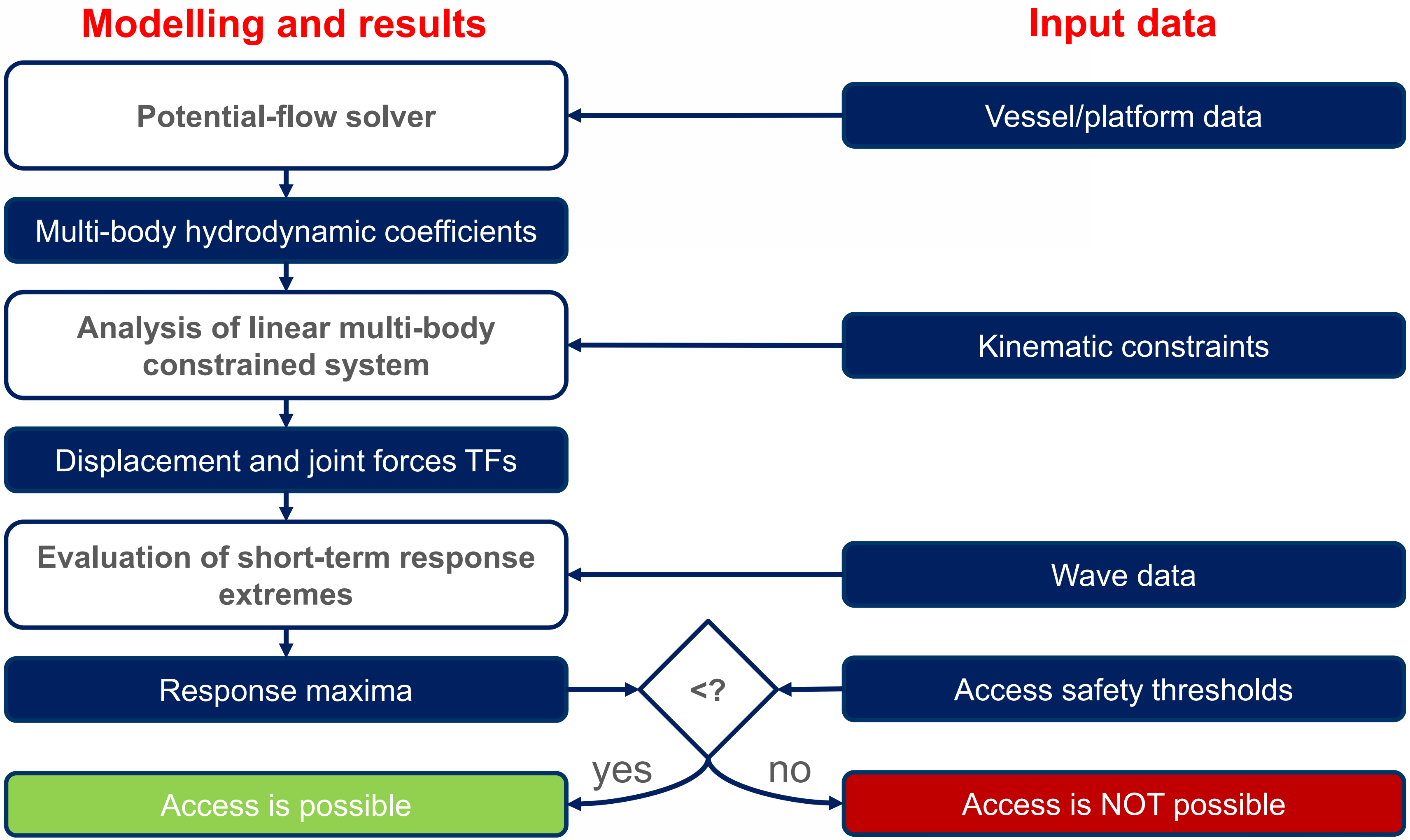
- The bow-mounted fender helps in:
  - Absorbing the impact energy
  - Providing friction at the contact surface

- O&M technicians step-over from the vessel to a platform mounted ladder

- Access is possible when:
  - No-slip conditions occur at the fender
  - Relative rotations are below tolerance limits

