We thank the two anonymous reviewers for their useful comments to our manuscript. We found them valuable that helps to greatly improve the quality of the manuscript. Per your suggestion, we have carefully revised the manuscript (track-changed) following both reviewers' comments. Our point-by-point response (in blue) to the comments are as below:

Response to reviewer #1.

I have reviewed the manuscript [os-2015-93] titled "Common Characteristics of Directional Spreading-Steepness Joint Distribution in Freak Wave Events" by Liu and Yue. The authors constructed hindcast simulations of ocean conditions to analyze the wave parameters that closely related to freak waves. They found common visual features in direction spreading-steepness joint distributions when freak waves occurred. The common features seem obvious and interesting. The paper is generally written well and easy to follow. I have only minor comments, and suggest that the manuscript be published in OS.

We thank reviewer #1 for your encouragement. Our point-to-point response to your questions is as below.

1. The model used in the study is WAVEWATCH III (WW3), which is a spectral model to describe the statistic characteristics of ocean waves. It is impossible to simulate freak waves using WW3. How to build the connection between the simulated results and the freak waves is important, but unclear in the paper.

Response: We agree with the reviewer that in our previous version there were not enough information on the connection between the simulated results and freak waves. As the reviewer pointed out, it is impossible to simulate freak waves in WW3.

However, the freak wave-related parameters deduced from simulated results can be considered as an approximation of corresponding parameters of statistical sea states which is pertinent to freak waves. Some previous studies (Zakharov et al., 2007; Badulin et al., 2008; Toffoli and Bitner-Gregersen, 2011） have indicated that the freak wave only has a very limited influence on the statistical properties of ocean waves for its typically timescale is only few wave periods, and we have highlighted this in the first paragraph of Model Configurations:

2 Model configurations

As a state-of-the-art third generation spectral model, WAVEWATCH III (WW3) (Tolman, 2002, 2009) offers good descriptions of statistical sea states from a kinetic approach that well mimics directional spectrum. Short-lived freak waves can last only for ~~1 to 10~~ wave periods (Janssen, 2003) and hardly influence relatively long-time wave statistical characteristics (Toffoli and Bitner-Gregersen, 2011). ~~Nevertheless, even~~ in complex conditions, the evolution of spectrum with the spectral kinetic description appears to be consistent both qualitatively and quantitatively with solutions for the weakly nonlinear dynamical equations for ~~water~~ waves (Zakharov et al., 2007; Badulin et al., 2008).

In summary, our simulated results of sea states do not contain information of freak waves, although they can be used to indicate the conditions when with freak waves occurring. In the first paragraph of Model Configurations, more explanations about freak waves and simulated results are added in order to avoid the confusions.

[Line 59-62, line64, os-2015-93_manuscript_revised_marked.pdf (hereafter, os..pdf)]:

that well mimics directional spectrum. Although the WW3 model can not give the simulation of freak waves, the freak-wave related parameters deduced from simulated results can be considered as an approximation of corresponding parameters of statistical sea states which is pertinent to freak waves. Short-lived freak waves can last only for ~~1 to 10~~ a few

~~Nevertheless, e~~Even in complex conditions,

2. Page6, line14-17 “Tamura et al., (2009) and In et al., (2009) have introduced frequency peakedness-directional spreading joint distribution”. Where “Steepness” is used in the paper instead of “peakendness”. What’s the difference between steepness and peakedness in the joint distribution?

Response: We agree with reviewer that in previous studies, frequency peakedness-directional spreading joint distribution has been introduced (Tamura et al. (2009; In et al., 2009). However, in this paper, we tend to use ‘Steepness’ instead of ‘frequency peakedness’. The parameterization of ‘frequency peakedness’ in WW3 model adopted the method of Goda (1970), and is different in the parameterization of single-peaked spectrum and double-peaked spectrum. We find that there are always some abrupt changes in frequency peakedness when the spectrum switches from single peak to double peak. Goda’s approach to parameterize the frequency-peakedness is not always suited in double-peaked spectrum. So the frequency peakedness is not used in the joint distributions.

Freak waves are nonlinear phenomena essentially and wave steepness is the direct parameter to characterize the nonlinear level of ocean waves. So the steepness is adopted as the joint distribution factor. We also add some more explanations in the

[line135-137, os..pdf]:

samples that they used in their research show similar visual feature. We find that there are always some abrupt changes in frequency peakedness when the peak number of spectrum varies. For this, the frequency peakedness is not used in the joint distributions. Freak waves are

3. Page5, Line26, “Burgers et al., (2008)” change to “and Burgers et al. (2008)”

Response:

We have corrected it according to reviewer’s comment. (line119, os..pdf)

4. Page5, Line 4, “Where” change to “where”

Response:

We have corrected it according to reviewer’s comment. (line99, os..pdf)

5. Page6, Line 14,”Tamura et al., (2009), In et al., (2009)” change to “Tamura et al. (2009) and In et al. (2009)”

Response:

We have corrected it according to reviewer’s comment. (line132, os..pdf)

Response to reviewer 2.

