Wave Loads in Shallow Water

12th International Workshop on Wave Hindcasting and Forecasting, Hawaii's Big Island, Oct. 30th – Nov. 4th 2011

Hans Fabricius Hansen

Iris Pernille Lohmann

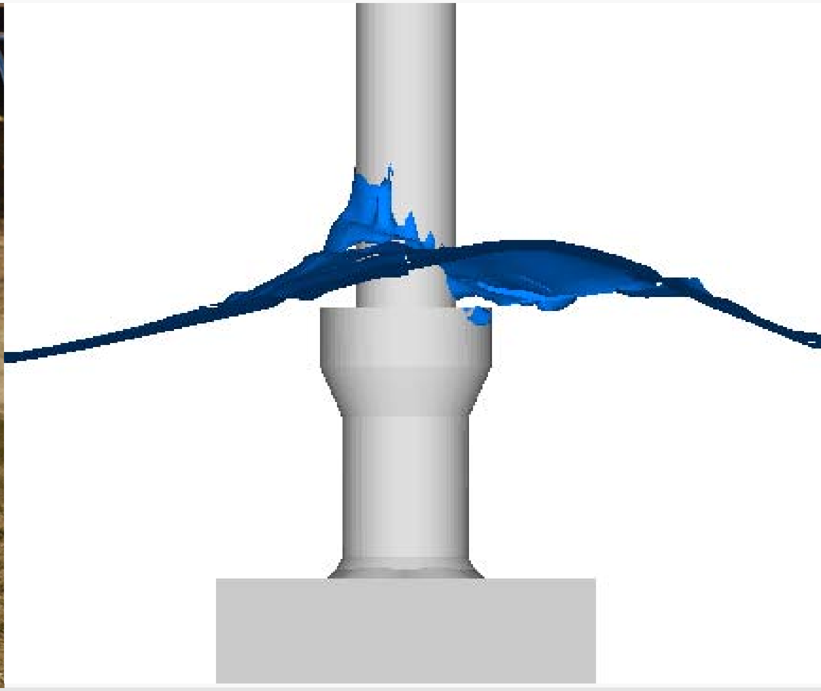
Flemming Schlütter

Ports and Offshore Technology Department, DHI Denmark

Partially funded by the ForskEL Project 2010-1-10495,
Wave loads on offshore wind turbines

Motivation

- Increasing number of shallow water structures being constructed
- Uncertainty in appropriate design wave loads
  - Wave height distribution tend to depart from Rayleigh
  - Decrease in maximum wave height
  - Wave breaking induce slamming loads
- Requirement for methodology to account these opposing but interrelated effects on design loads



Methodology Outline

- Wave loads on offshore wind turbine foundation in irregular near-breaking and breaking waves modelled in physical and numerical models
- Wave load dependency on wave breaking parameter and Ursell parameter established
- Monte-Carlo method adopted to simulate sea state dependent wave loads
- Adaption of Tromans and Vanderschuren method (1995) allows for derivation of most probable extreme wave load in historical storms
- Maximum wave load with given recurrence periods estimated from traditional extreme value analysis

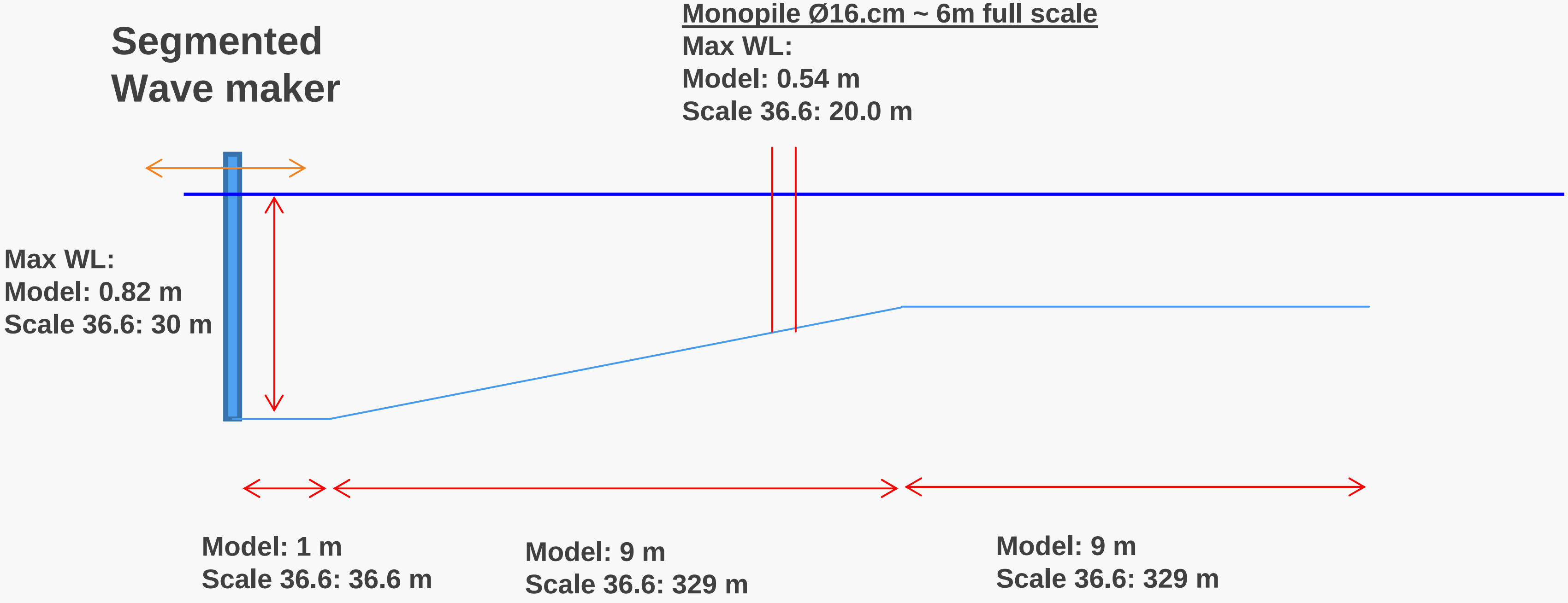
Conclusions

- Wave breaking has the effects that;
  - extreme waves deviate from Rayleigh distribution
  - decreasing height of the highest waves
  - wave heights (of unidirectional seas) appear to obey Battjes and Groenendijk distribution
  - extreme wave loads increase non-linearly and with large spreading
- Loads are correlated to wave breaking limit and Ursell number
- Above correlation allows for estimating load distribution from known quantities, such as spectral moments and wave height distribution, whereby site specific design loads can be established
- Inclusion of short-term variability in load is important for the distribution of maximum load

