The influence of correlated spectral parameters in risk analysis of scour protections

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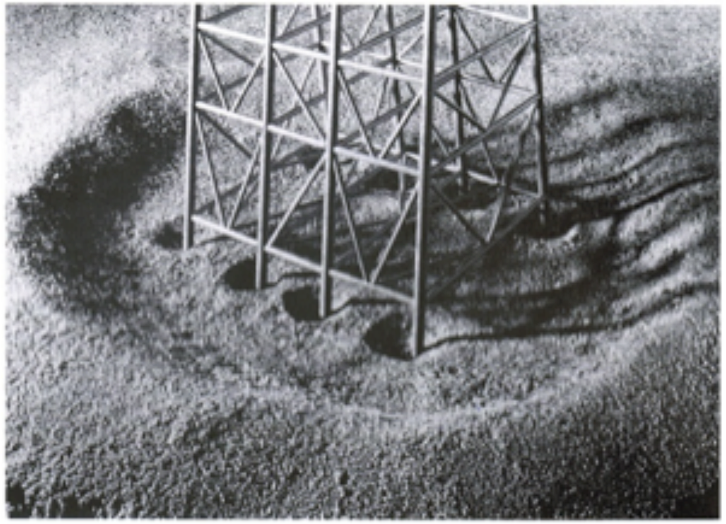
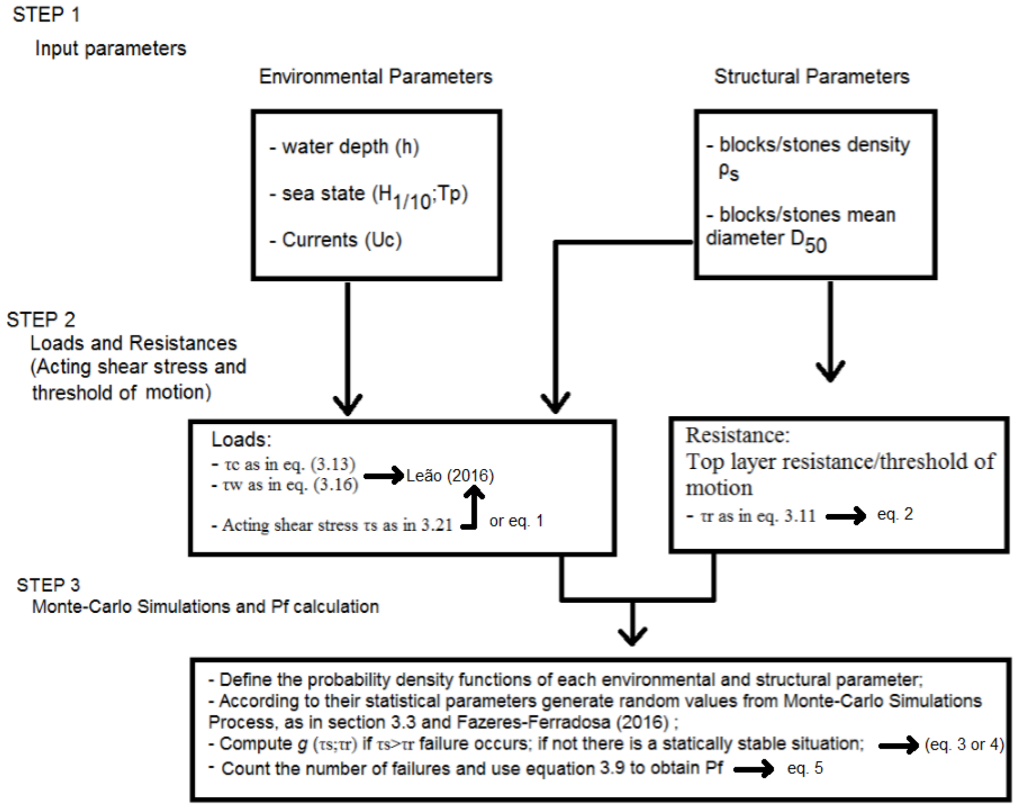
Revisiting the past



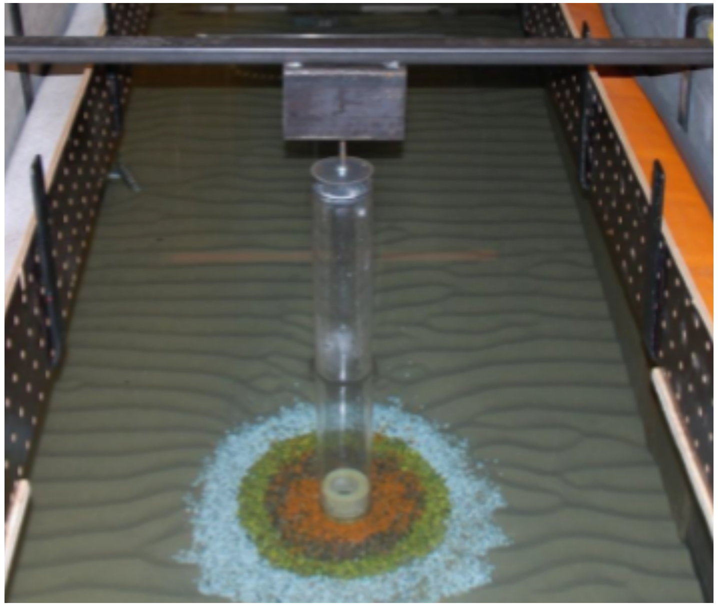


Improvements recommended from the last year:

