# Spectral parameters to characterize the risk of rogue waves occurrence in a sea state

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**Abstract.** In a previous paper ([7]), we discussed the natural variability of some spectral parameters that may characterize a sea state, and concluded that deviations that might be observed close to occurrences of extreme waves were well within the natural range of variability. As a consequence, prediction of increased risk of rogue waves occurrence cannot be made from a simple local examination of the spectrum, but would require investigation of either simultaneous values of several parameters, or of the time history of a parameter over durations of the same order of magnitude as a storm.

In the present study, we investigate that second possibility, *i.e.* since the excursions on the time-scale of a sea-state are not decisive, we consider the next time-scale, that of a whole storm. To this aim, the Frigg database [4] is searched for storms, and an attempt is made to select within the set of storms a subset of “freaky storms” where there are observations of high crests with respect to the prevailing significant wave height. The histories of spectral parameters during the storms are then computed, and differences from histories in the subset and some other storms (since the other storms cannot all be ”freaky”) are sought for.

Similarly to the previous study, those parameters are preferred that might be related to rogue wave occurrence. They were determined either from theoretical wave considerations (Benjamin-Feir instability indicators), or from meteorological ones (spectral front bandwidth, that might reveal “running fetch” situations).

## 1 Introduction

Significant wave height $H_S$, peak period $T_p$ and main wave direction are sufficient to describe sea states for most practical purposes. However, that information is clearly not sufficient to detect increases in the risk of occurrence of unexpected rogue waves in a sea state. We thus study observations of additional parameters, in hope that on one hand they exhibit special properties when rogue waves occur, and that on the other hand they can be related to some theoretical mechanism of rogue wave generation and thus validate the assumption that the corresponding mechanism is active in nature on those occasions when rogue waves are observed.

It should be noted that in order to be useful, a parameter must have a characteristic change for some duration at a significantly larger time-scale than that of the individual wave. Otherwise, the change in the parameter would merely be a detection of the rogue wave and could not be used for forecast, nor would it mean anything more than “the wrong place at the wrong time” and it thus could not fully validate a particular generation mechanism.

The next higher time-scale, that of a stationary sea state, was investigated in a previous paper ([7]). We concluded that sea state spectral parameters that exhibit sensitivity to rogue wave occurrences:

- do not depart from the normal range of aleatory variations but show only slight biases, and
- exhibit a high rate of false alarm.

We recommended that one try to find out criteria based on combined occurrence of several characteristics, including directional ones, or based on the next higher time-scale, *i.e.* the process or the time-history of characteristics over a whole storm duration.

The present study investigates the latter suggestion, that of characteristics derived from a whole storm.

Ersdal and Kvitrud ([1]) report on a total of 6 storms in the North Sea, and for two of them, damage was observed at two different locations. Similarly, damage was also reported at a BP platform during the storm of the famous “New Year Wave”. It is thus not unlikely that storms as a whole might have some characteristics related to an increase in the risk of occurrence of rogue waves.

## 2 Benjamin-Feir Instability indices

Many authors put forward non-linear focusing as a generating mechanism for rogue waves, and suggest to characterize it through an index of the Benjamin-Feir instability (BFI) computed by dividing steepness by adimensional bandwidth.

Results reported in [7], and recalled in figure 1, show that though sea state BFI indices are biased towards higher values when rogue waves occur, that bias is of little practical value since a small BFI index is no garantee that rogue waves will not occur, and alerts for 80% of the rogue waves would require to send warnings more than half of the time.

Yet, the high natural variability of BFI index might be a consequence of the difficulty to obtain stable estimators when considering short *in situ* records, especially with respect to that part of spectral bandwidth that is relevant to the Benjamin-Feir instability and that is focused on the spectral peak.

Goda (1983) [2] recognizes that the narrowness parameter $Q_p$ and the other ones that are based on spectral moments are sensitive, at least to some extent, to the tail of the spectrum and/or the cut-off frequency used in the measurements and analysis. He suggests the use of normalized peak height $\Phi_p = S(f_p) f_p / m_0$ as a measure of the sharpness of the spectral peak.