Experimental Setup

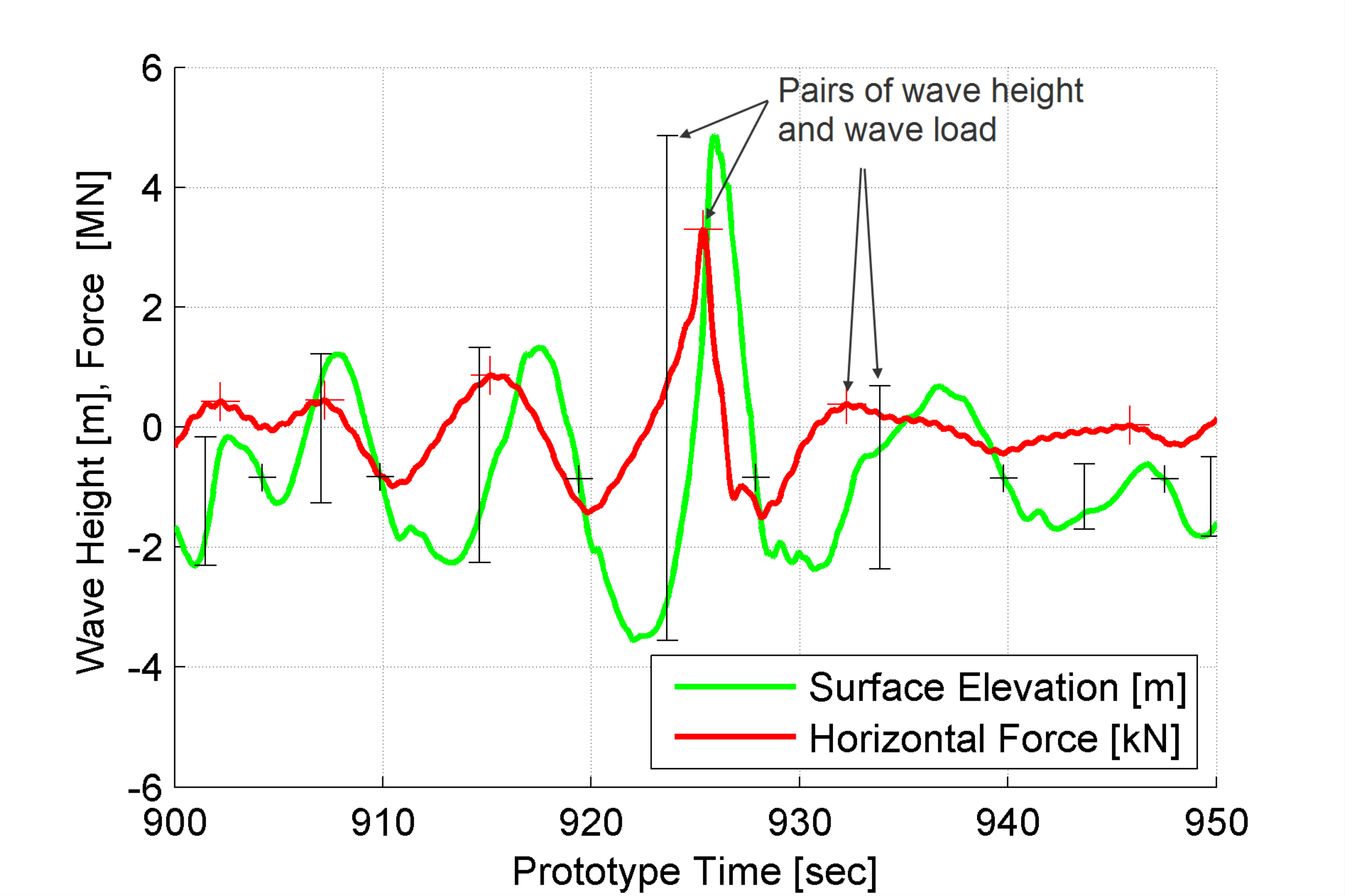
- Wave Conditions
  - Regular
  - Irregular 2D
  - Irregular 3D