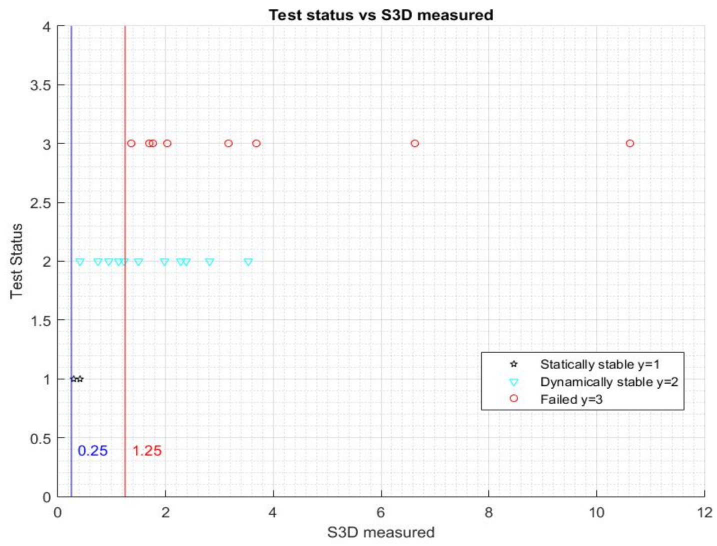
- Consider the correlation between variables;
- Improve the random generation with field data incorporation;
- Assemble the joint probability functions.

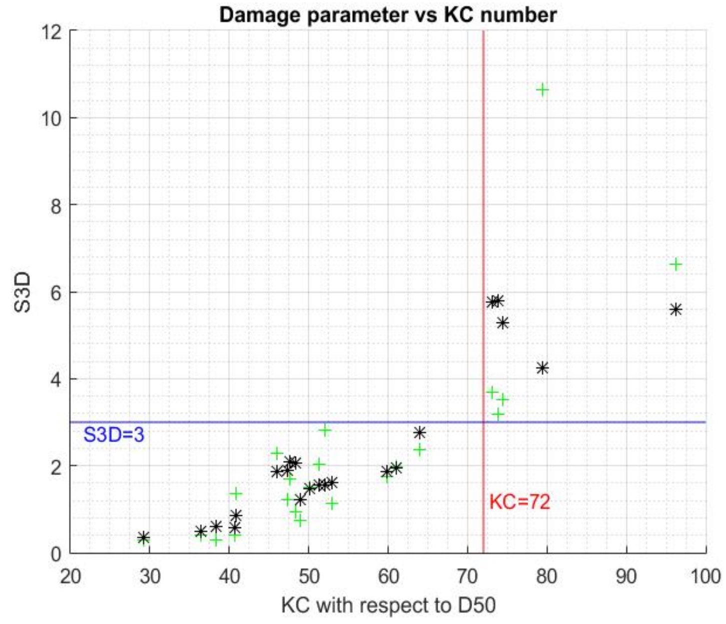
Revisiting the past

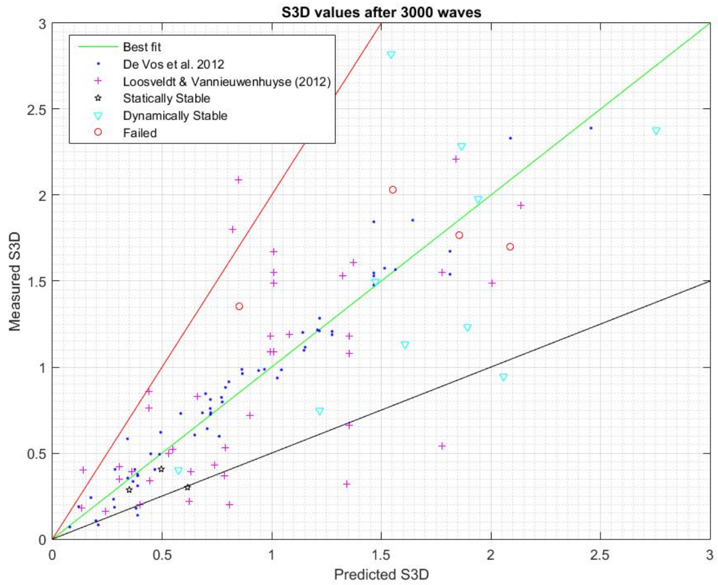
$$\frac{S_{3D,predicted}}{N^{b_0}} = a_0 \frac{U_m^3 T_{m-1,0}^2}{\sqrt{gd}\,(s-1)^{\frac{3}{2}} D_{n50}^2} + a_1 \left(a_2 + a_3 \frac{\left(\frac{U_c}{w_s}\right)^2 (U_c + a_4 U_m)^2 \sqrt{d}}{g D_{n50}^{\frac{3}{2}}} \right)$$



