A Spectral Description for Extreme Sea States Offshore Denmark

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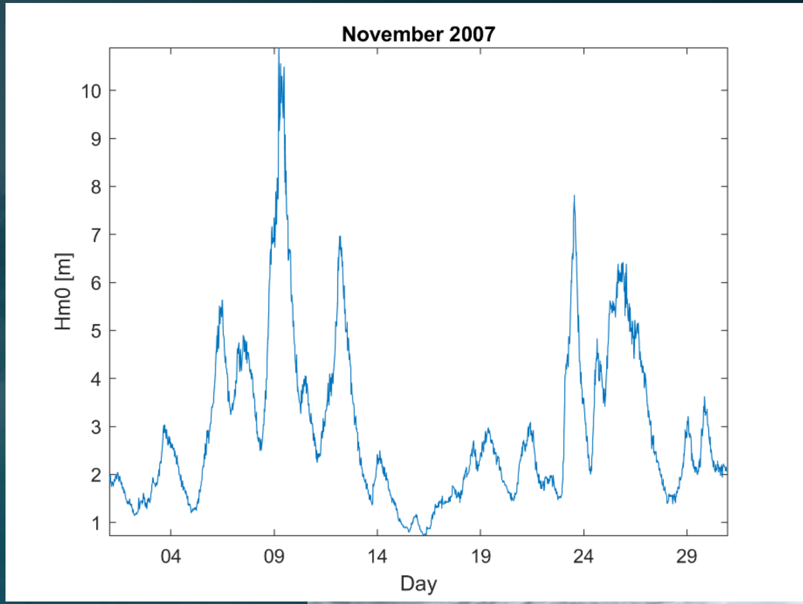

November 2007
Hm0 [m]
1
2
3
4
5
6
7
8
9
10
04
09
14
19
24
29
Day

AWARE Motivation

… awareness in the industry that:

1. in harsh environments the risk of a wave breaking in deep water is non-negligible, and
2. The probability of an extreme crest occurring (in some sea states) is higher than previously used in design.

Challenged the design basis underlying the existing structural assessment of DUC structures

Lead to a major structural reliability reassessment project AWARE – **A**bnormal **W**ave **A**ssessment & **Ri**sk **E**valuation.

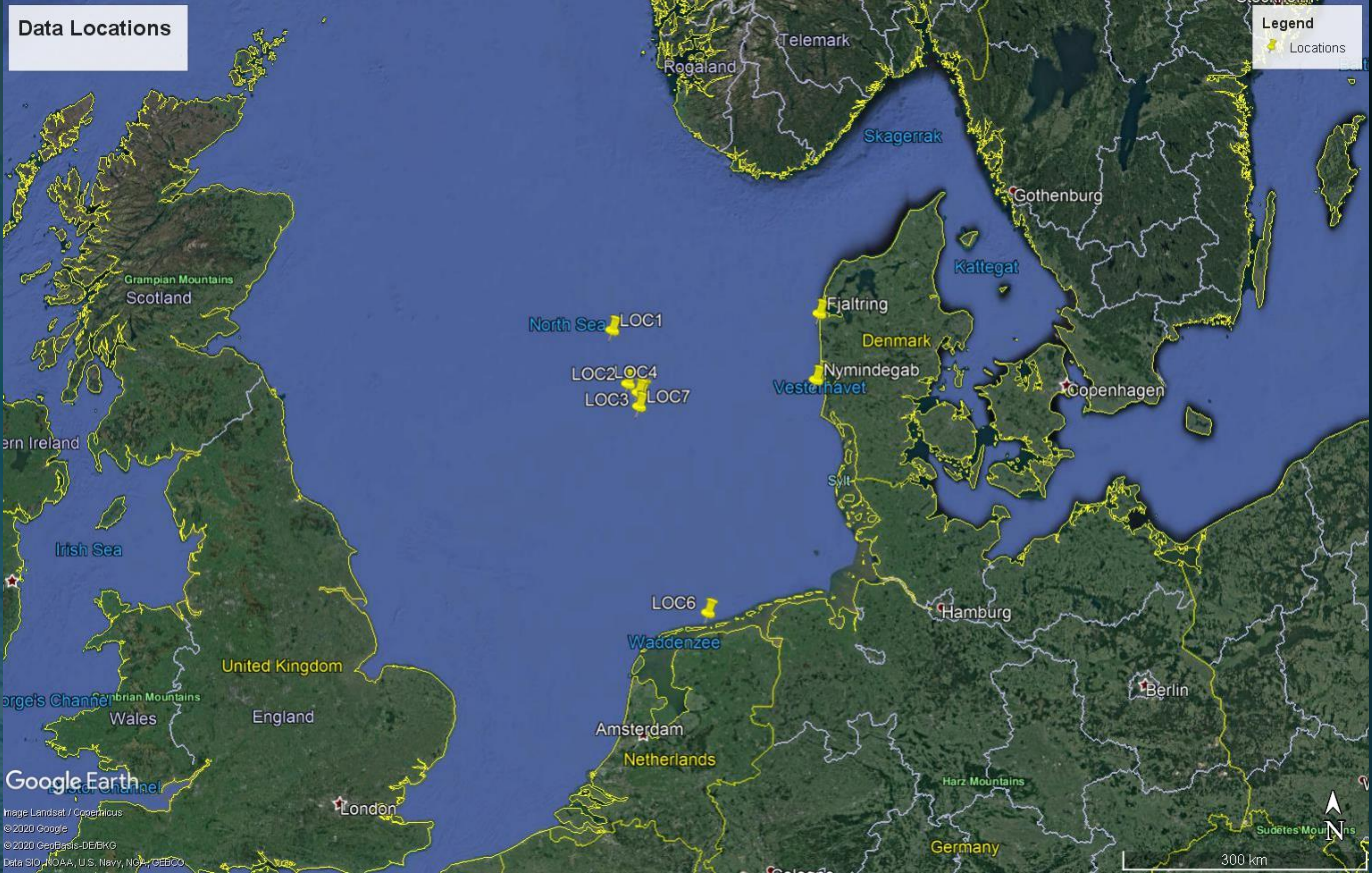
The need for the Spectral Description

- Input to the AWARE reliability analyses were Monte Carlo simulations of wave spectral parameters, for many sea states.
- The parameters H_{m0}, T_p, T_{02},θ_p, σ_p
- $S(f)$ and $\sigma(f)$ determined from the parameters, for each sea state.
- Spectra used to produce realisations of heights and crests for loading estimates.
- Spectral descriptions in terms of the parameters needed