Bathymetry Cross-section



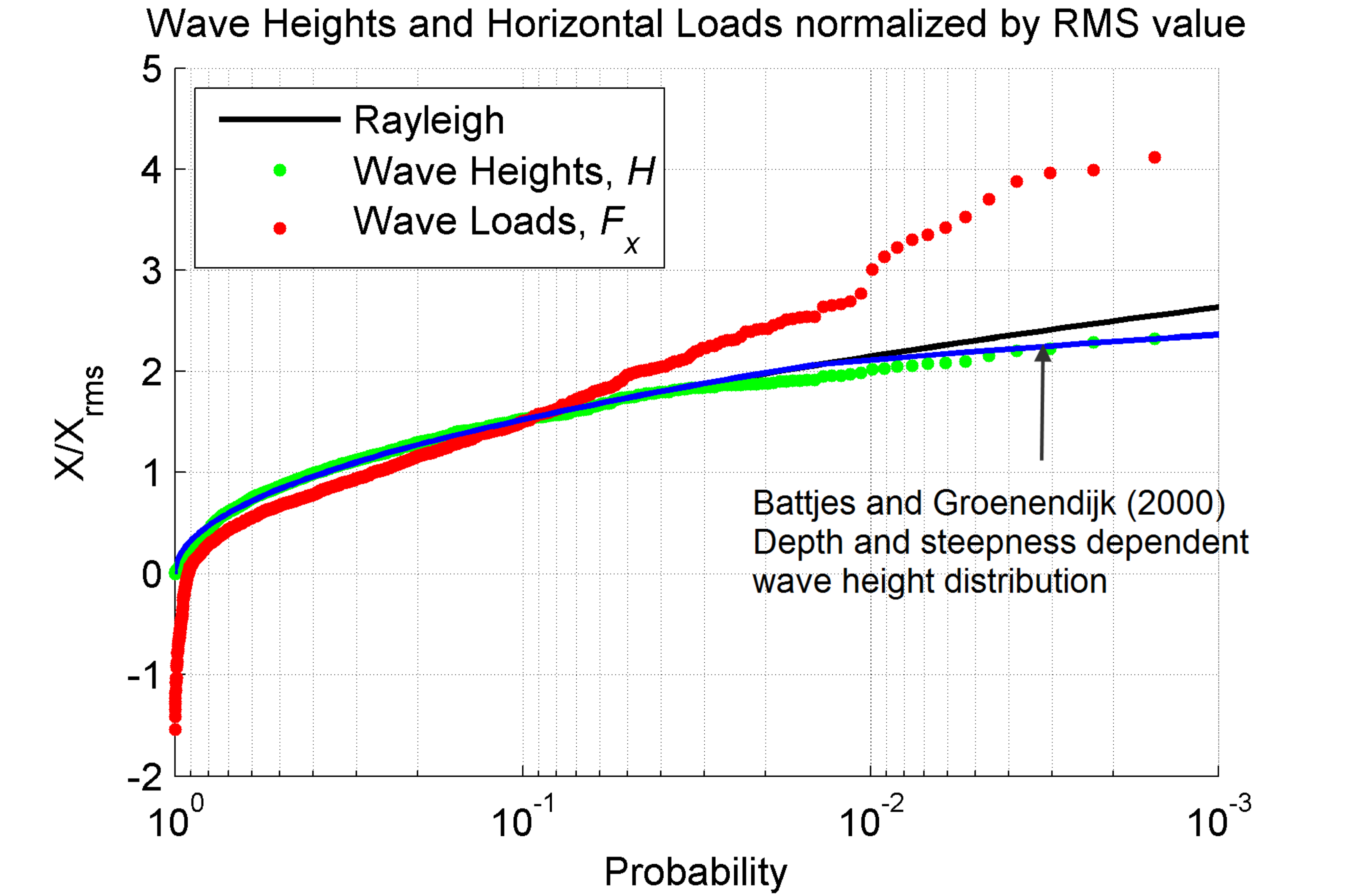
Wave Loads in Nearly Breaking Waves

- Example of time trace from physical model test – H_{m0} = 8.2m, T_p = 12.6s



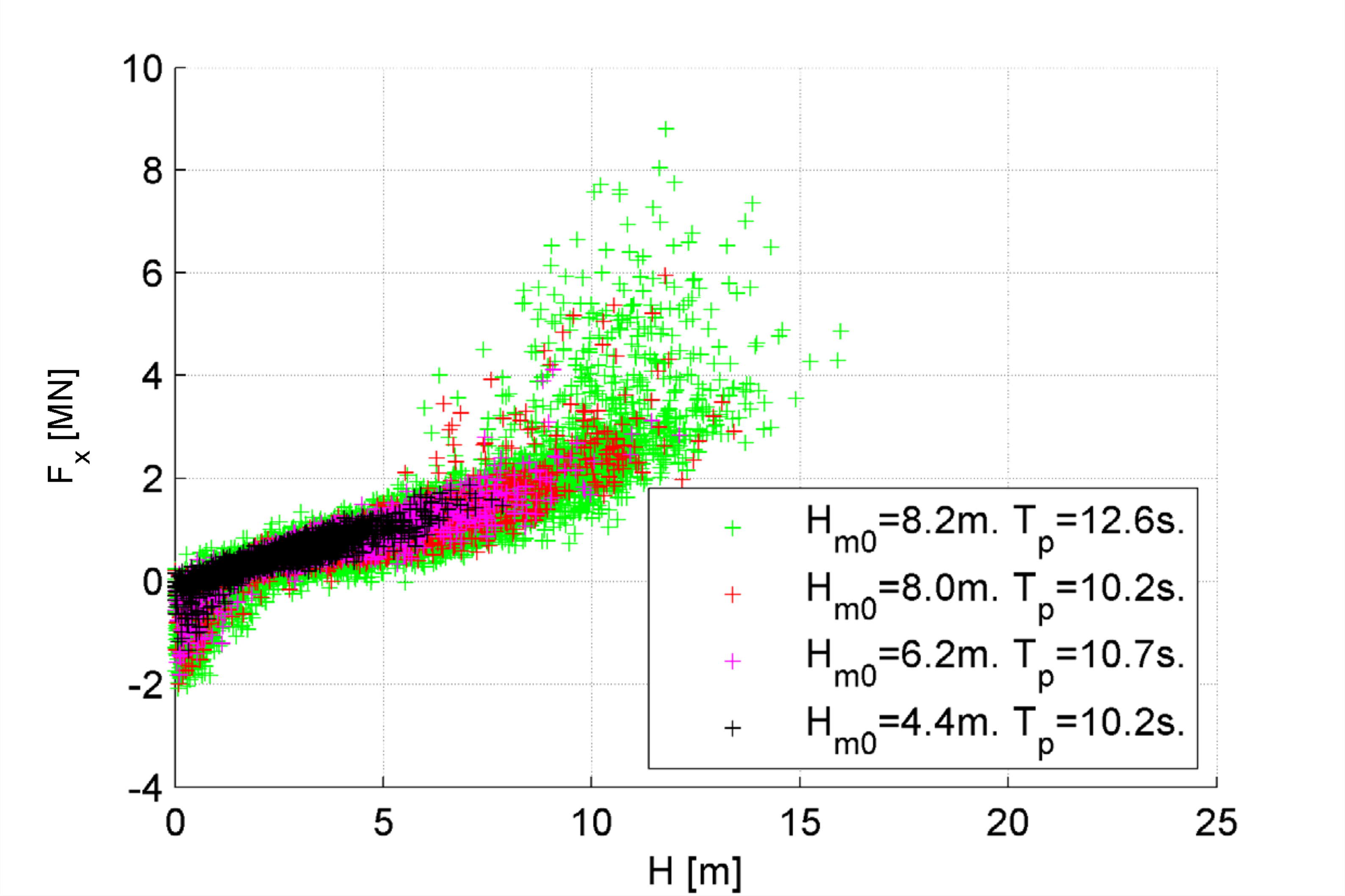
Distribution of Wave Heights and Loads

- Distributions deviate from Rayleigh