Insights into dynamic scour protections



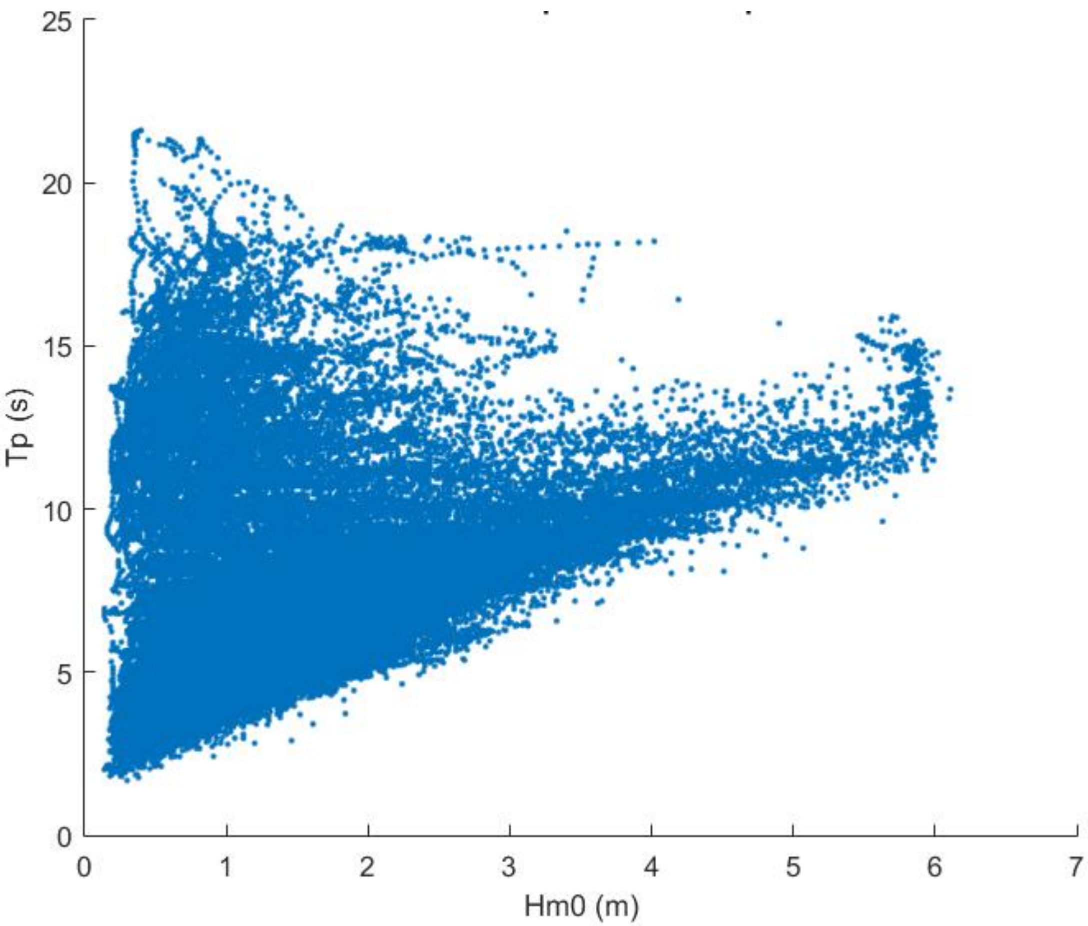




- Dynamic failure criterion;
- Physical influence of environmental and structural variables on the S3D;
- New design limits;
- Comparison with former design approaches.

Case study – Horns Rev III

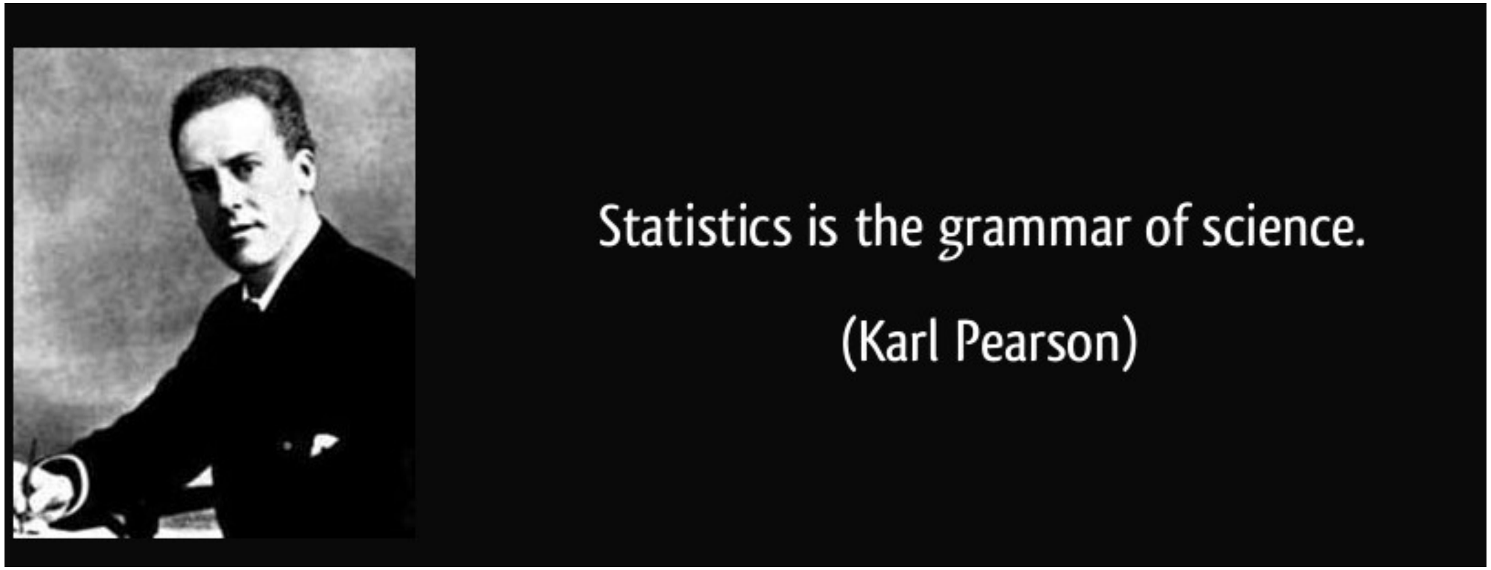
DMI, 2013; Kristensen et al., 2013	
Latitude	55.725º
Longitude	7.750º
Water depth	(≈) 10-20 m
Diameter	4 m – 4.5 m
Monopile	Founded at 25-39 m
Dist. to shore	(≈) 30 km
Area	144 km^2
Nº of turbines	49
Turbine's capacity	8 MW
Installed capacity	(≈) 400 MW