Source: Windcat Workboats

Methodology/2



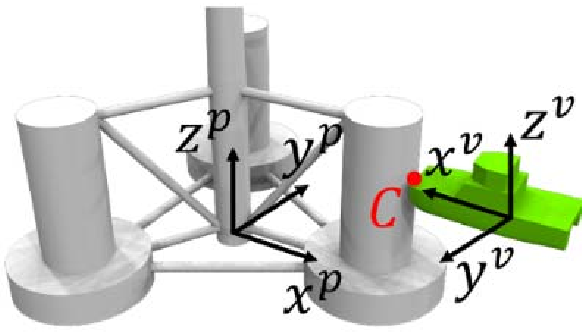
Methodology/3

Analysis of constrained multi-body system: approach

- Floating body equation of motion in frequency domain
  - Multibody hydrodynamic coefficients from DNV SESAM
  - Linearization of mooring and quadratic damping

$$\boldsymbol{G}(j\omega)\boldsymbol{\zeta}(j\omega)=\boldsymbol{f}(j\omega,\theta)$$

$$\boldsymbol{G}(j\omega)=-\omega^2[\boldsymbol{M}+\boldsymbol{A}(\omega)]+j\omega[\boldsymbol{B}(\omega)+\boldsymbol{B}_l]+[\boldsymbol{C}+\boldsymbol{C}_l]$$



- The fender acts as a joint between the two bodies
  - Motion is constrained: equation has to be rewritten
  - Relative translations at contact point are impeded

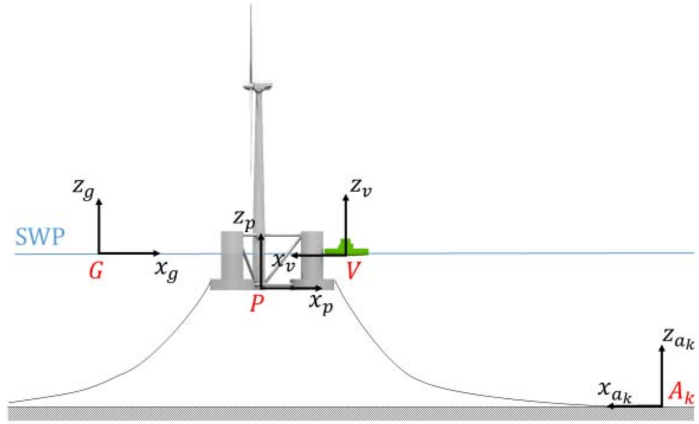
$$\begin{bmatrix} \boldsymbol{G} & \boldsymbol{D}^T \\ \boldsymbol{D} & \boldsymbol{0} \end{bmatrix} \begin{Bmatrix} \boldsymbol{\zeta} \\ \boldsymbol{\lambda} \end{Bmatrix} = \begin{Bmatrix} \boldsymbol{f} \\ \boldsymbol{0} \end{Bmatrix}$$

Displacements

Reaction forces

Constraint matrix

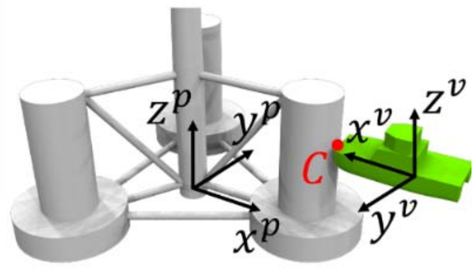
$$\boldsymbol{D}=\begin{bmatrix} 1 & 0 & 0 & 0 & +z_C^v & -y_C^v & 1 & 0 & 0 & 0 & +z_C^p & -y_C^p \\ 0 & 1 & 0 & -z_C^v & 0 & +x_C^v & 0 & 1 & 0 & -z_C^p & 0 & +x_C^p \\ 0 & 0 & 1 & +y_C^v & -x_C^v & 0 & 0 & 0 & -1 & -y_C^p & +x_C^p & 0 \end{bmatrix}$$