The study of freak waves is important because of their potential damages to ships, coastal and oceanic structures. However, they are very difficult to observe, which enables the wave model simulation a good choice besides experimental and theoretical approaches. A key study of freak waves is how to predict their occurrence.

Usually, this question is studied using some wave parameters derived from wave spectrum. The authors of present study list these parameters, discuss their relationships with freak wave occurrence, find disadvantages of using single parameter and propose their new approach of multi-parameters. The study uses the well-developed third generation wave modelâ˘A˘TWaveWacth III to simulate wave spectra. The figures show compellent details and the explanations are reasonable. Their result is interesting and meaningful, giving useful information on future study of freak wave occurrence. The whole paper is well organized with beautiful results and proper discussions. I think it can be published with some modifications.

We thank the reviewer for the encouragement. We have modified the manuscript according to your suggestions and hope you find the revision acceptable.

1. In page 4, lines 4-5: you mentioned that "Short-lived freak waves can last only for 1 to 10 wave periods". I am not quite clear about the expression "wave periods", does it have a value? or how to define this value?

Response: The "wave periods" is a description about the typical timescale of freak waves following Janssen (2003). It doesn't have a decisive value and is just a general description. The periods of ocean waves are always ranging from 1 to 20 seconds. To avoid confusion, we have reworded '1~10 wave periods' to 'a few wave periods'.

2. In page 4, lines 10-12: in Section 2 "Model configurations", I think it is not clear to readers on the following issues: 1) What is the outer/inner grid (or area) of the model, so you should explain how to define them. 2) You need to explain more about the model setup, i.e. how many source terms are considered in your calculations? 3) The data specification should be more detailed: the resolutions, the time span and your considerations on how to determine the time span (in other words, how do you determine the calculation period of the model).

Response: We thank the reviewer for bringing those to our attention.

1) The outer/inner grid information has now been added in Table 1. The simulated results are easily affected by the errors propagated from the outside boundary of model grid, so the inner grids that cover the freak wave incidents' positions are set in the middle of outer grids.

[line68-72, line86-88, os..pdf]:

Seven freak wave incidents in the ocean used in this study and the defined model grid are shown in Table 1. Hindcast simulations are conducted by WW3 multi-grid technique. The simulated results are easily affected by the errors propagated from the outside boundary of model grid, so the inner grids that cover the freak wave incidents' positions are set in the middle of outer grids. The coarse reso-

2) The implementations of WW3 in our simulations follows Tolman (2002, 2009) with few exceptions. As such, we feel it only necessary to a few explanations of the model setup. The wave directions are set to 36 (by 10 degree), and the number of frequencies ranges from 0.0412 to 0.4056 is set to 25 levels, with the increment factor of 1.1. The freak wave incidents do not occur in the shallow water, so only three source terms are considered in the model: wind-wave interaction term, nonlinear wave-wave interactions term and a dissipation (whitecapping) term

[line73-78, os..pdf].

3) We use the Cross-Calibrated, Multi-Platform Ocean Surface Wind Velocity (Atlas et al., 2011) to force the wave model, which is 0.25 degree resolution at 6 hours interval. A reanalysis ocean current from National Marine Data & Information Service (China) is also taken into account in the model for the diagnosis of the results. **[line79-82, os..pdf]**

For WW3, it always needs 1 to 2 days to spin-up the model in cold start conditions. In our simulations, we allow more than 3 days for the model to spin-up before the freak wave incident time. **[line83-85, os..pdf]**

Table 1. Time, position information and model set up of freak wave incidents.

Case	Time(UTC)	Position	Outer grid of model	Inner grid of model	Note
Case1	30 Dec 1980 05:30	156°11'E, 31° N	115°-180°E, 10°-65°N	140°-160°E, 25°-40°N	Northwest Pacific
Case2	23 Jun 2008 04:00	144°-145°E, 35°-36°N	115°-180°E, 10°-65°N	140°-160°E, 25°-40°N	Northwest Pacific
Case3	13 Dec 1978 00:00	44°N, 24°E	70°W-10°E,10°-75°N	30°W-20°W, 40°-50°N	Atlantic
Case4	1 Jan 1995 15:20	2°28'E, 58°11'N	70°W-10°E,10°-75°N	5°W-5°E, 55°-65°N	New Year Wave
Case5.1 Case5.2	18 Nov 1997 01:10 20 Nov 1997 01:51	1°44'E, 60°45'N	70°W-10°E,10°-75°N	5°W-5°E, 55°-65°N	Alwyn oil platform
Case6	27 Jul 2002 12:00	22.17°E, 37.97 °S	0.5 °E-60°E, 70°S-0°N	17°E-27°E, 43°S-33°S	FA platform

case1, case2 and case3 are for ship sinkings which are thought to be caused by freak waves.

case4, case5 and case6 are freak waves that are recorded by in-situ measurements.