Horns Rev III – Hindcast model

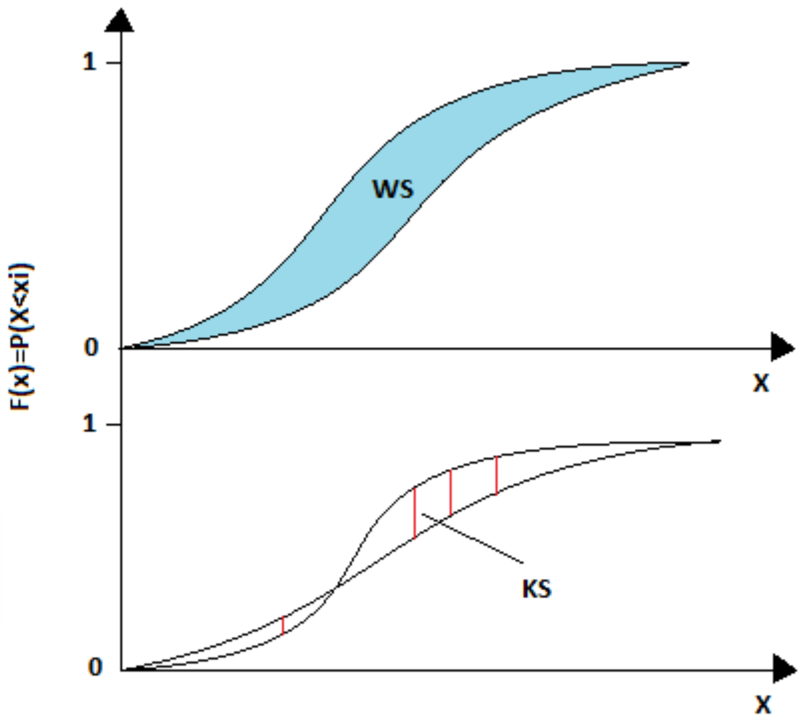
Variable	Hindcast model; spatial and time resolution	Record Duration	Hindcast validation	Output for the statistical modelling	Statistical Model
Source	DMI (2013)			DMI (2013); Energinet (2013)	Present research
H_{m0}	DMI-WAM; 2 km; 1 hour	10 years (2003-2013)	1 year of observations (2012) available from Nymindegab and Horns Rev 2 met mast.	Time domain (Hm0; Tp)	Kernel & Copula Model (DNV, 1992; 2007 - Weibull 3p + Lognormal conditional?)
T_p					
U_c	DMI-HBM; 5 km; 1 hour	10 years (2003-2013)	Currents verified by water level verification at coastal tide gauges (Esbjerg Havn and Hvide Sande Havn)	Current bottom velocity = 0.3 m/s (0.2-0.9 m/s)	Weibull Distribution (DNV, 1992)

Statistical modelling of significant wave heights (H_{m0}) and peak periods (T_p)