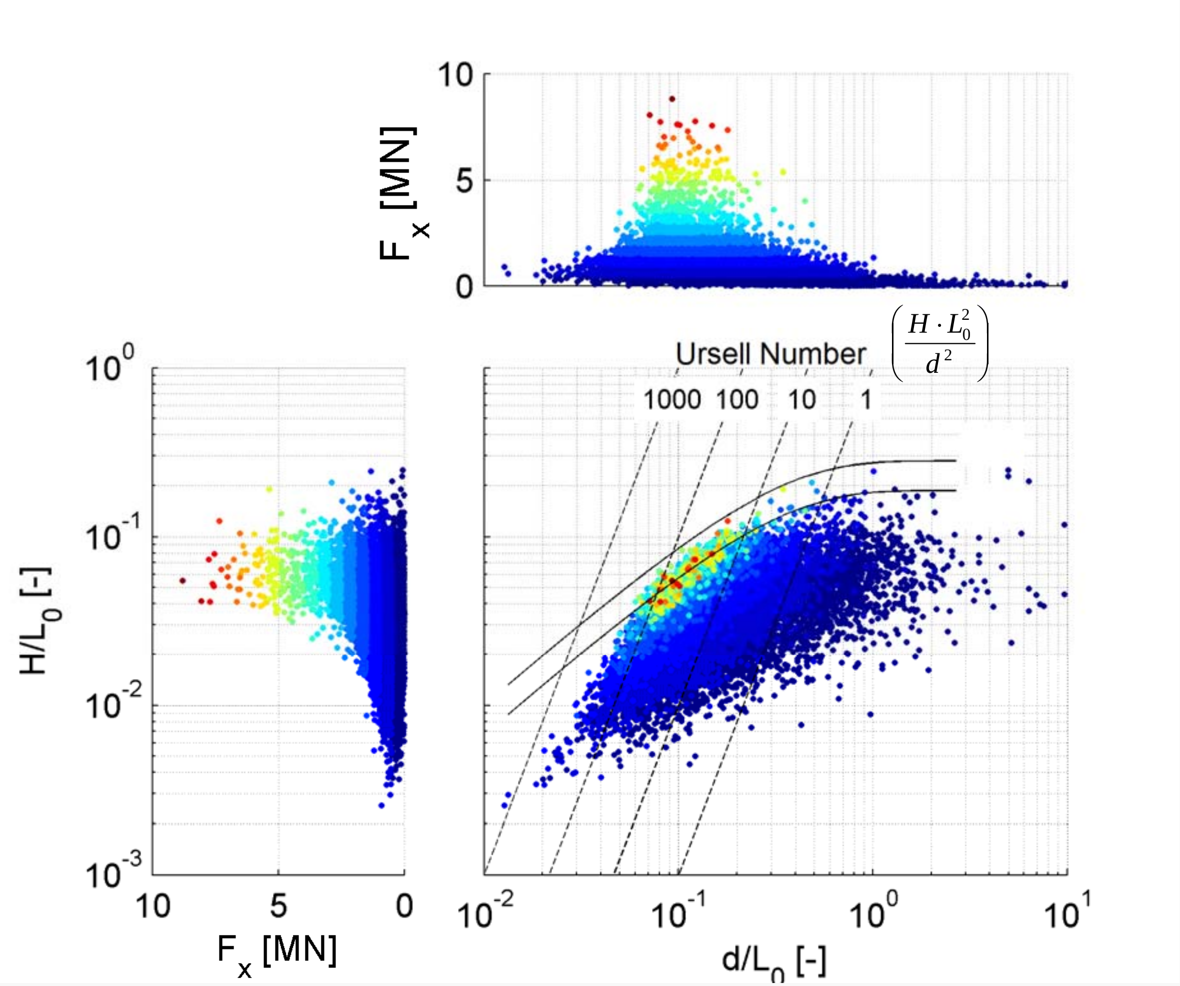


Wave Height Dependency

- Significant scatter starting at ~ 8 meter wave height



Steepness and Depth Dependency

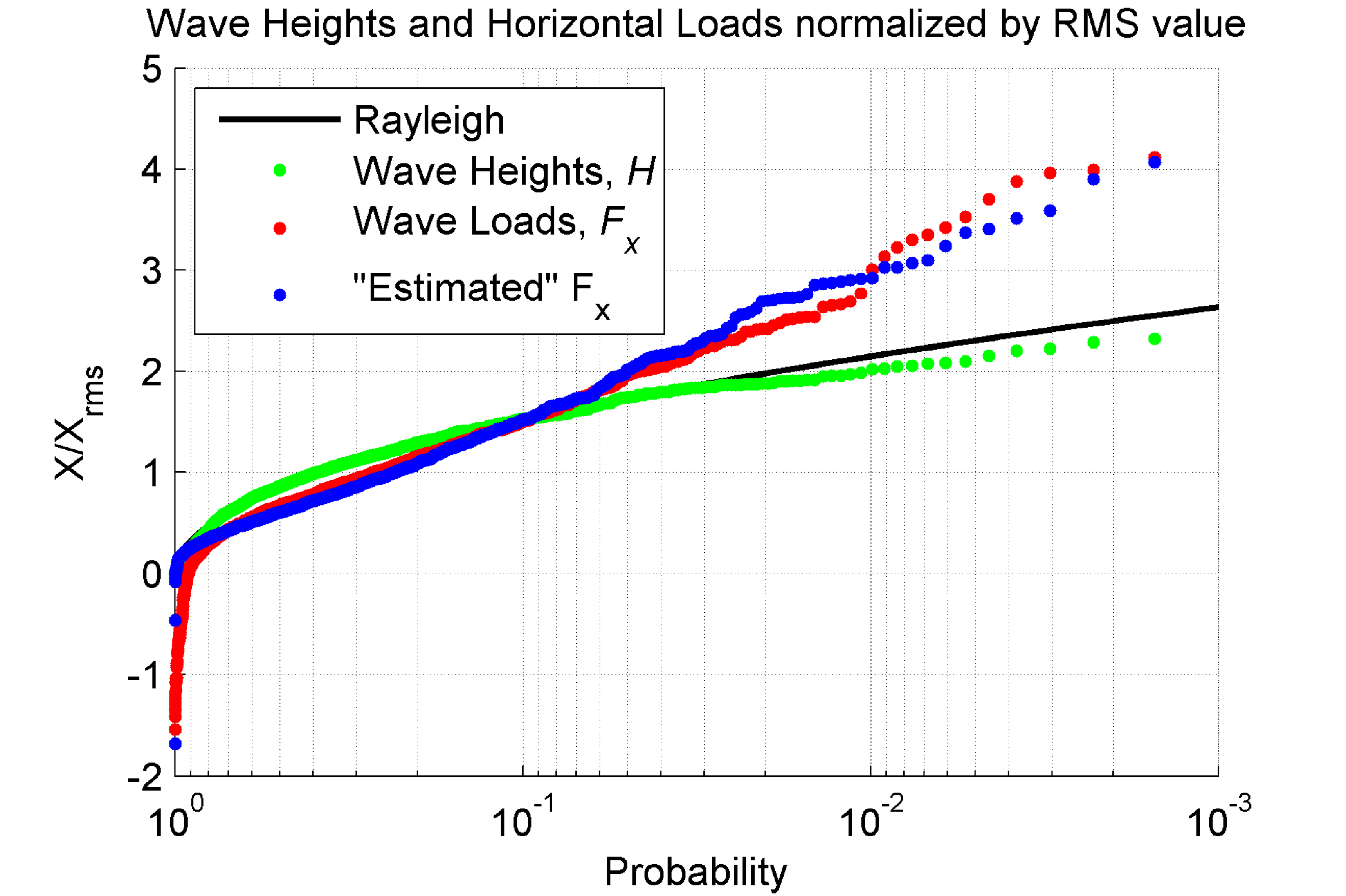


- Describe *F*:

$$F_x(A, Ur) = \{a_1 \times \exp(a_2(A - a_3))\} \times \{b_1 + b_2 \times Ur^{b_3})\}$$