Approach to develop Spectral Description

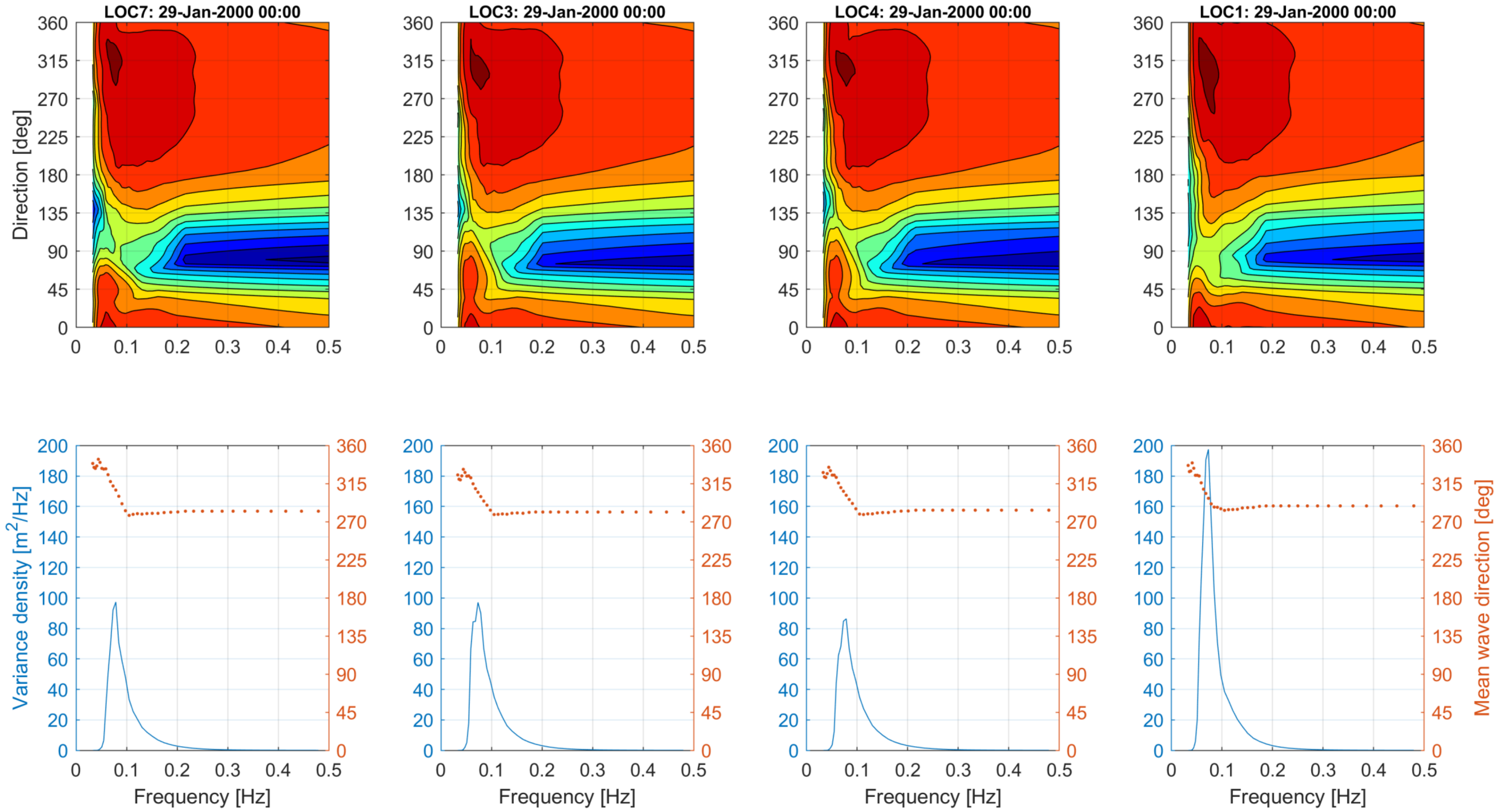
- Investigate spectra in available DUC measured and hindcast data, to determine important features
- Investigate validity of using existing spectral forms
- Develop new spectral forms, if necessary
- Evaluate spectral forms against measured and hindcast data

Data Locations



Location Name	Location Short Name	Water depth [m re. MSL]	Sensor	Data Type	Time Step
Location 1	LOC1	67	Saab L/2, Saab REX	Power Spectra	30 minutes
Location 2	LOC2	42	DWR	DWR Raw Data	60 minutes, 30 minutes
Location 3	LOC3	42	Saab REX	Power Spectra	30 minutes
Location 4	LOC4	41	DWR	DWR Raw Data	30 minutes
Location 5	LOC5	45	Saab REX	Power Spectra	30 minutes
Location 6	LOC6	8	Saab REX	Power Spectra	30 minutes
Fjaltring	FJG	18	DWR	Power Spectra	30 minutes
Nymindegab	NYB	20	DWR	Power Spectra	30 minutes

Location Short Name	Number of Records	H_{m0} Range [m]	T_p Range [s]
LOC1	269,870	[0.20, 11.7]	[1.77, 22.7]
LOC2	26,274	[0.03, 8.69]	[2.11, 23.4]
LOC3	213,991	[0.00, 10.9]	[1.84, 22.6]
LOC4	8,722	[0.57, 8.86]	[3.19, 18.4]
LOC5	165,816	[0.16, 10.9]	[1.89, 22.6]
LOC6	13,279	[0.19, 5.21]	[2.00, 20.6]
FJG	79,953	[0.11, 6.76]	[2.68, 22.4]
NYB	96,424	[0.28, 6.09]	[2.62, 23.0]



LOC7: 29-Jan-2000 00:00
LOC3: 29-Jan-2000 00:00
LOC4: 29-Jan-2000 00:00
LOC1: 29-Jan-2000 00:00
Direction [deg]
Variance density [m2/Hz]
Mean wave direction [deg]
Frequency [Hz]