3. In page 7, lines 1-3: you mentioned that "A continuous sea state with large steepness (> 0.08) and small directional spreading (< 27°) lasting a long time means a "freakish" sea state. Do you have any idea about how long time is enough to generate freak waves?

Response: The conclusion is deduced from the seven freak wave incidents. It means that "the mentioned conditions" is easy to generate freak waves, although it's not a sufficient condition. We don't have a clear answer about how long time is enough to generate freak waves and will keep this in mind in the future study.

4. You mentioned three parameters to study freak wave occurrence: steepness, spectra bandwidth and directional spreading. However, you only discussed the joint distribution of steepness and directional spreading. Actually, there are several combinations of these parameters. Why do not you discuss other combinations?

Response: As the response to reviewer 1 in the 2nd question, the parameterization of frequency peakedness is not always performance well in the double peaked spectrum. So we used steepness instead of frequency peakedness. **[line 135-137,**

os..pdf]

The following are some small suggestions:

1. In page 5: 1) You should explain every parameter in equations 1 and 2, and you missed θ, and the meaning of F is not exact. 2) Line 15: “spectra bandwidth” can be “spectral bandwidth” 3) Line 23: “BFI” should be “BFIs” 4) Line25: “freak waves occurs” is wrong

Response:

1) More explanations about σ, θ and F are added.
σ is the relative radian frequency, θ is the wave direction, F is the wave energy density spectrum,
(line99-100, os..pdf)

2) “spectra bandwidth” is revised to “spectral bandwidth” **(line93; line109,114, os..pdf)**

3) “BFI” revised to “BFIs” **(line116,247, os..pdf)**

2. Both “water waves” and “ocean waves” appear in this paper, I think it is better to use one of them for consistency.

Response: “water waves” is revised to “ocean waves” **(line31,34,66,120, os..pdf).**

We thank review #2 for your useful comments that improves the quality of the manuscript.

We also make some other modifications or corrections when checking the manuscript. (Line3-7,180-181(authors are modified to the first version of manuscript);line158)

Common characteristics of directional spreading-steepness joint distribution in freak wave events

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Abstract

Seven freak wave incidents previously documented in the real ocean in combination with model hindcast simulations are used to study the variations associated with freak wave-related parameters, such as wave steepness, directional spreading, and frequency bandwidth. Unlike the strong correlations between the freak wave parameters and freak waves' occurrence which were obtained in experimental and physical research, the correlations are not clear in the freak waves occurred in the real ocean. Wave directional spreading-steepness joint distribution is introduced and common visual features were found in the joint distribution when freak waves occur among seven "freakish" sea states. The visual features show that freak wave incidents occur when the steepness is large and directional spreading is small. Besides the steepness is large and directional spreading is small, a long-duration relatively rough sea state is also necessary for the freak wave generation. The joint distribution is more informative than the sequential variation of any single statistical wave parameter. The continuous sea states of local large steepness and small directional spreading are supposed to be "freakish" sea states, and two-dimensional distribution visualization is found to be a useful tool for freak waves forecast. The common visual features of joint distributions supply an important cue for the theoretical and experimental research.

1 Introduction

Freak wave (also known as rogue wave, extreme wave, and unexpected wave) has been a hot topic during the last decades in engineering and science research. Recently, two candidate mechanisms that lead to freak waves are debated. One is linear and the other is nonlinear. The linear mechanism is considered as a result of linear focusing in fixed time and position due to water ocean wave's dispersion, geometrical, current and wind force (Kharif and Pelinovsky, 2003). Nevertheless, freak wave is essentially a nonlinear phenomenon because of the large wave steepness of freak waves. Freak waves could also be produced as a result of the instability of water ocean waves. Because of the abrupt and huge energy focusing characteristics of freak waves, the instability is more considered to be self-instability rather than externally forced. Benjamin and Feir (1967) found the instability of uniformly traveling trains of Stokes waves, the Benjamin-Feir instability (B-F instability). B-F instability is considered as the most probable candidate for the freak wave occurrence, which has been validated by lots of experimental and physical results. The studies on freak waves' dynamics are mostly focused on the B-F instability and the extreme wave events can be caused by B-F instability in different circumstances.