- with parameters $a_{1\text{-}3}$ and $b_{1\text{-}3}$ found from least-square optimization

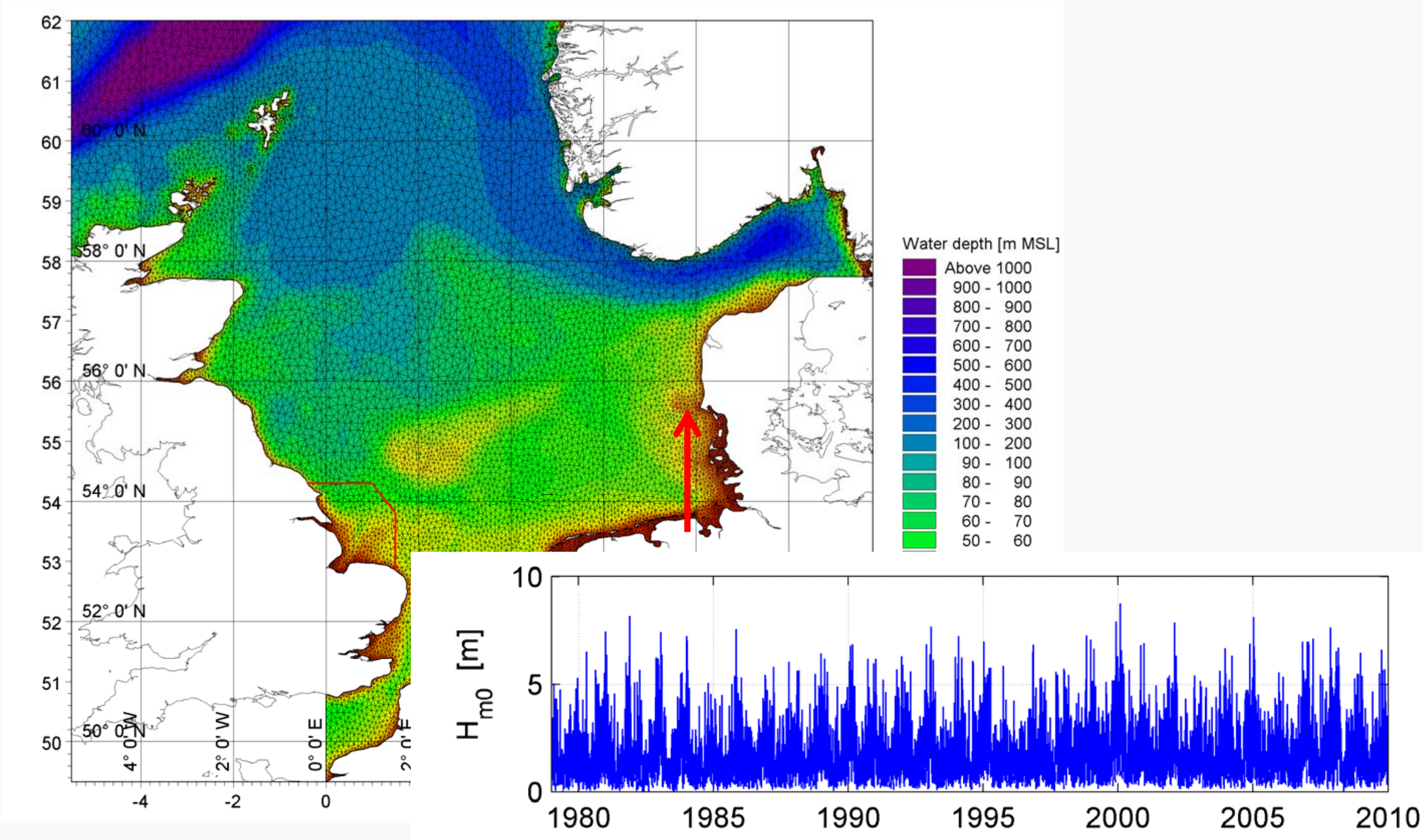
Distribution of Wave Heights and Loads



Force distribution reconstructed through random sampling from spectral moments, m_0, m_1 and m_2, a ”known” wave height distribution and estimated force function