Torsethaugen-Haver*

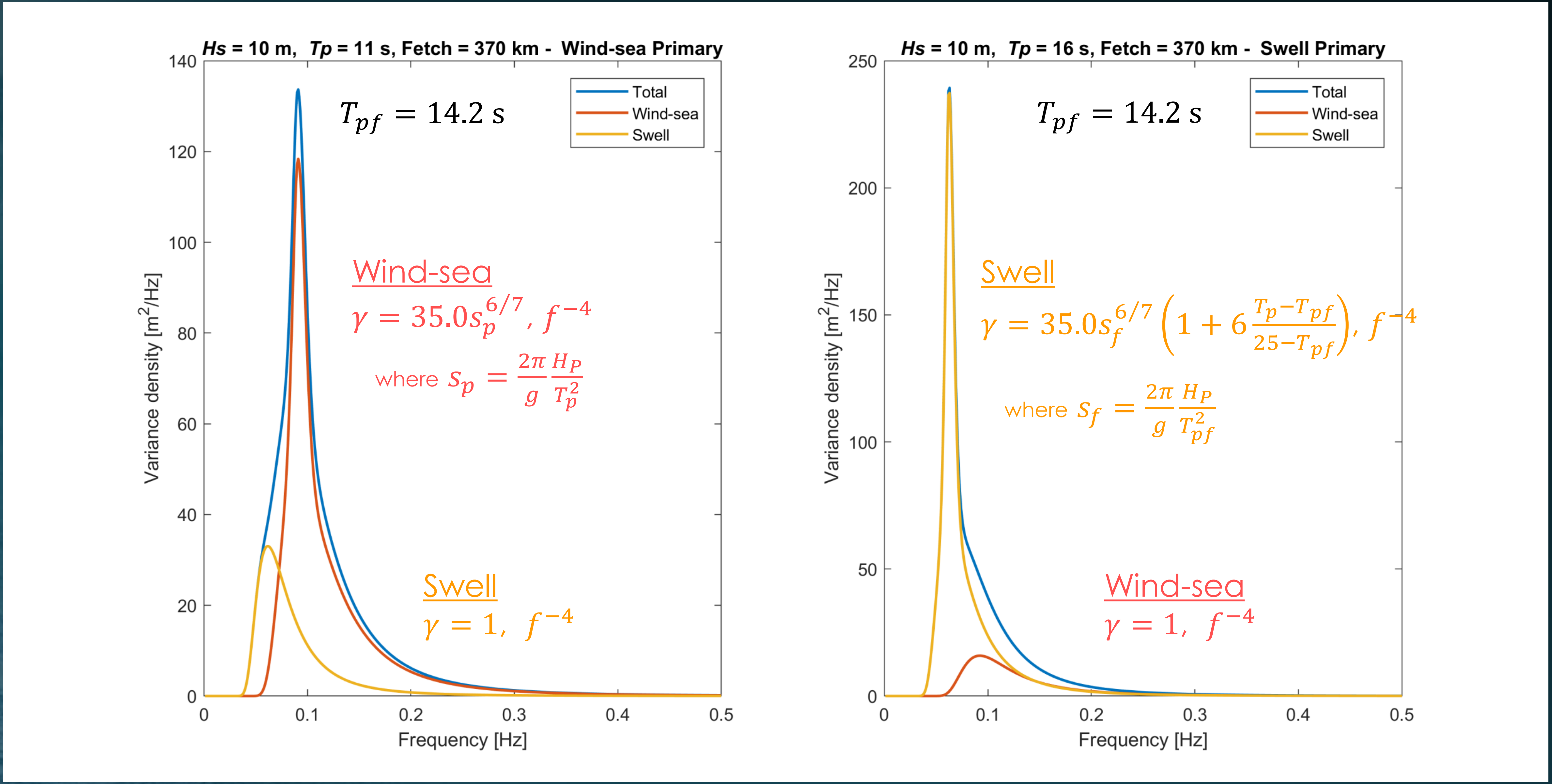
- two-component (wind-sea and swell) spectrum – JONSWAP-like components.

- shape depending on whether the sea state is determined as being wind-sea dominated or swell dominated

- If the spectral peak period, T_p, is less than a peak period, T_{pf}, characterising a fully-developed spectrum, the dominant component is the wind-sea; otherwise the swell component is dominant.

$$T_{pf} = 0.78 F_e^{1/6} H_{m0}^{1/3}$$

*(Torsethaugen, Knut and Haver, Sverre. Simplified double peak spectral model for ocean waves. 2004., Paper No. 2004-JSC-193)



Hs = 10 m, *Tp* = 11 s, Fetch = 370 km - Wind-sea Primary
Total
Wind-sea
Swell
$T_{pf} = 14.2$ s
Wind-sea
$\gamma = 35.0 s_p^{6/7}, \ f^{-4}$
where $s_p = \frac{2\pi}{g}\frac{H_P}{T_p^2}$
Swell
$\gamma = 1, \ f^{-4}$
Variance density [m^2/Hz]
Frequency [Hz]
0
20
40
60
80
100
120
140
0
0.1
0.2
0.3
0.4
0.5
Hs = 10 m, *Tp* = 16 s, Fetch = 370 km - Swell Primary
Total
Wind-sea
Swell
$T_{pf} = 14.2$ s
Swell
$\gamma = 35.0 s_f^{6/7}\left(1 + 6\frac{T_p - T_{pf}}{25 - T_{pf}}\right), \ f^{-4}$
where $s_f = \frac{2\pi}{g}\frac{H_P}{T_{pf}^2}$
Wind-sea
$\gamma = 1, \ f^{-4}$
Variance density [m^2/Hz]
Frequency [Hz]
0
50
100
150
200
250
0
0.1
0.2
0.3
0.4
0.5