L. Sun, R. Eatock Taylor, and Y. S. Choo, “Response of interconnected floating bodies,” IES J. Part A Civ. Struct. Eng., vol. 4, no. 3, pp. 143–156, 2011

Methodology/5

Analysis of constrained multi-body system: access criteria



Condition 1

- No-slip at fender

$$|\lambda_3(t)| \leq \mu_s [F_b + \lambda_1(t)]$$

$$\alpha(t) = +\lambda_3(t) - \mu_s \lambda_1(t) \leq \mu_s F_b \longrightarrow \alpha(j\omega) = +\lambda_3(j\omega) - \mu_s \lambda_1(j\omega)$$

$$\beta(t) = -\lambda_3(t) - \mu_s \lambda_1(t) \leq \mu_s F_b \longrightarrow \beta(j\omega) = -\lambda_3(j\omega) - \mu_s \lambda_1(j\omega)$$

Transfer functions

Condition 2

- Small relative rotations at fender

$$|\Delta\rho(t)| \leq \Delta\rho_{\lim} \longrightarrow \Delta\rho(j\omega) = \zeta_4(j\omega) + \zeta_{10}(j\omega)$$

$$|\Delta\psi(t)| \leq \Delta\psi_{\lim} \longrightarrow \Delta\psi(j\omega) = \zeta_6(j\omega) - \zeta_{12}(j\omega)$$

Methodology/6

Calculation of short-term response extremes

Wave directional spectrum

Response transfer functions α, β, Δρ,Δψ

Variance of linear response

$$\sigma_x = \int_0^{2\pi}\int_0^{\infty} \left|H_{\eta x}(j\omega,\theta)\right|^2 S_{\eta\eta}(\omega,\theta)\,d\omega\,d\theta$$

Distribution of response crests

$$F(x_c) = 1 - e^{-(x_c/2\sigma_x)^2}$$

Distribution of response extremes

$$F_E(x_c) = F(x_c)^N = \left[1 - e^{-(x_c/2\sigma_x)^2}\right]^N$$

Extreme response (with exc. prob.)

$$x_c = \sqrt{2\sigma_x^{\,2}}\left[-\ln\left(1 - F_E^{\,1/N}\right)\right]^{1/2}$$

F_E = 0.95 in this work

Comparison with access thresholds and evaluation of accessibility

L. H. Holthuijsen, Waves in Oceanic and Coastal Waters. New York: Cambridge University Press, 2007.
Det Norske Veritas, Environmental conditions and loads, DNV-RP-C205, 2014.

Case study

Floating platform and vessel data

Catamaran CTV

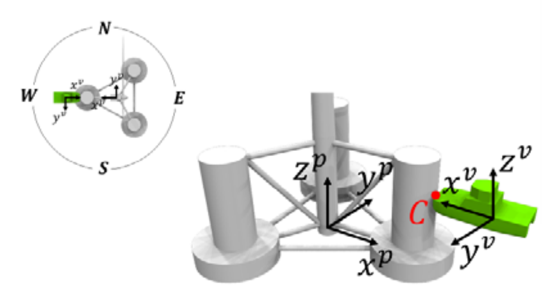
CTV		
Displacement	102	t
Length/Beam/Draft	24/10/1.37	m
Water plane area	94.45	m^2
Fender friction coefficient	1.2	-
Bollard push force	135	kN
Heave/roll/pitch natural period	3.0/3.5/4.5	s

OC4 floating platform

OC4		
Displacement	13473	t
Total draft	20	m
Diameter of central/offset col.	6.5/12.0	m
Diameter of heave plates	24	m
Spacing between offset columns	50	m
Heave/roll/pitch natural period	18/27.5/27.5	s