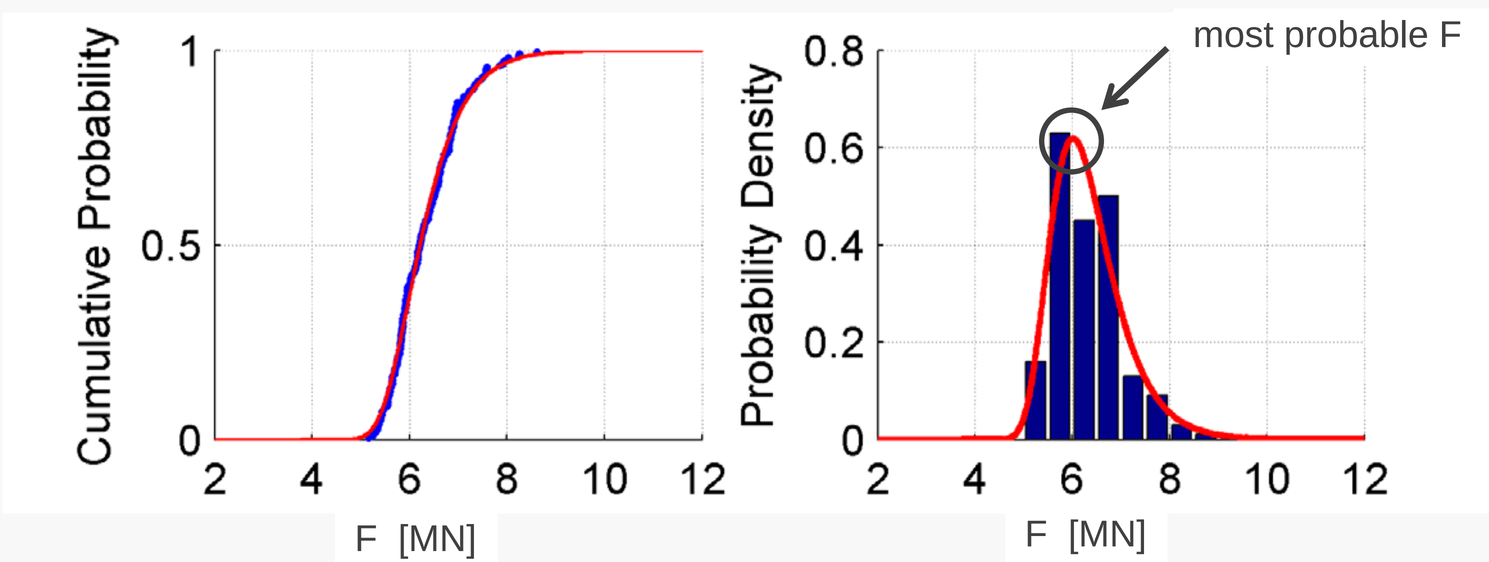
Example of Application – Wave Climate

- Hindcast data at exposed shallow water site, from 31 years North Sea/Baltic Sea model, applying the unstructured mesh code MIKE 21 SW



Example – Storm modes

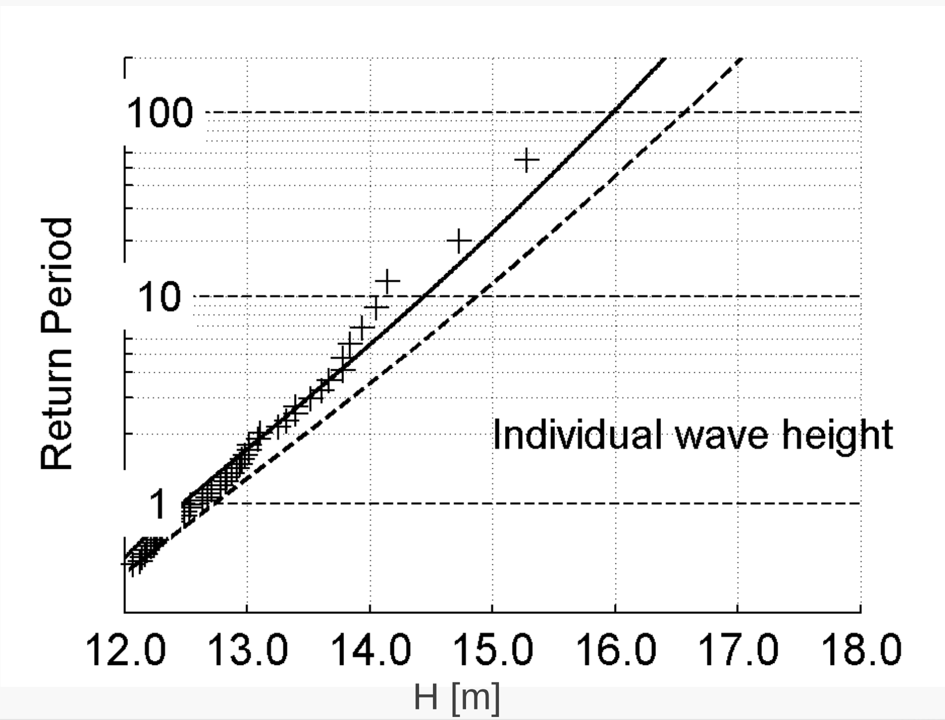
- Storms identified from H_{m0} time series, using separation criterion
- Integration over sea states of short-term wave height distribution yields most probable individual wave height in storm
- Individual waves in storm sea states are simulated by random sampling, using;
  - Battjes and Groenendijk wave height distribution (2000)
  - Longuet-Higgins joint wave height/period density function (1983)
- Forces are calculated from estimated *F*(*A*,*Ur*) function and maximum is stored
- Above procedure is repeated many times for each storm sea state and the distribution of maximum force thereby obtained.