Modified JONSWAP – Wind-sea

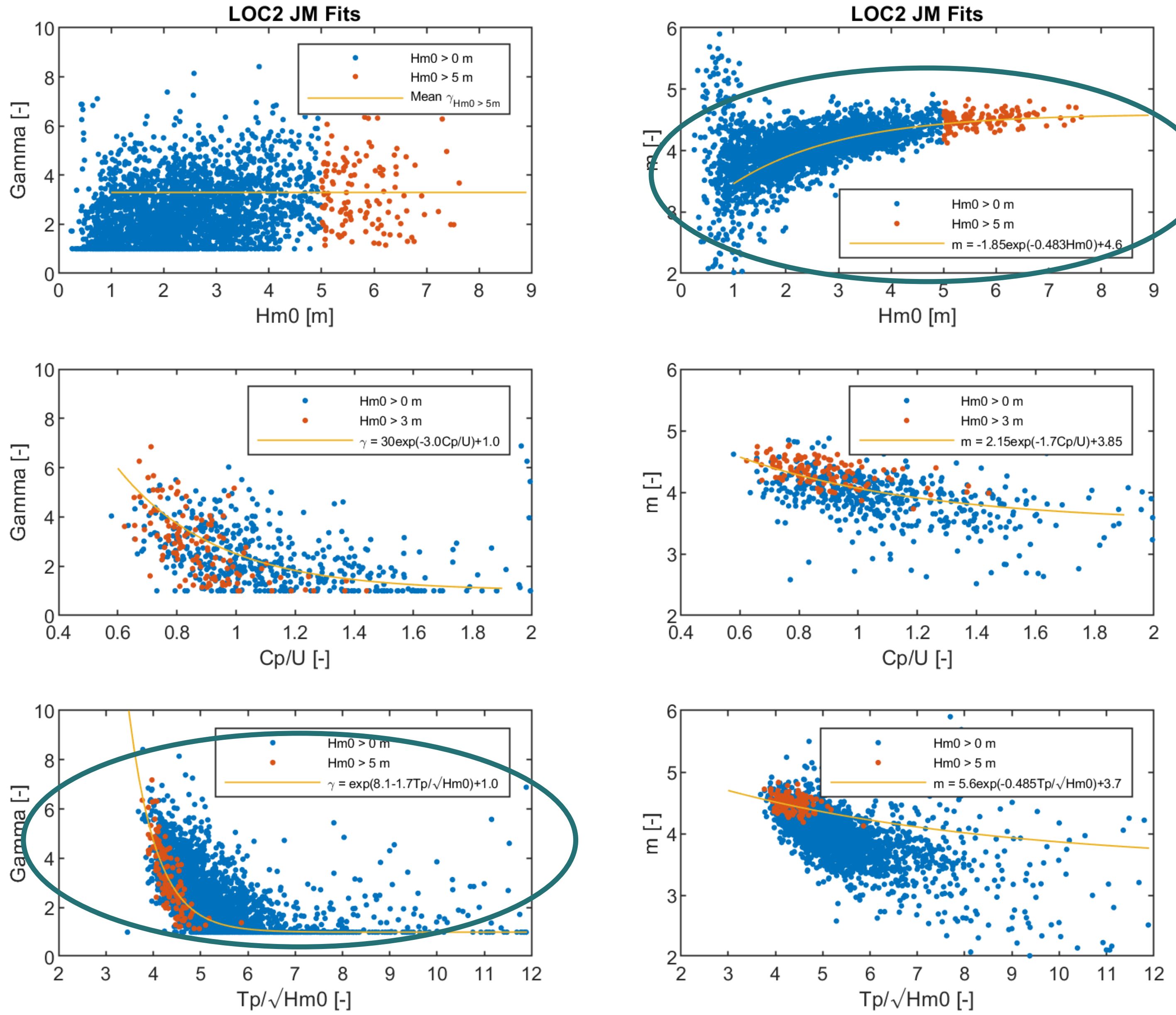
$$G_{JM}(f) = \frac{\alpha g^2}{(2\pi)^4} f^{-m} \exp\left[-\frac{m}{4}\left(\frac{f}{f_p}\right)^{-4}\right]\gamma^q$$

$$q = \exp\left[\frac{-\left(f - f_p\right)^2}{2\sigma^2 f_p^2}\right]$$

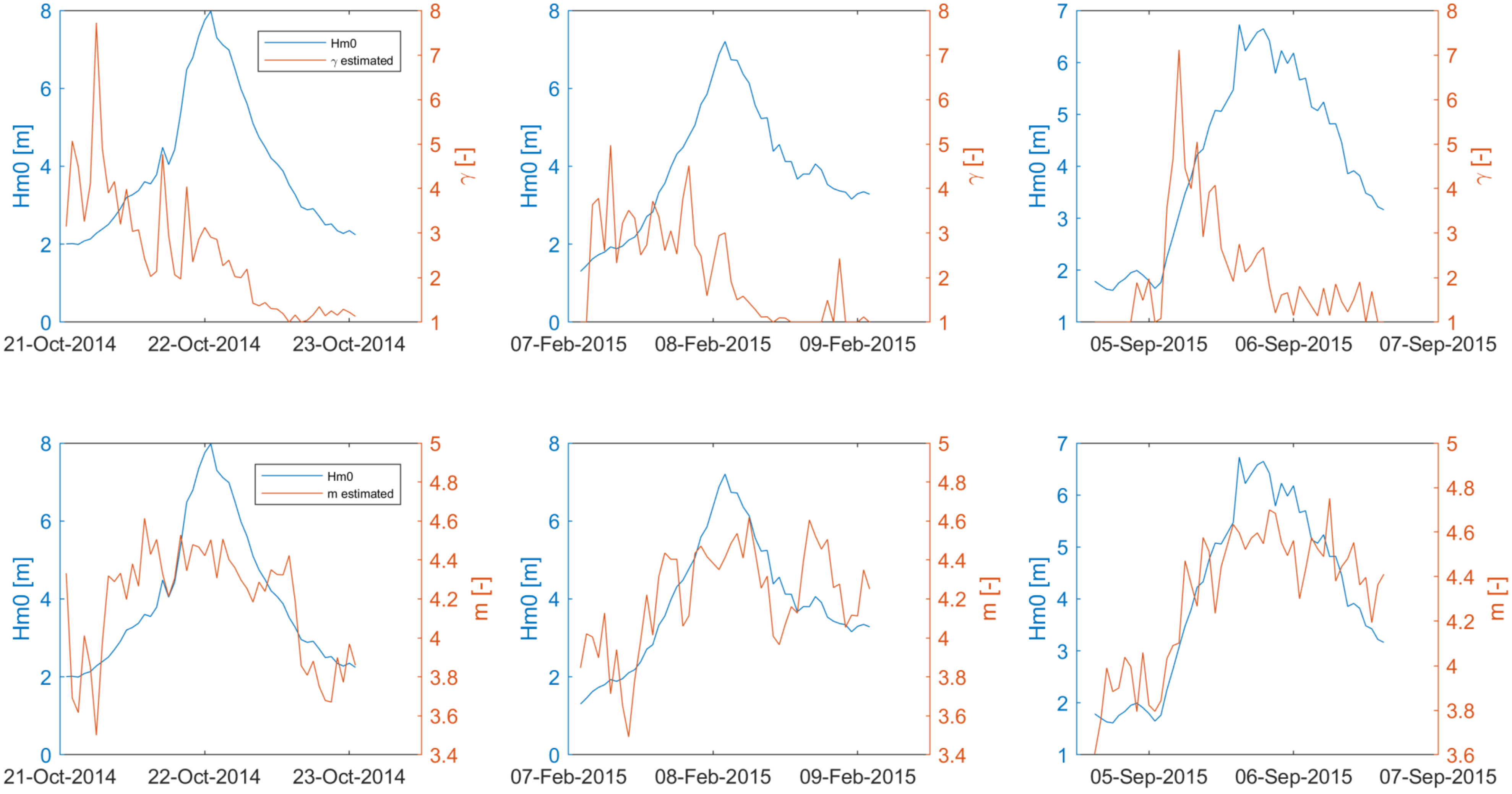
$$\sigma = 0.07 \quad \text{for} \quad f \leq f_p$$
$$\sigma = 0.09 \quad \text{for} \quad f > f_p$$