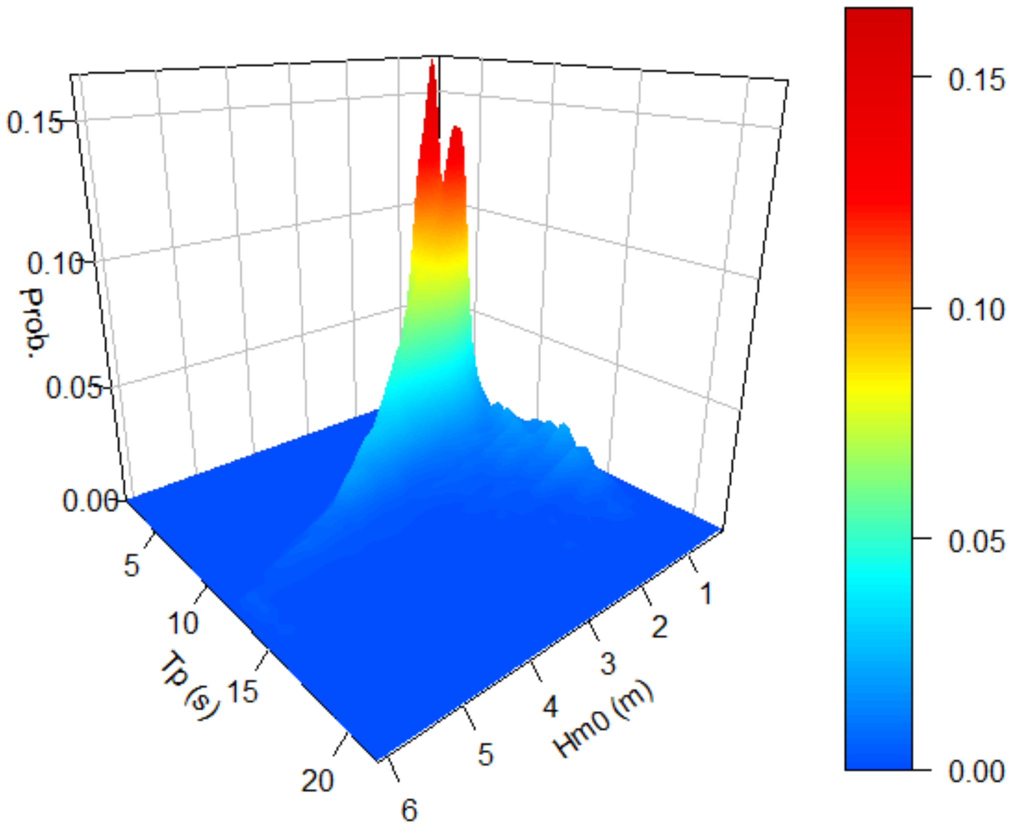


Fitting a Marginal

Marginals CDF	KS_Hm0	KS_Tp	WS_Hm0	WS_Tp
Normal	0.11679	0.0948	0.2173	0.5983
Exponential	0.2133	0.3402	0.3464	2.5045
Rayleigh	0.11301	0.1385	0.1824	0.6344
GEV	0.22232	0.1711	0.3606	1.1154
GP	0.1716	0.2892	0.2285	1.6682
LogNormal	0.0071	0.0176	0.0162	0.1293
Weibull	0.0594	0.0783	0.1149	0.493
Weibull 3p	0.0594	0.0569	0.1249	0.4315



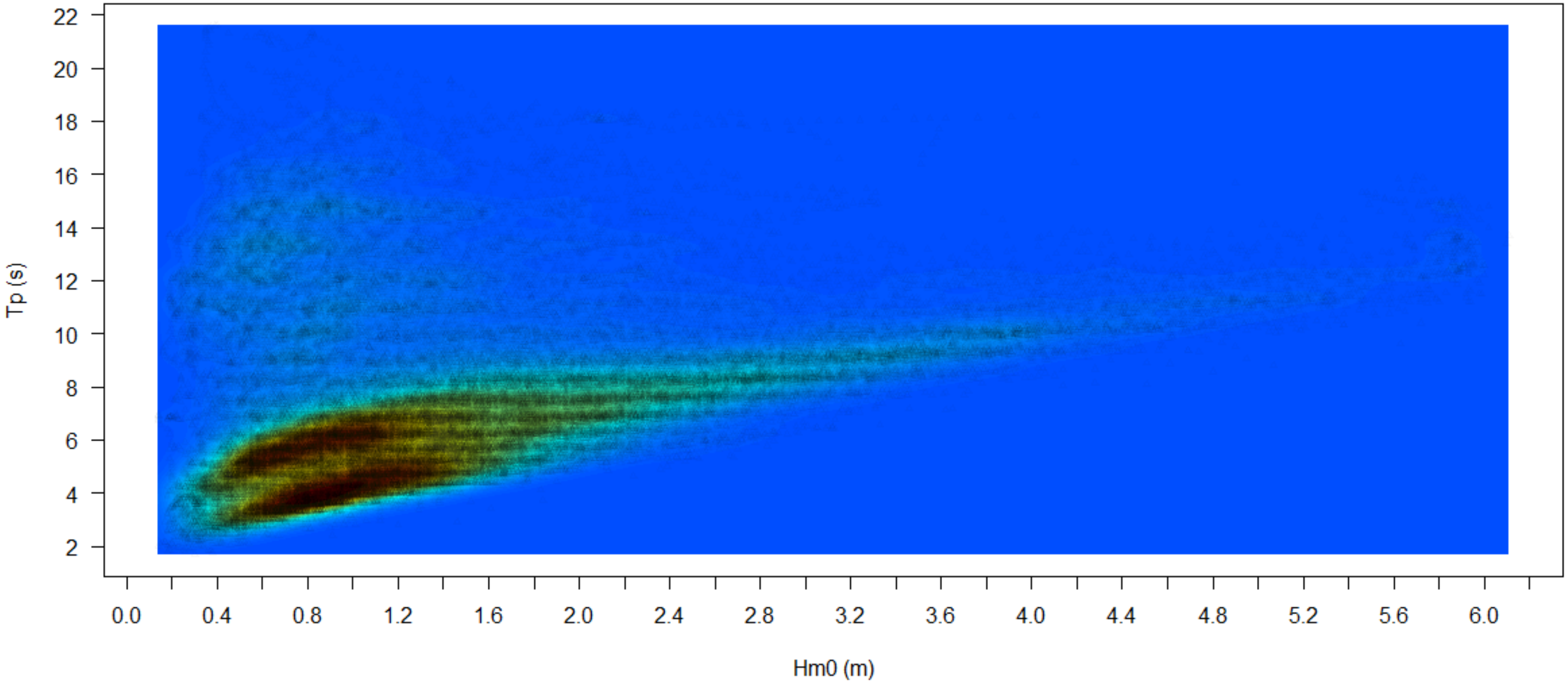
Kernel Density Estimation



KDE

- Non-parametric model
- Epanechnikov version
- Joint model of Hm0 e Tp.
- ECDF-EDK<1.05%