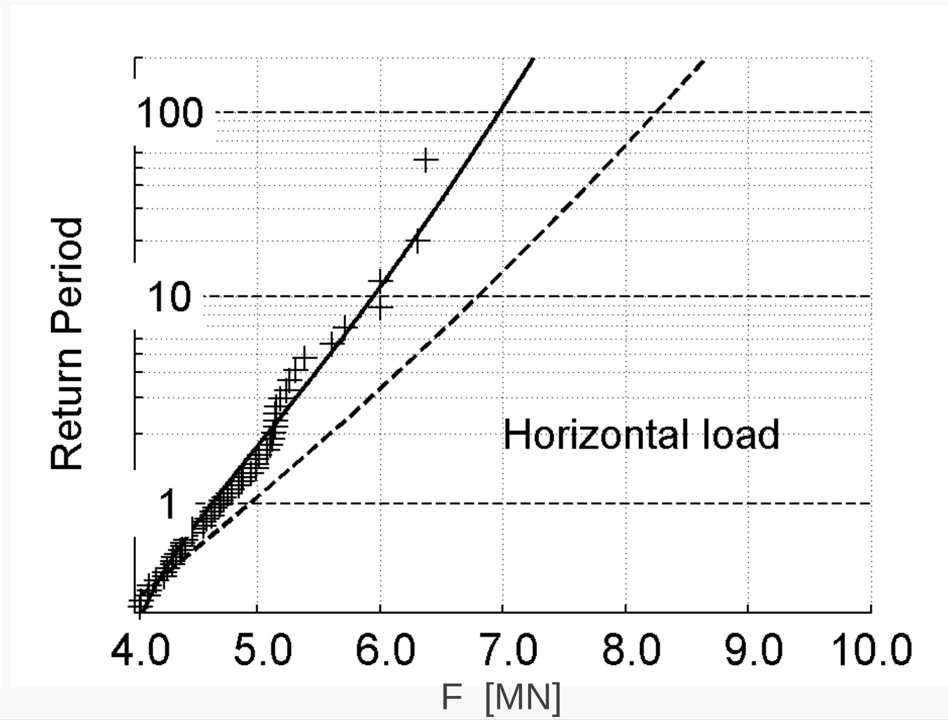


Example – Long-term distribution of modes

- Derived values of most probable load (mode) in historical storms provide basis for extreme value analysis of force on foundation
- Convolution with short-term variability of load conditional on most probable load gives long-term distribution of maximum load [1)]

$$P(F_{\max}) = \int_0^\infty P(f \mid F_{mp}) \cdot p(F_{mp})\, dF_{mp} = \int_0^\infty \exp\left(-\exp\left(-\ln N\left(\left(\frac{f}{F_{mp}}\right)^\beta - 1\right)\right)\right) \cdot p(F_{mp})\, dF_{mp}$$