Case study/2

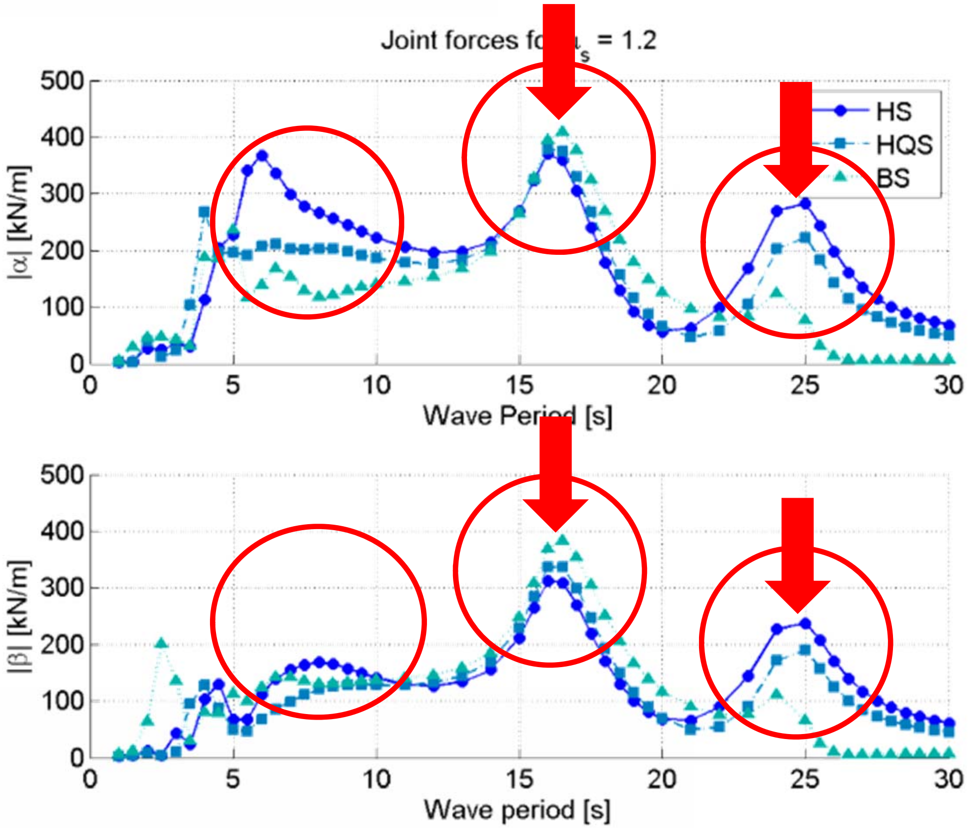
System transfer functions – Joint forces (α and β)



$$\alpha(j\omega) = +\lambda_3(j\omega) - \mu_s\lambda_1(j\omega)$$ (upward slip)

$$\beta(j\omega) = -\lambda_3(j\omega) - \mu_s\lambda_1(j\omega)$$ (downward slip)

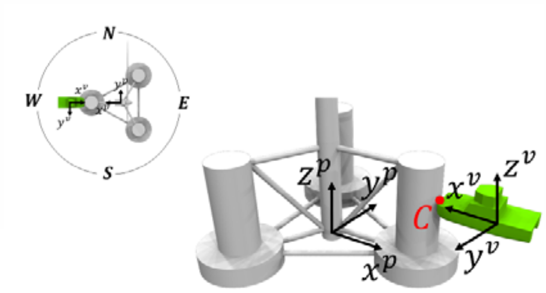
- Short (5-12 s) and very long (20-25 s) waves
  - Upward slip is more probable than downward
  - Head seas give higher contact forces than in beam seas
- Medium length/long waves (12-20 s)
  - Upward and downward slip are equally probable
  - Beam seas give higher contact forces than in head seas
- Slip is highly probable at 16.5 s and 24 s
  - Shifted from platform natural periods (18 s, 27.5 s)!
  - Relative motion drives contact forces!