That measure of bandwidth has several advantages:

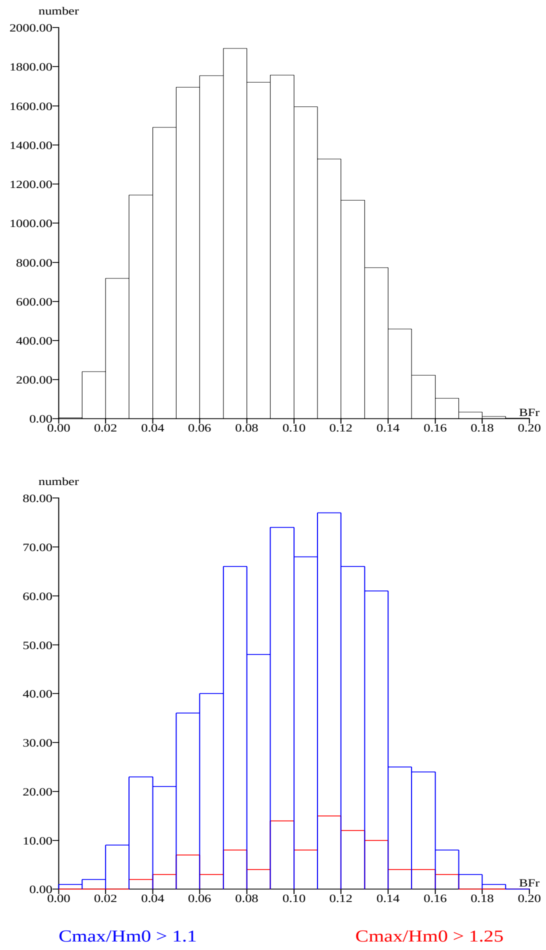

**Fig. 1.** Histogram of the robust Benjamin-Feir index values for 18000 sea states at Frigg

- it is not significantly affected by the cut-off frequency or a poor estimation of the spectral tail and of its shape;
- it enables to define in the same manner a “spectral front bandwidth” $\Phi_{fp}$ using the restriction of $m_0$ to $[0,f_p]$;
- it enables to define a spectral asymetry coefficient that is also free from the influence of the spectral tail: $A_S = (\Phi_p - 2\Phi_{fp})/\Phi_p$.

That definition is often discarded because of the difficulties in estimating presisely $S_{max}$, especially for measured spectra. However, a resonable amount of robustness may be achieved by using in such cases the weighted average of the