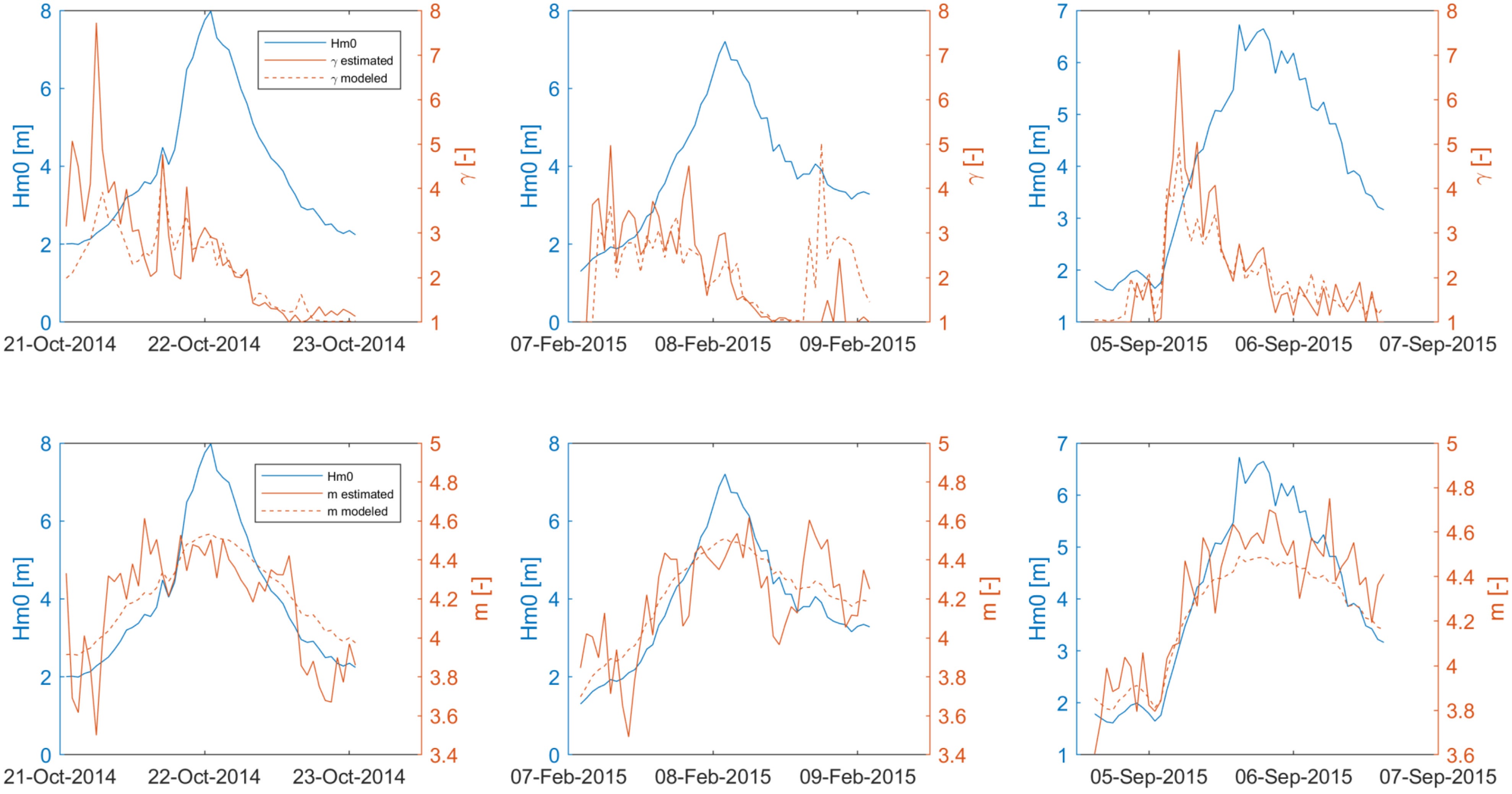
Peak Enhancement Parameter & Tail Slope Index Relationships