Kernel Density Estimation



Copulas model

Sklar's theorem:

$$H_{m0} \sim Ln(\mu_{H_{m0}};\sigma_{Hm0}) \therefore u = F\left(H_{m0}\right)$$

$$T_P \sim Ln(\mu_{T_P};\sigma_{T_P}) \therefore v = F\left(T_P\right)$$

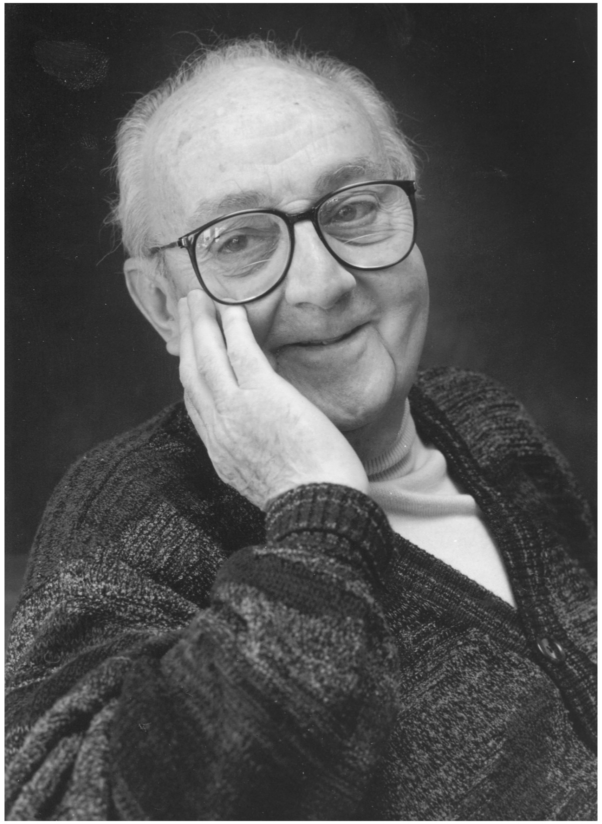
If Hm0 and Tp are continuous, then there is only a function, the so-called Copula, which expresses the joint cumulative density function:

$$F\left(H_{m0};T_p\right) = C\left(F\left(H_{m0}\right);F\left(T_{p)}\right)\right) = C\left(u;v\right)$$

$$(u;v)\in[0;1]^2$$

What's the purpose?

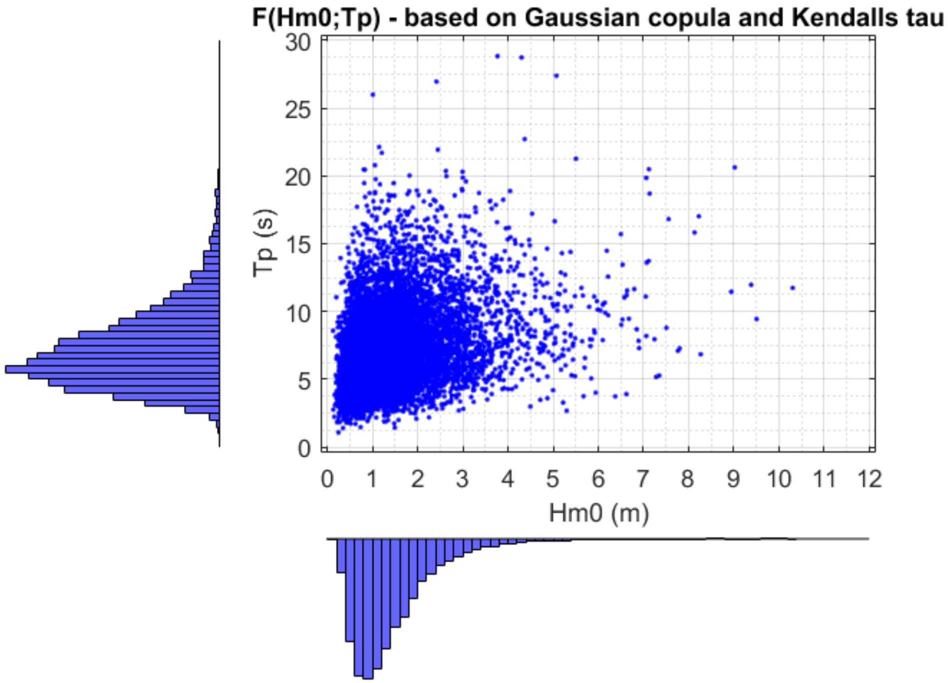
Copulas allow us to build a joint model (i.e. correlated) only with the knowledge of the marginal function of each random variable and a measure of dependence!



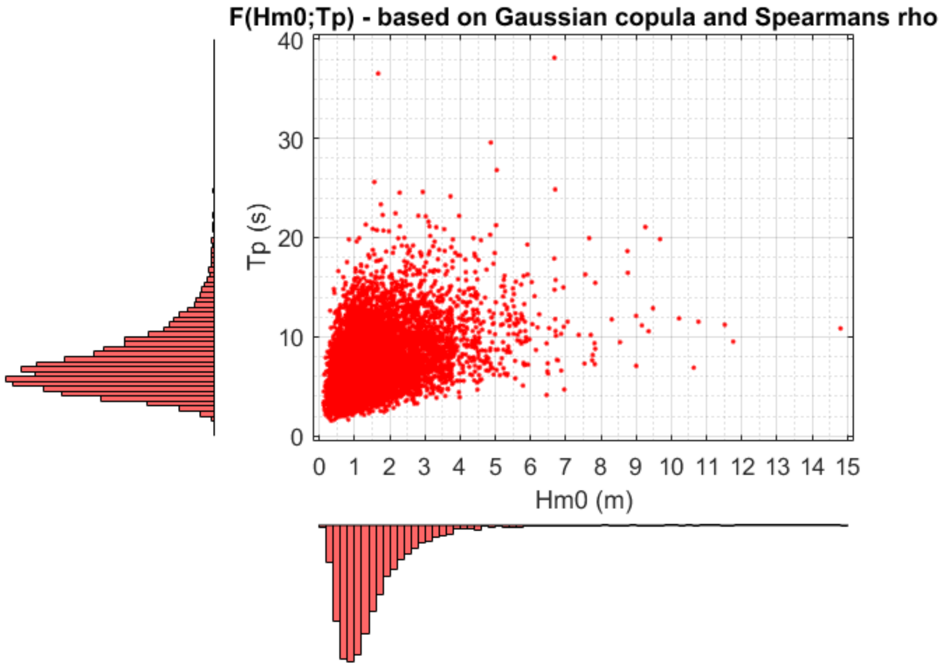
"All models are wrong, but some are useful."