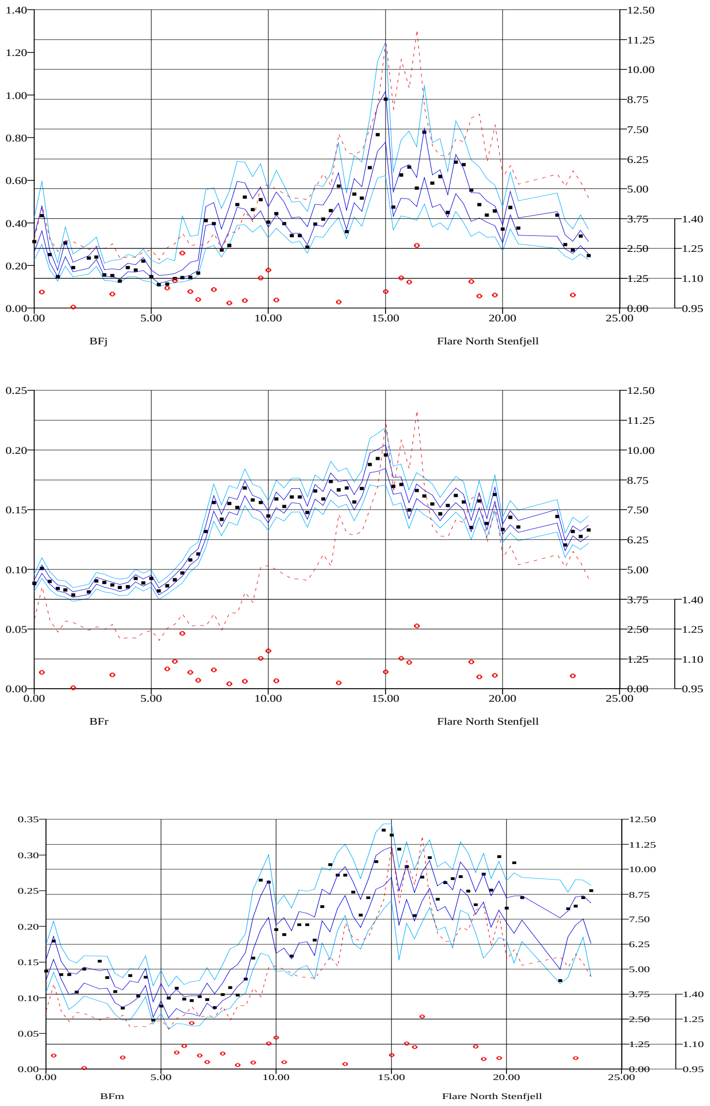

**Fig. 2.** Time-history of crests (dashed red), normalized crests (red circles), BF Index (black dots) and its 10, 30, 70 and 90% aleatory variability fractiles (solid blue)

peak value and of its two neighbours. The following relationships then hold:

$$S_{ave} = \frac{S(imax-1) + S(imax) + S(imax+1)}{3}$$

$$f_{max} = \delta f \left( imax + \frac{S(imax+1) - S(imax-1)}{S(imax-1) + S(imax) + S(imax+1)} \right)$$

$$\Phi_p = \frac{m_0}{S_{max}} = C\delta f$$

$$C_0 = \frac{m_0}{S_{ave}\delta f}$$

where $\delta f$ is the frequency discretization interval.

For a triangular shape, we have the bandwidth at level $S_{max}$ is zero and at level $S_{ave}$ $\frac{2}{3}2\delta f$, thus:

$$\frac{S_{ave}}{S_{max}} = \frac{2\Phi_p - \frac{4}{3}\delta f}{2\Phi_p}$$

and replacing in the previous equations:

$$\frac{C}{C_0} = \frac{C - \frac{2}{3}}{C}$$

$$C = C_0 - \frac{2}{3}\frac{C_0}{C}$$

One can then solve the equation,

$$C^2 - C_0 C + \frac{2}{3}C_0 = 0$$

$$C = \frac{C_0}{2}\left(1 + \sqrt{1 - \frac{8}{3C_0}}\right)$$

Since $C$ is close to $C_0$, we have approximately

$$\Phi_p \; \approx \; \frac{m_0}{S_{ave}} - \frac{2}{3}\delta f$$

Figure 2 compares the time-history of the BFI index computed using $\Phi_p$ as a measure of bandwidth (bottom) to the robust BFI index defined in [7] (center) and to the common definition proposed by Janssen [3] (top), for the same Stenfjell storm measured at Ekofisk as in [7]. It can be seen that the use of $\Phi_p$ is acceptable, and that it exhibits a similar behaviour as the other versions of the BFI index, though its variability is much more of the order of magnitude of the Janssen version than of that of the robust one.

In order to make more emphasis on the storms where the spectrum rises steeply on the low-frequency side, which might be a token of a steep sea state and/or of a “running fetch” situation, we might want to base the BFI index on the spectral front bandwidth. The corresponding effect is shown on figure 3. Variability seems to be further increased, and to thus mask any possible detection of “running fetch” situations through the spectral front bandwidth based BFI index.

We could not identify on the time-histories of those Benjamin-Feir instability indices any special feature that might have some chances to be related to rogue wave occurrence.