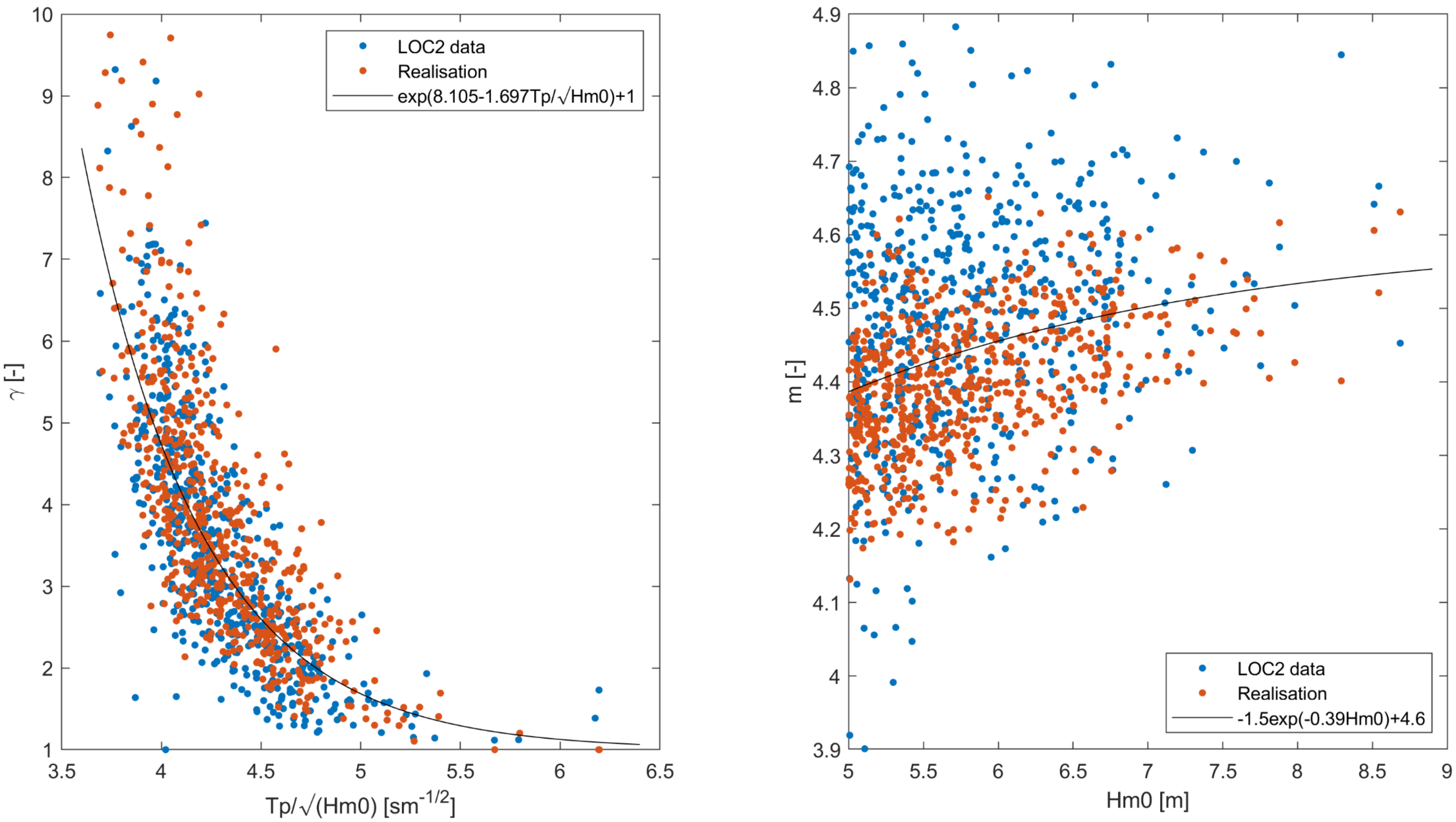
- Derived from the fits of the JM spectrum to the Loc2 measured spectra
- Peak enhancement parameter estimates were constrained to the range $1.0 \leq \gamma \leq 30.0$.
- JM spectrum fits produce the four parameters $\alpha' = \alpha g^2/(2\pi)^4$, f_p, γ, and m.