George Edward Pelham Box

Copulas – Elliptical and Archimedean Copulas



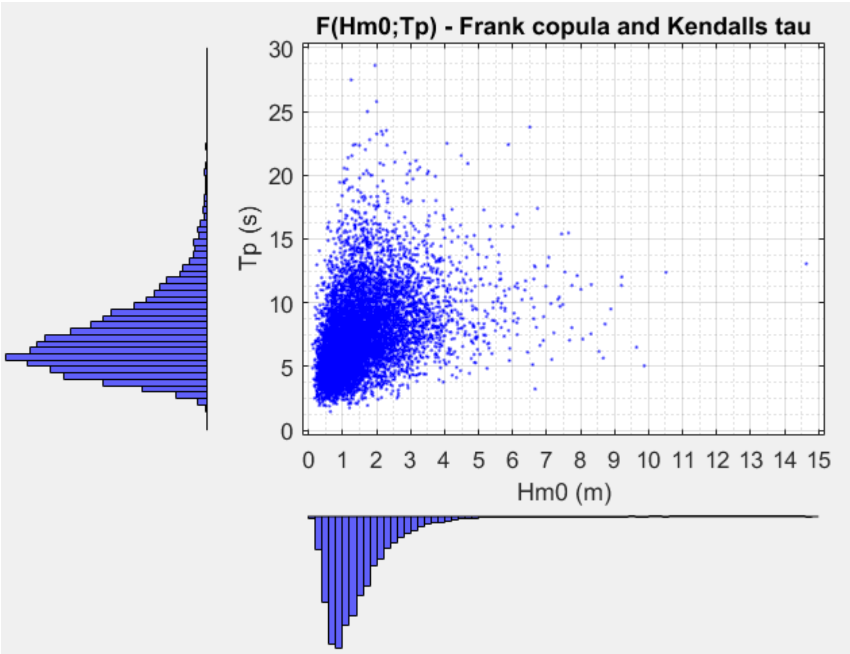
- Physical limitations;
- Measures of dependence;
- Tails correlation;
- The cumulative error.



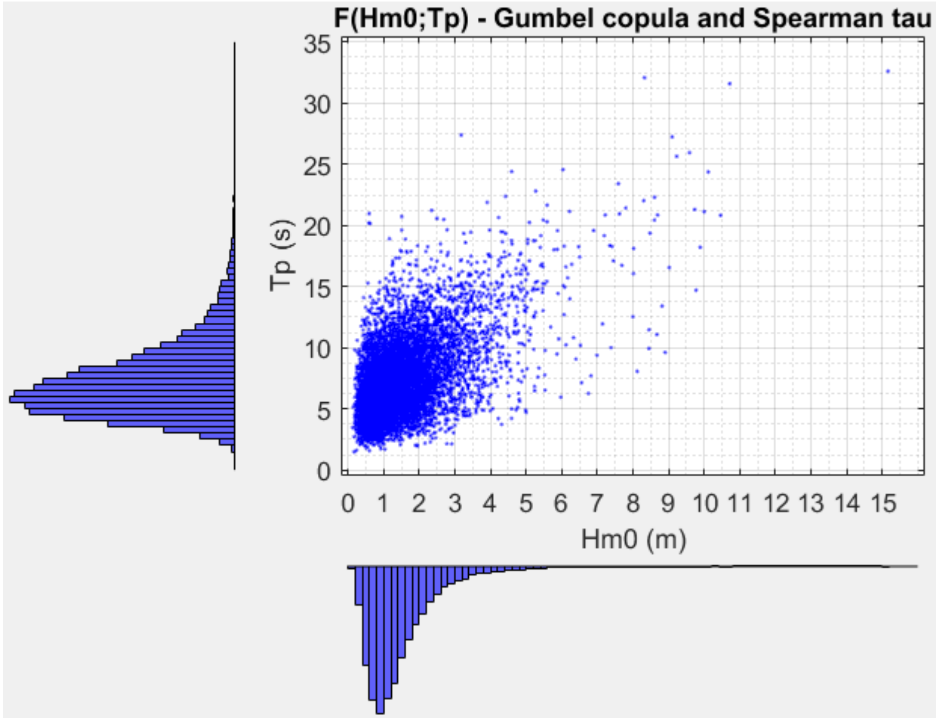
- The type of copula and measure of dependence will affect the Pf associated to the damage parameter or the shear-stress evaluation (Gaussian; t-copula).