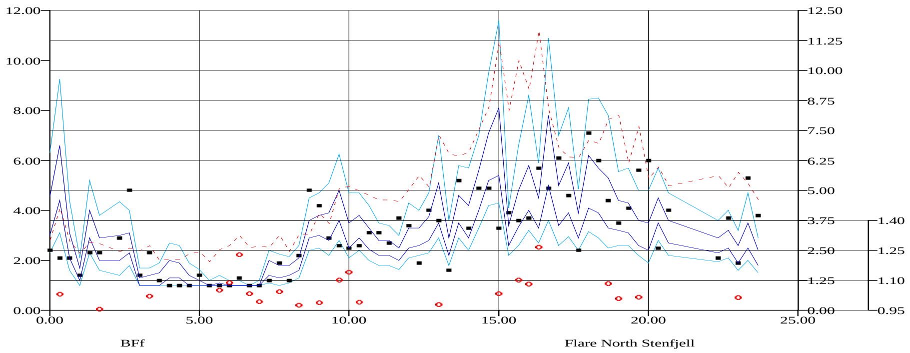

**Fig. 3.** Time-history of crests (dashed red), normalized crests (red circles), BF Index (black dots) and its 10, 30, 70 and 90% aleatory variability fractiles (solid blue)

## 3 Spectral bandwidth

In a previous study ([5]), we showed that no relation could be found between the average steepness of a sea state and rogue wave occurrence. Since Benjamin-Feir instability is characterized by steepness divided by bandwidth, the lack of influence of steepness might blur the effect of bandwidth by adding to the variability with no other consequence.

We may thus want to study bandwidth alone, *i.e.* look for changes in the spectral shape independantly of changes in the steepness of the sea state that varies for many reasons with the coming and going of wave systems and could thus be only a secondary cause for rogue waves.

Figure 4 shows the time-history of the spectral bandwidth (top) and of the spectral front bandwidth (bottom) for the same storm as previously. It may be noted that bandwidth exhibits a sharp decrease at the start of the storm, but that such behaviour could be observed on the arrival of any swell system, or even on any change from a confused sea state to a well-organized one.

On the particular storm that we studied, there does not seem to be much more to derive from the history of bandwidth parameters than from that of Benjamin-Feir Instability indices.

## 4 Comparison of storms

A characteristic feature may remain unnoticed for a single storm, yet it should appear on the study of a large number of such storms. The database used in [8] and complemented as reported in [7] was scanned for storms.