“HS” = “Head Sea”, “HQS” = “Head Quartering Sea”, “BS” = “Beam sea”

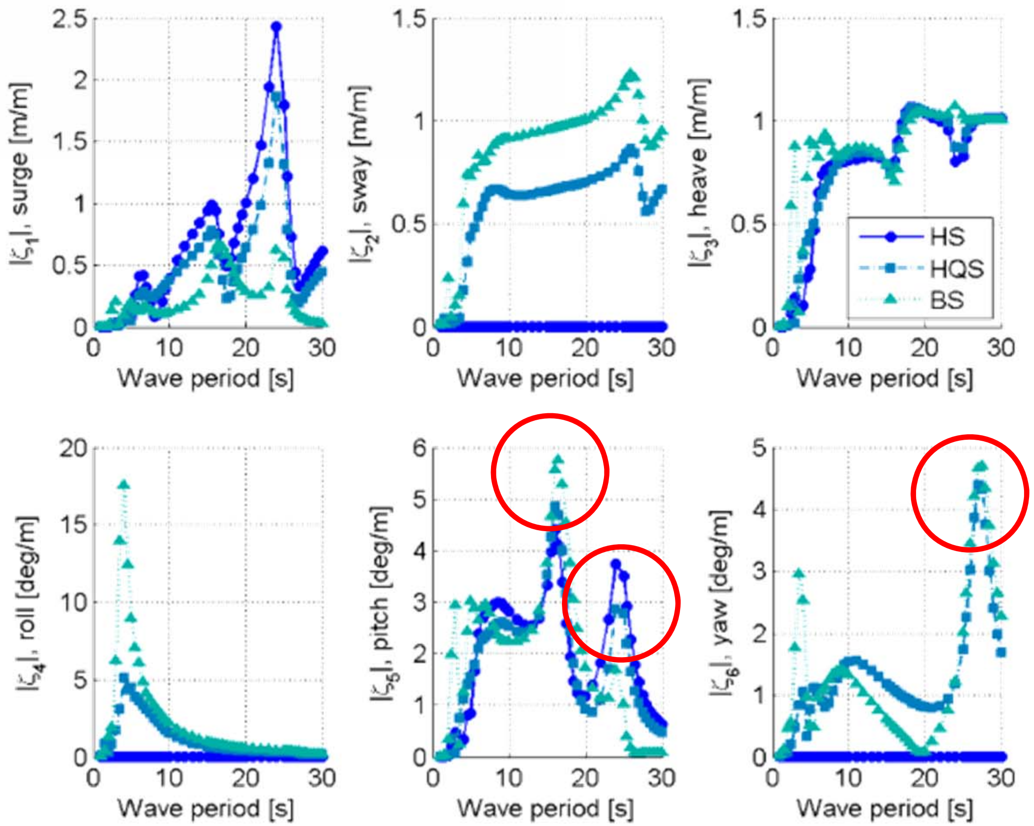
Case study/3

System transfer functions – Catamaran displacements



- When free to move, bodies respond to:
  - Catamaran: short waves (small inertia)
  - Floating platform: long waves (high inertia)

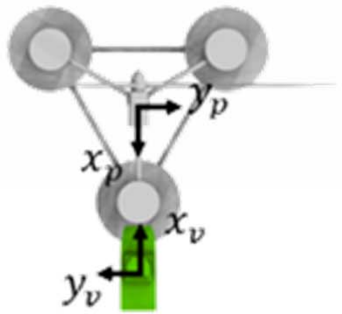
- When constrained, bodies exchange forces through the joint
  - Catamaran: response also to longer waves, when contact forces are higher