Copulas – Elliptical and Archimedean Copulas

Now we are able to generate random correlated values of H_{m0} and T_p in order to simulate the performance function, and to obtain the Pf of the scour protection.

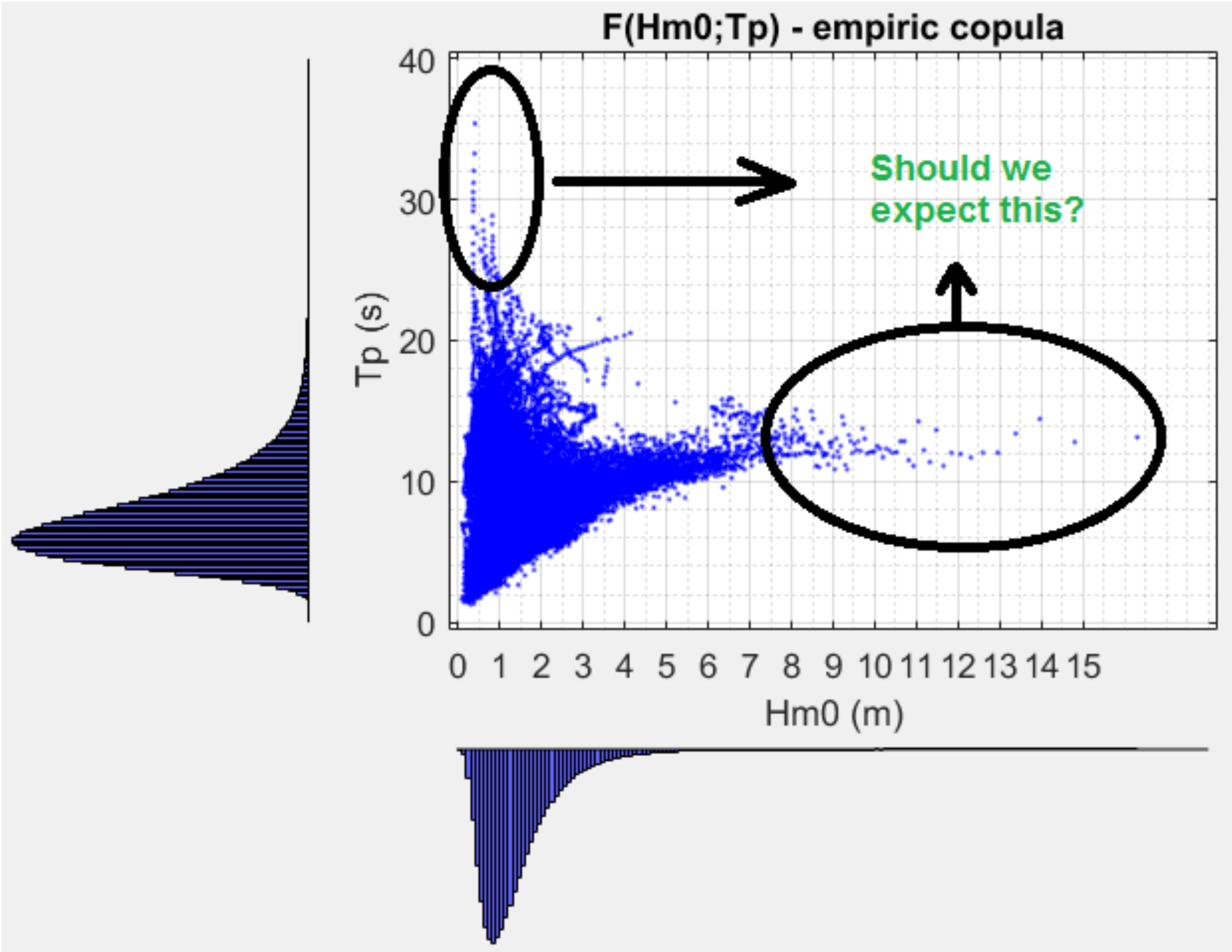


- Frank; Clayton; Gumbel



- Seasonality, spatial distribution, angle of attack, wind vs swell…

Imagination is the limit and physics is the playground



From statistical modelling to risk analysis

1 - Determine the random variables that rule scour phenomena and describe them by their probability density function

2 - Define the probabilistic model for the scour occurrence

3 - Use Monte-Carlo Method to simulate the random variables

4 – Define the failure criteria, using the performance function g(x)

5 – Calculate g(x) for each pair of simulated random variables and obtain P_f

6 – P_f gives a measure of uncertainty related to a global safety factor

Conclusions and achieved goals

The recent work on the statistical model led to the following conclusions:

- Non-parametric models presented a better goodness of fit, however they do not have an analytical expression that might be useful for further analysis;
- The models must be adapted to respect the hydrodynamic constraints;
- Treating the data for seasonality, sea components and spatial variability is crucial for a proper modelling;
- t-copula provided the best score in terms of the negative log-likelihood estimation;
- The measure of dependence affects the design spectral parameters, which ultimately influence the probabilities of failure;
- Although the copulas might not be able to fit the overall sample, they are still able to provide high percentiles correlated values that are suitable for design purposes.

General goals achieved:

- Statistical model of correlated spectral parameters to design scour protections;
- New failure criteria for statically stable and dynamically stable scour protection;
- Peer-review validation of both parts of the work (ongoing process);

Future work

- For the presented case study, the consequences of failure are being quantified in terms of monetary units.

- Writing the PhD thesis.

- New opportunities ahead!

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THANK YOU!

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