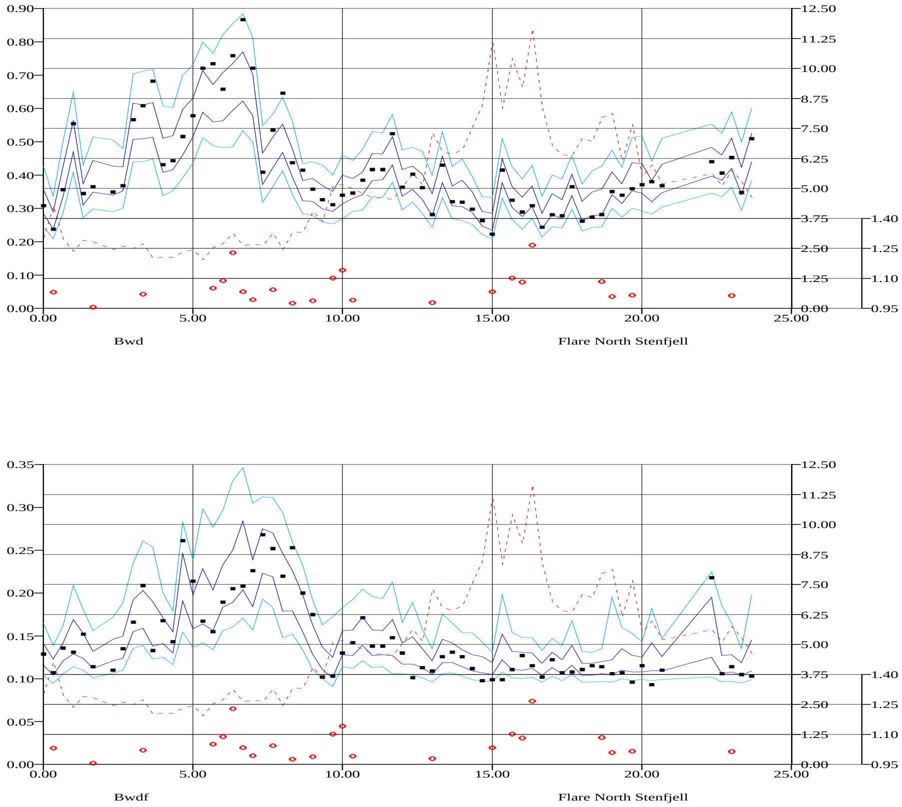

**Fig. 4.** Time-history of crests (dashed red), normalized crests (red circles), Bandwidth (black dots) and its 10, 30, 70 and 90% aleatory variability fractiles (solid blue)

Storms are defined as durations of at least 12 consecutive hours where significant wave height remains above 5 meters. Those storms were identified on the two different datasets of the database: the synthetic parameters computed by Oceanor on the measurements carried out on the field, and the values computed at Ifremer from the available time-series at QP. The Oceanor data cover the period from January 1979 to March 1989. That period contains 105 storms, 56 of which are also present in the data at Ifremer for which time-records of the water surface elevation are available with a 2 Hz sampling frequency, as measured with a radar distancemeter from the QP platform on the Frigg field.

A typical example of time-histories of the bandwidth parameters during a Frigg storm is given in figure 5. Comparison over several storms can be made