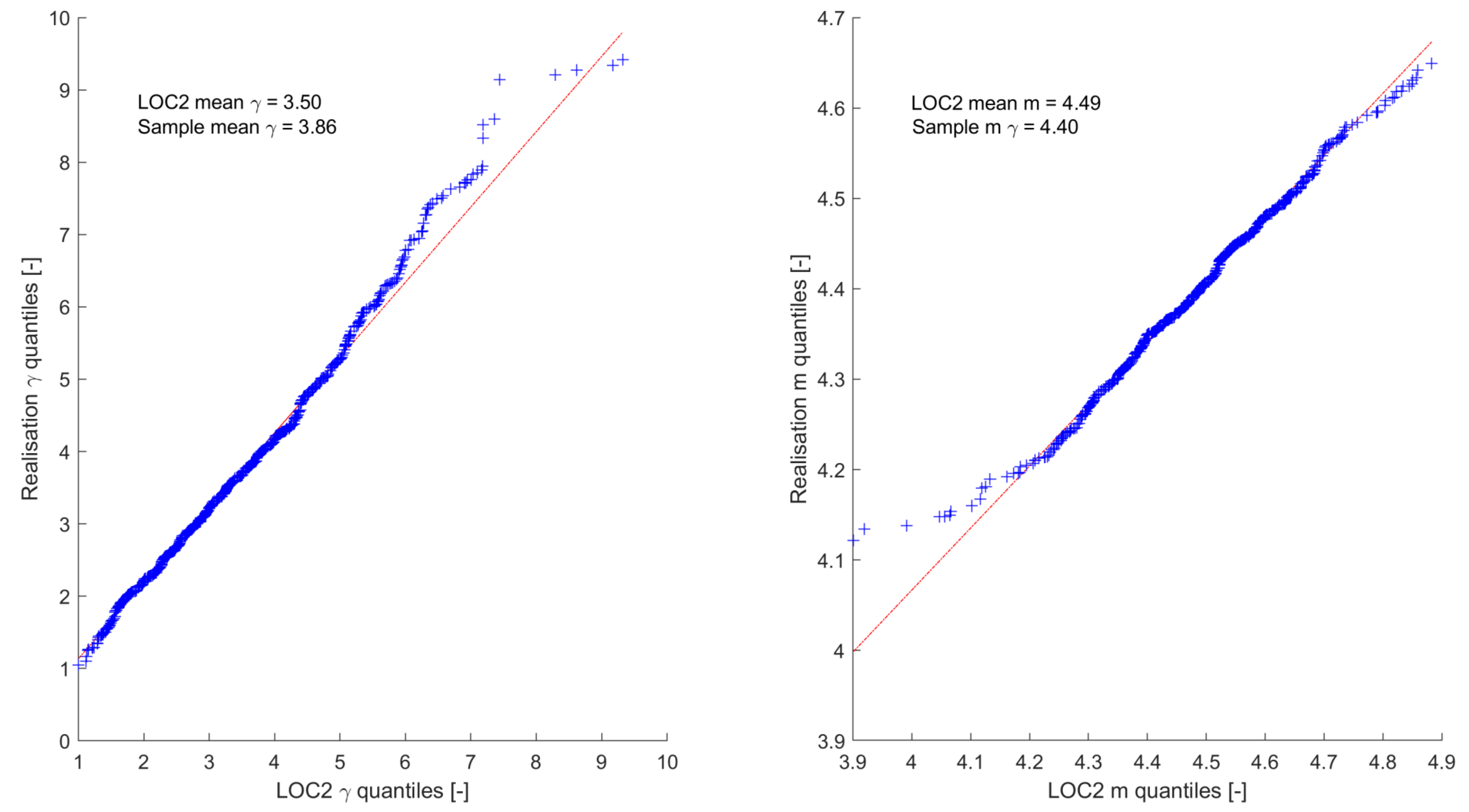


LOC2 JM Fits
Gamma [-]
Hm0 [m]
Hm0 > 0 m
Hm0 > 5 m
Mean γHm0 > 5m
LOC2 JM Fits
m [-]
Hm0 [m]
Hm0 > 0 m
Hm0 > 5 m
m = -1.85exp(-0.483Hm0)+4.6
Gamma [-]
Cp/U [-]
Hm0 > 0 m
Hm0 > 3 m
γ = 30exp(-3.0Cp/U)+1.0
m [-]
Cp/U [-]
Hm0 > 0 m
Hm0 > 3 m
m = 2.15exp(-1.7Cp/U)+3.85
Gamma [-]
Tp/√Hm0 [-]
Hm0 > 0 m
Hm0 > 5 m
γ = exp(8.1-1.7Tp/√Hm0)+1.0
m [-]
Tp/√Hm0 [-]
Hm0 > 0 m
Hm0 > 5 m
m = 5.6exp(-0.485Tp/√Hm0)+3.7


Hm0
γ estimated
Hm0 [m]
γ [-]
21-Oct-2014
22-Oct-2014
23-Oct-2014
07-Feb-2015
08-Feb-2015
09-Feb-2015
05-Sep-2015
06-Sep-2015
07-Sep-2015
Hm0
m estimated
m [-]
0
2
4
6
8
1
3
5
7
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5


Hm0
γ estimated
γ modeled
Hm0 [m]
γ [-]
21-Oct-2014
22-Oct-2014
23-Oct-2014
07-Feb-2015
08-Feb-2015
09-Feb-2015
05-Sep-2015
06-Sep-2015
07-Sep-2015
Hm0
m estimated
m modeled
m [-]


LOC2 data
Realisation
exp(8.105-1.697Tp/√Hm0)+1
γ [-]
Tp/√(Hm0) [sm^-1/2]
LOC2 data
Realisation
-1.5exp(-0.39Hm0)+4.6
m [-]
Hm0 [m]


LOC2 mean γ = 3.50
Sample mean γ = 3.86
Realisation γ quantiles [-]
LOC2 γ quantiles [-]
0
1
2
3
4
5
6
7
8
9
10
LOC2 mean m = 4.49
Sample m γ = 4.40
Realisation m quantiles [-]
LOC2 m quantiles [-]
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9