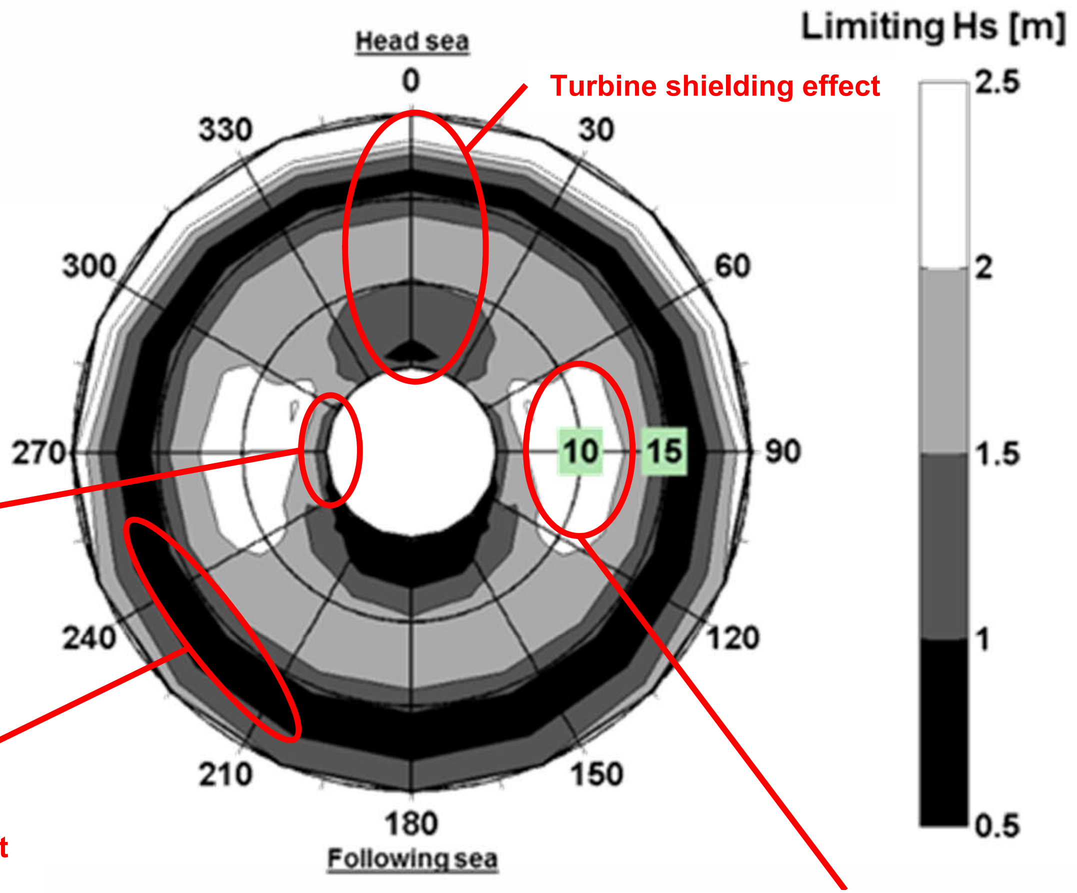


"HS" = "Head Sea", "HQS" = "Head Quartering Sea", "BS" = "Beam sea"

Case study/4

System transfer functions – Limiting wave height in regular waves





M. Wu, "Numerical analysis of docking operation between service vessels and offshore wind turbines," Ocean Eng., vol. 91, pp. 379–388, 2014

Case study/5

Offshore location and data – Aberdeen, Scotland

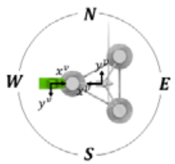
Coordinates: 57.000º N, 1.875º W
Distance from the coast: 10 km
Water depth: 90 m

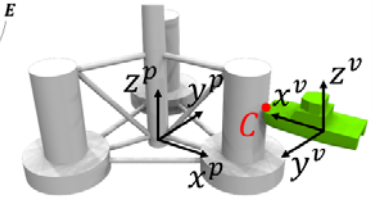
Reanalysis data: IH Cantabria

- GOW: Global Ocean Waves
  - 0.125º spatial resolution (lat/lon)
  - 1 hour time resolution
  - 1980-2013 spanned period
- Time series of:
  - Hs, significant wave height
  - Tp, wave peak period
  - θm, mean wave direction
  - σθ, mean directional spreading