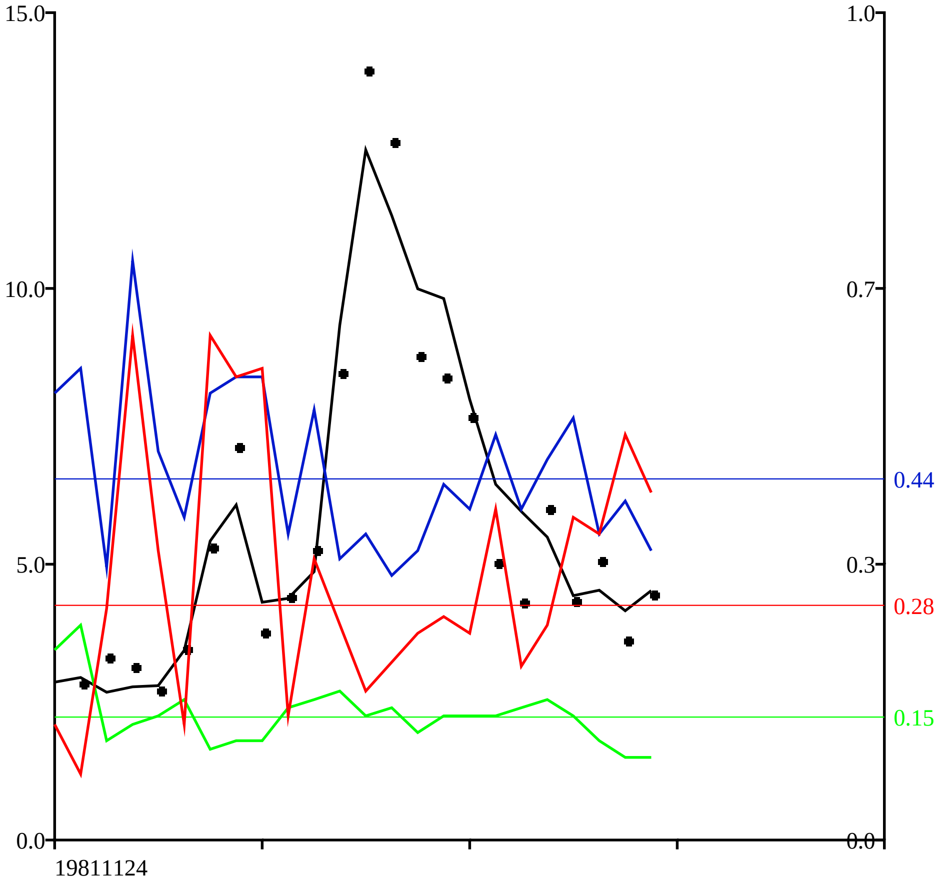

**Fig. 5.** Time-history of crests (black dots), significant wave height (black line), bandwidth $\Phi_p$ (blue line), spectral front bandwidth $\Phi_{fp}$ (green line), spectral asymetry $A_S$ (red line) and their averages over the storm

from figure 6. Those consecutive storms cannot but exhibit a variety of levels of risk with respect to rogue wave occurrence. Large crest to $H_S$ ratios were observed for the two first ones. Yet, there is no visible relationship with the histories of the bandwidth parameters.

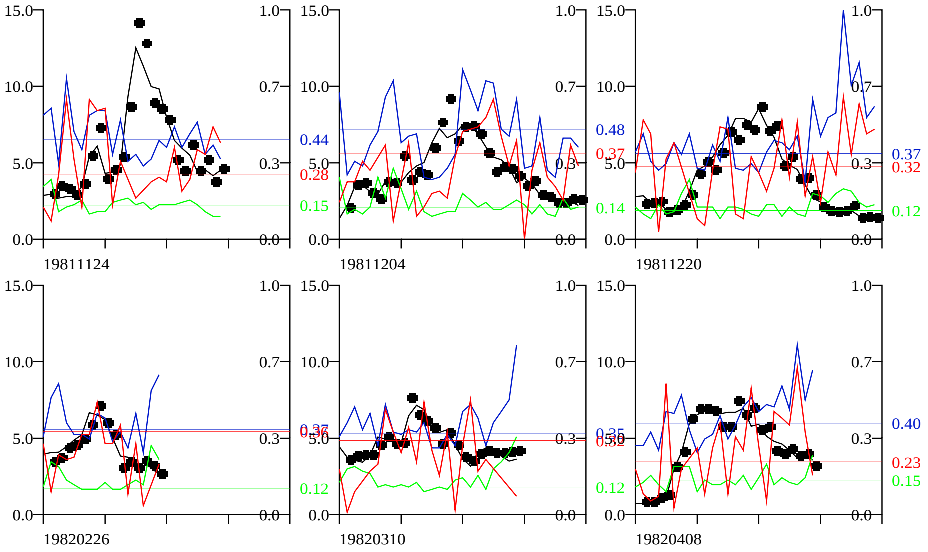

**Fig. 6.** Time-histories of crests (black dots), significant wave height (black line), bandwidth $\Phi_p$ (blue line), spectral front bandwidth $\Phi_{fp}$ (green line), spectral asymetry $A_S$ (red line) and their averages over the storms

## 5 Conclusions

The present study shows that dimensionless parameters related to spectral shape are rather constant over all storms in the database, as could be hinted from the results of another previous study [6].

As for the height and period (or steepness), it was shown at the previous Rogue Waves workshop[5] that steepness does not have any influence on the probability of rogue wave occurrence, and that significant wave height has only a limited one.

The time-history of spectral parameters evolution during a storm seems thus not to be a good candidate for the definition of warning systems. Furthermore, one may wonder about the validity of the assumption that some storms are more prone to extreme waves than others, or at least about the fact that such a characteristic would be reflected in the non-directional wave spectra.

Should the asumption be invalidated, *i.e.* extreme waves have no higher probability to happen in some storms than in any other, then either rogue waves would be normal extremes of the distribution, confirming some previous results obtained by Robin & Olagnon [8] on a subset of the database investigated here, either it would mean that the dataset is still too small for the differences to appear, or that the storm characteristics that are related to abnormal extremes should be sought elsewhere than in the spectrum.

## References

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