TMWF Spectrum

- Torsethaugen Modified

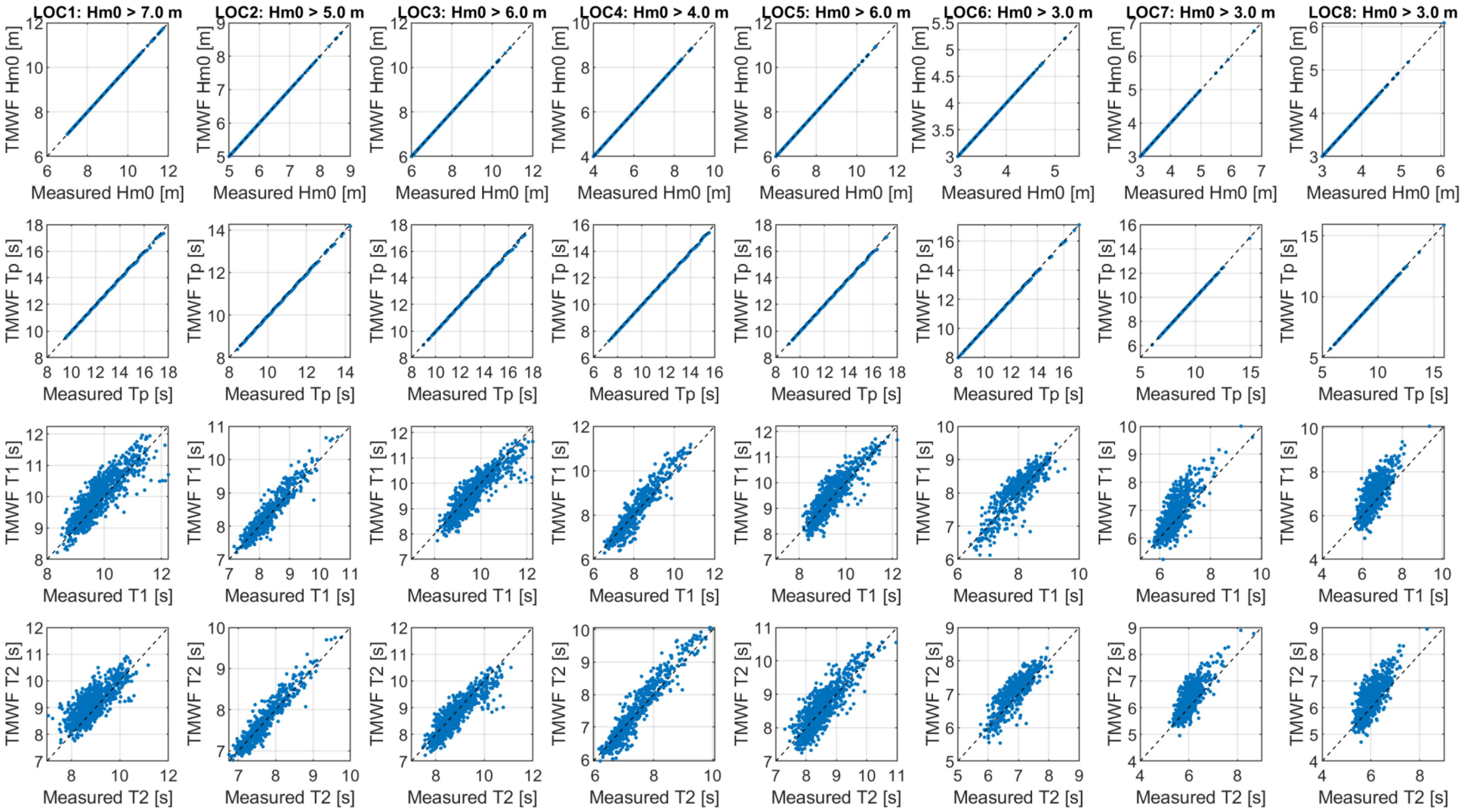
Wind-sea Primary

- Wind-sea replaced with Modified JONSWAP
    - $\gamma = \exp\left(8.1 - 1.7\frac{T_p}{\sqrt{H_{m0}}}\right) + 1$
    - $m = -1.85\exp(-0.483H_{m0}) + 4.6$
- No swell

Swell Primary

- Torsethaugen expression used

Scatter plots of TMWF against measured



The Exponential Transfer Function

$$S_{\text{AWARE}}(f; H_{m0}, T_p, T_{02}, F_e, a) = \begin{cases} S_{\text{TMWF}}(f; H_{m0}, T_p, T_{02}, F_e)\exp(-af) & \text{for} \quad f \leq 2f_p \\ S_{\text{TMWF}}(f; H_{m0}, T_p, T_{02}, F_e)\exp(-a2f_p) & \text{for} \quad f > 2f_p \end{cases}$$

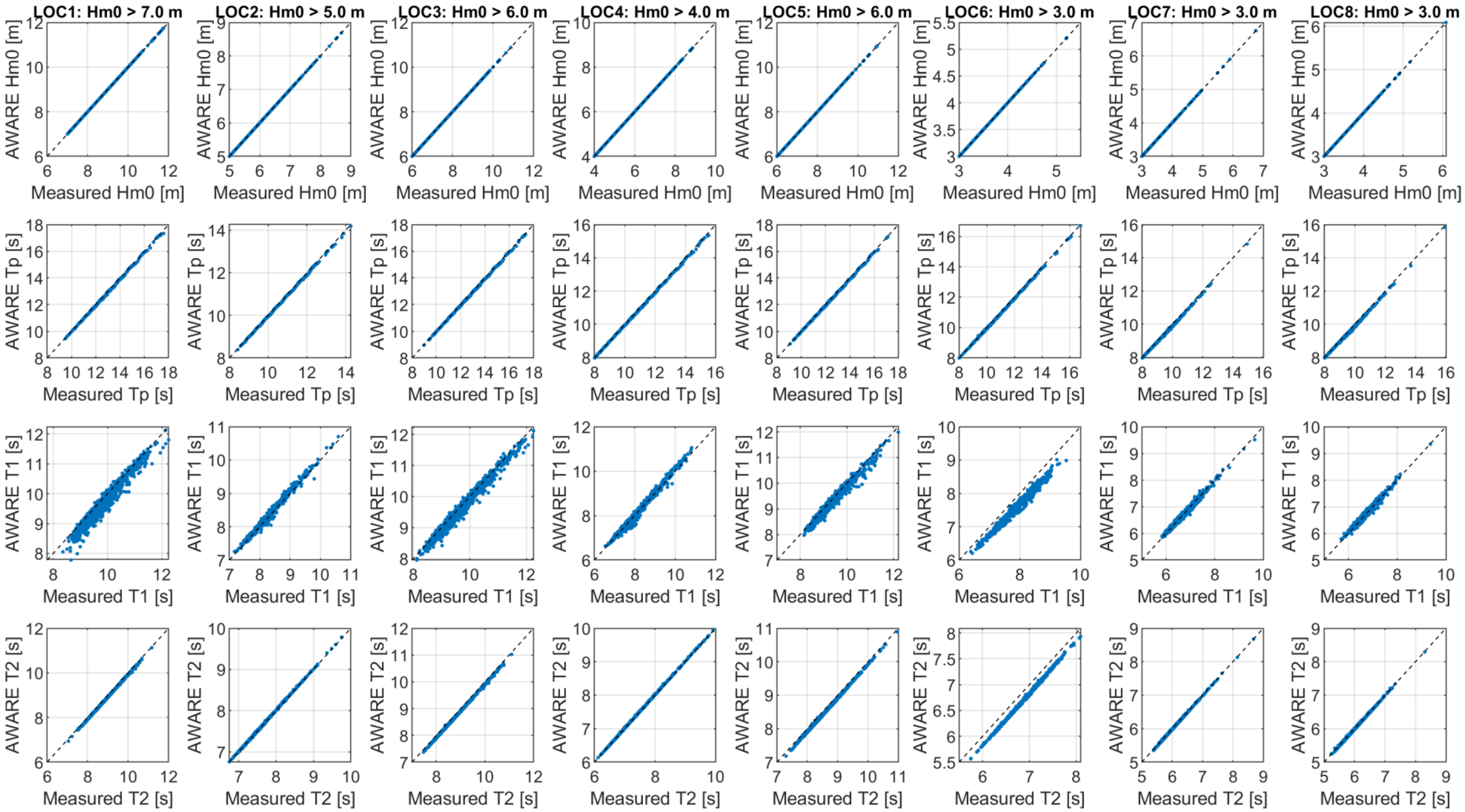
The values a of the exponential transfer function determined directly for each spectrum (from simulations), to achieve a minimum of the objective function,

$$O = \left(T_{02,S_A} - T_{02,S_T}\right)^2 + \left(T_{p,S_A} - T_{p,S_T}\right)^2$$

where subscript S_A indicates the estimate from the S_{AWARE}, and subscript S_T indicates the value used to estimate S_{TMWF}, with the constraint

$$\left|T_{p,S_A} - T_{p,S_T}\right| / T_{p,S_T} \leq 0.05.$$

Scatter plots of AWARE against measured



Take Aways

- JONSWAP-like function provides a flexible form for fitting unimodal wave spectra.
- Peak enhancement parameter can be expressed as a function of $T_p/\sqrt{H_{m0}}$
- The tail slope index, m, (f^{-m}), can be expressed as a function of H_{m0}.
- Improved T_{02} with application of exponential transfer function