Case study/6

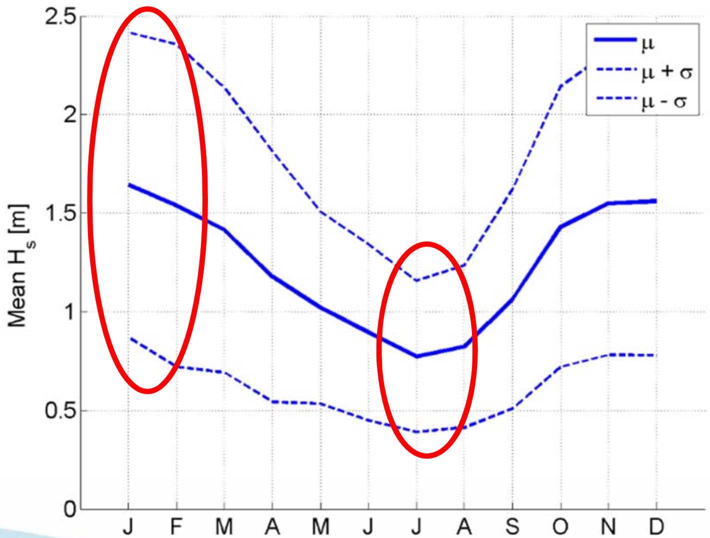
Offshore location and data – Aberdeen, Scotland





	Wave significant height [m]							
Wave peak period [s]	0.5	1.5	2.5	3.5	4.5	5.5	6.5	
2	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
3	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%
4	6.9%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	7.3%
5	9.1%	4.5%	0.0%	0.0%	0.0%	0.0%	0.0%	13.6%
6	7.5%	9.1%	0.6%	0.0%	0.0%	0.0%	0.0%	17.1%
7	5.5%	7.8%	2.0%	0.0%	0.0%	0.0%	0.0%	15.4%
8	4.9%	7.3%	3.0%	0.5%	0.0%	0.0%	0.0%	15.7%
9	3.5%	4.4%	2.3%	1.0%	0.1%	0.0%	0.0%	11.4%
10	2.2%	2.9%	1.2%	0.6%	0.3%	0.1%	0.0%	7.3%
11	1.5%	2.1%	0.6%	0.3%	0.1%	0.1%	0.0%	4.6%
12	0.9%	1.3%	0.4%	0.2%	0.0%	0.0%	0.0%	2.7%
13	0.5%	0.6%	0.2%	0.1%	0.0%	0.0%	0.0%	1.3%
14	0.4%	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.9%
15	0.4%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.6%
16	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%
17	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
	45.3%	40.8%	10.2%	2.7%	0.6%	0.1%	0.0%	100.0%

Wave mean direction [deg]								
E	1.5%	1.5%	0.6%	0.3%	0.1%	0.0%	0.0%	3.9%
ESE	3.8%	3.2%	1.1%	0.4%	0.2%	0.1%	0.0%	8.8%
SE	5.1%	4.5%	1.3%	0.4%	0.1%	0.0%	0.0%	11.3%
SSE	3.7%	4.3%	1.5%	0.4%	0.1%	0.0%	0.0%	10.0%
S	3.0%	3.1%	0.8%	0.1%	0.0%	0.0%	0.0%	7.0%
SSW	3.9%	3.5%	0.5%	0.1%	0.0%	0.0%	0.0%	7.9%
SW	1.3%	1.1%	0.1%	0.0%	0.0%	0.0%	0.0%	2.5%
WSW	0.4%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
W	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
WNW	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
NW	0.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%
NNW	0.6%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%
N	1.9%	1.5%	0.2%	0.0%	0.0%	0.0%	0.0%	3.6%
NNE	9.9%	9.9%	2.4%	0.6%	0.1%	0.0%	0.0%	22.9%
NE	5.0%	3.2%	0.5%	0.1%	0.0%	0.0%	0.0%	8.9%
ENE	3.0%	2.3%	0.5%	0.2%	0.0%	0.0%	0.0%	6.0%
	45.4%	40.9%	10.2%	2.7%	0.6%	0.1%	0.0%	100.0%