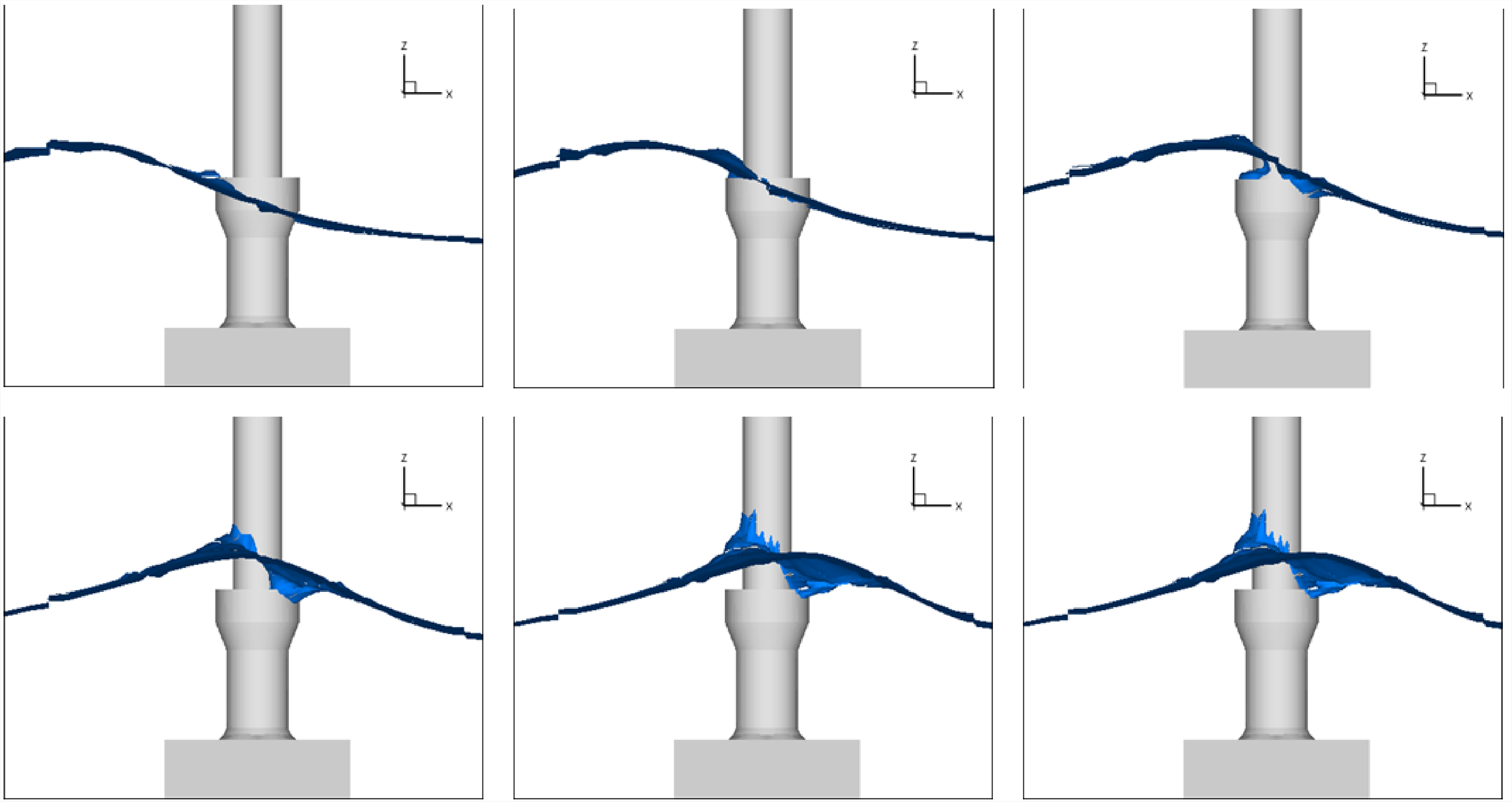




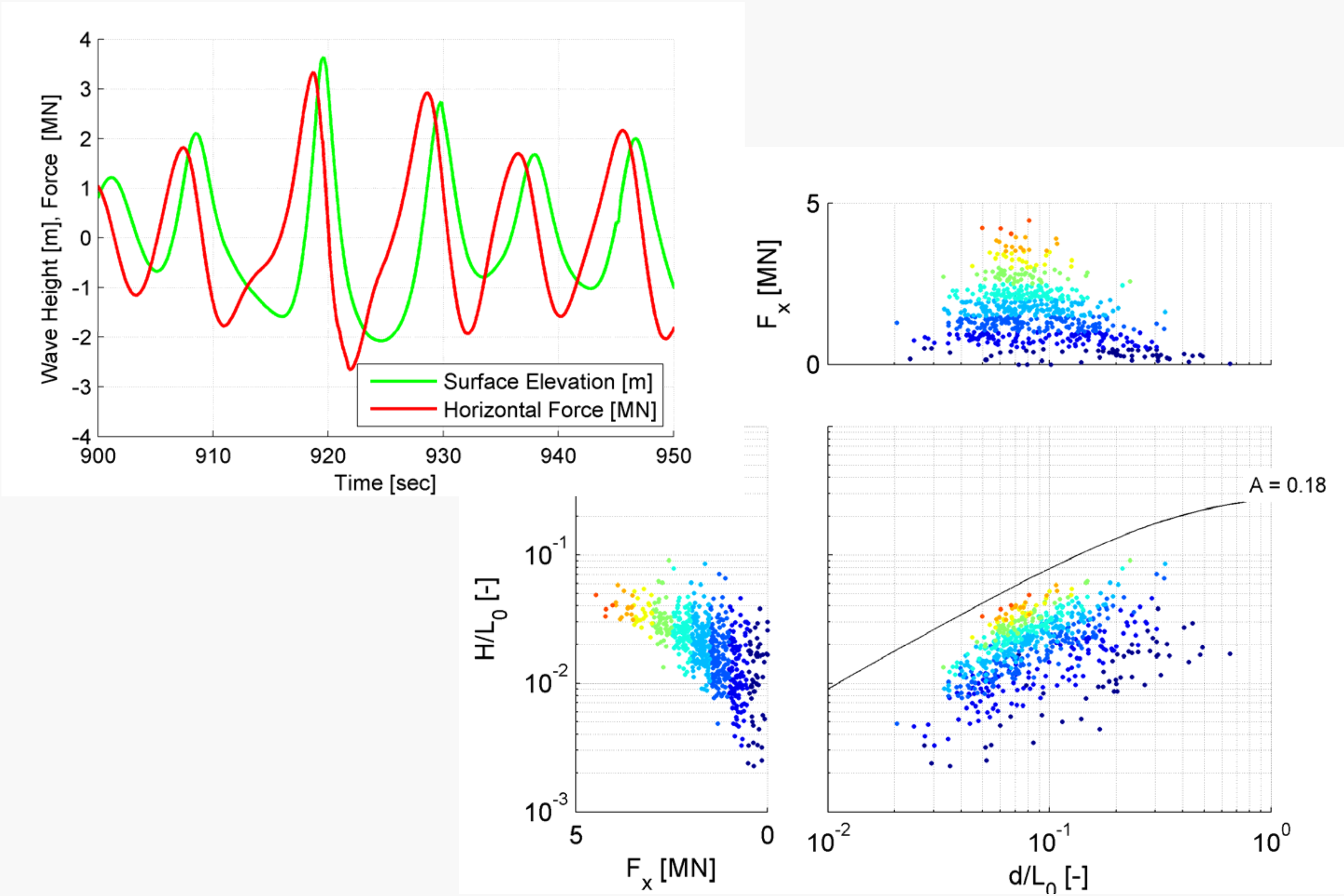
[1)] Tromans and Vanderschuren (1995)

Example – Loads computed with CFD

- Numerical wave tank based on DHI CFD-code NS3 applied
- Irregular long-crested seas simulated on sloping foreshore
- Gravity-based wind turbine foundation structure resolved in model
- Loads computed from integration of surface pressure on foundation



Example – Loads computed with CFD



Conclusions

- Wave breaking has the effects that;
  - extreme waves deviate from Rayleigh distribution
  - decreasing height of the highest waves
  - wave heights (of unidirectional seas) appear to obey Battjes and Groenendijk distribution
  - extreme wave loads increase non-linearly and with large spreading
- Loads are correlated to wave breaking limit and Ursell number
- Above correlation allows for estimating load distribution from known quantities, such as spectral moments and wave height distribution, whereby site specific design loads can be established
- Inclusion of short-term variability in load is important for the distribution of maximum load

Future improvements

- Are there physical constraints on the maximum load that needs to be considered?
- Extension to directionally spread seas

References

Thank you for your attention

- References

  - Battjes, J. A. and Groenendijk, H. W., *Wave height distributions on shallow foreshores*, Coastal Engineering 40 (2000) 161-182, January 2000.
  - Goda, Y., *Random Seas and Design of Maritime Structures*, Advanced Series on Ocean Engineering - Vol. 15 (2nd Edition)
  - Longuet-Higgins, *On the Joint Distribution of Wave Periods and Amplitudes in a Random Wave Field*, Proc. Royal Society A, 1983, 389 (1797), p. 241
  - Tromans, P.S. and Vanderschuren, L., *Response Based Design Conditions in the North Sea: Application of a New Method*, OTC 7683, pp. 387-397, 1995.