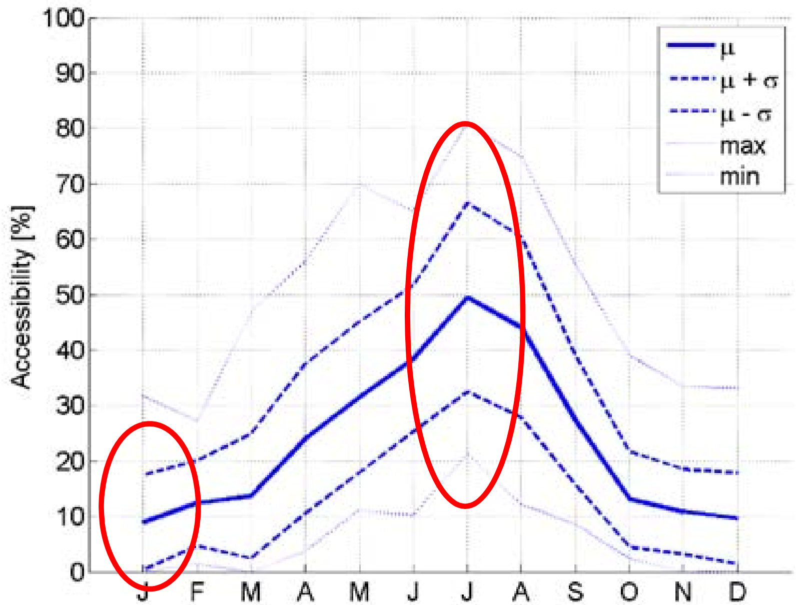


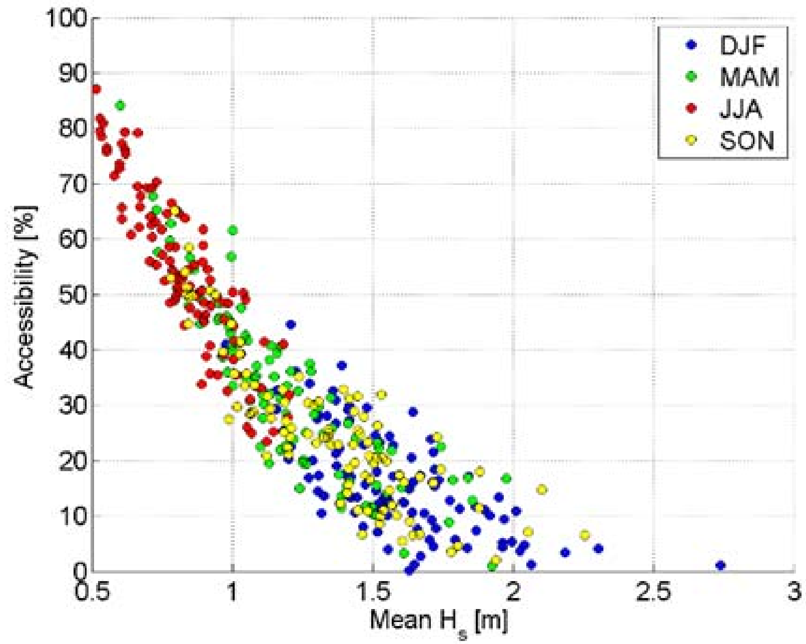
- 86.1% of Hs less than 2 m
- 80.4% of Tp between 4.5 and 10.5 s

41.1% of θm between E and S
41.4% of θm between N and E

Long-term accessibility – Aberdeen, Scotland

Average 1980-2013 accessibility: 23.7 % (87 days/year)





- Large monthly variation
- More variability in summer than in winter

- Small spreading for small (<1 m) and large Hs (>2 m)
- Intermediate region indicates sensitivity to Tp and θm

Need for reliable and long-term metocean data

Conclusions

Conclusions

- Developed methodology to evaluate walk-to-work accessibility of floating turbine
  - Frequency domain approach: linearization of non-linear actions
  - Definition of access criteria
    - No-slip conditions at fender
    - Small relative rotations at fender
  - Calculation of short-term extreme responses

- Evaluated combined response of CTV and OC4 floating platform
  - Largest forces shifted from natural periods
  - Vessel response affected by platform response

- Evaluated long-term accessibility at Kincardine
  - Hindcast data 1980-2013: large climate variability (seasonal, year-by-year), mostly winter.
  - Average accessibility: 23.7 %. Large variability (seasonal, year-by-year), mostly summer.
  - Influence of wave period and direction for Hs between 1 m and 2 m

THANKS FOR YOUR ATTENTION!

Probabilistic assessment of floating wind turbine access by catamaran vessel

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