From the engineering point of view, the experimental and theoretical achievements should be validated in the ocean and be applied in practice. Its validation is difficult due to the rareness of freak waves and insufficient large-scale measurements. Most of the in-situ observations of freak waves are time-series surface elevation measurements, which can not provide spatial and directional spectrum information. There are some efforts that aim to set up a freak wave early-warning system in the ocean by experimental and theoretical research (Janssen, 2003; Mori and Janssen, 2006; Mori et al., 2011; Akhmediev et al., 2011a, b). Recent research found that some wave parameters have high correlation with freak waves' occurrence. Under unidirectional or small directional spreading (long-crested) conditions, the probability of freak waves is considered to increase when wave steepness increase and spectrum narrows (Gramstad and Trulsen, 2007; Waseda et al., 2009; Onorato et al., 2010). According to the results of hindcast simulated "freakish" sea states, it is expected to find the conditions that trigger freak waves in the ocean and check if the theoretical and experimental achievements are also applicable to oceanic freak waves. It will give useful information of certain circumstances which trigger freak waves and complement existing theoretical framework of freak waves.

2 Model configurations

As a state-of-the-art third generation spectral model, WAVEWATCH III (WW3) (Tolman, 2002, 2009) offers good descriptions of statistical sea states from a kinetic approach that well mimics directional spectrum. Although the WW3 model can not give the simulation of freak waves, the freak-wave related parameters deduced from simulated results can be considered as an approximation of corresponding parameters of statistical sea states which is pertinent to freak waves. Short-lived freak waves can last only for a ~~1 to 10~~few wave periods (Janssen, 2003) and hardly influence relatively long-time wave statistical characteristics (Toffoli and Bitner-Gregersen, 2011). ~~Nevertheless, e~~Even in complex conditions, the evolution of spectrum with the spectral kinetic description appears to be consistent both qualitatively and quantitatively with solutions for the weakly nonlinear dynamical equations for ~~water~~ ocean waves (Zakharov et al., 2007; Badulin et al., 2008).

Seven freak wave incidents in the ocean used in this study and the defined model grid are shown in Table 1. Hindcast simulations are conducted by WW3 multi-grid technique. The simulated results are easily affected by the errors propagated from the outside boundary of model grid, so the inner grids that cover the freak wave incidents' positions are set in the middle of outer grids. The coarse resolution for outer grid is 0.25°×0.25°and the fine resolution for the inner is 0.1°×0.1°. The implementations of WW3 in our simulations use the default model setting as defined in Tolman (2002, 2009) with few exceptions. The wave directions are set to 36 (by 10 degree), and the number of frequencies ranges from 0.0412 to 0.4056 is set to 25 levels, with the increment factor of 1.1. The freak wave incidents do not occur in the shallow water, so only three source terms are considered in the model: wind-wave interaction term, nonlinear wave-wave interactions term and a dissipation (whitecapping) term. We use the Cross-Calibrated, Multi-Platform Ocean Surface Wind Velocity (Atlas et al., 2011) to force the wave ~~model~~model, which is 0.25 degree resolution at 6 hours interval. A reanalysis ocean current from National Marine Data & Information Service (China) is also taken into account in the model for the diagnosis of the results. The nonlinear wave-wave interaction term is calculated by high resolution ~~WRT~~ DIA method (Tolman, 2002). For WW3, it always needs 1 to 2 days to spin-up the model in cold start conditions. In our simulations, we all allow more than 3 days for the model to spin-up before the freak wave incident time.

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Table1. Time, ~~and~~ position information and model set up of freak wave incidents

Case	Time(UTC)	Position	Outer grid of model	Inner grid of model	Note
Case1	30 Dec 1980 05:30	156°11’E, 31° N	115°-180°E, 10°-65°N	140°-160°E, 25°-40°N	Northwest Pacific
Case2	23 Jun 2008 04:00	144°-145°E, 35°-36°N	115°-180°E, 10°-65°N	140°-160°E, 25°-40°N	Northwest Pacific
Case3	13 Dec 1978 00:00	44°N, 24°E	70°W-10°E, 10°-75°N	30°W-20°W, 40°-50°N	Atlantic
Case4	1 Jan 1995 15:20	2°28’E, 58°11’N	70°W-10°E, 10°-75°N	5°W-5°E, 55°-65°N	New Year Wave
Case5.1	18 Nov 1997 01:10	1°44’E, 60°45’N	70°W-10°E, 10°-75°N	5°W-5°E, 55°-65°N	Alwyn oil platform
Case5.2	20 Nov 1997 01:51				
Case6	27 Jul 2002 12:00	22.17°E, 37.97 °S	0.5°E-60°E, 70°S-0°N	17°E-27°E, 43°S-33°S	FA platform

case1, case2 and case3 are for ship sinkings which are thought to be caused by freak waves.

case4, case5 and case6 are freak waves that are recorded by in-situ measurements.

3 Results and discussion

Seven hindcast simulations are aimed to obtain the directional spectrum that covers time span for the freak waves. Statistical wave parameters, including significant wave height (*Hs*), wave steepness (δ), directional spreading (σ_θ), frequency peakedness (Q_p) and BFI (the ratio between steepness and spectral bandwidth) are derived from directional spectrum. The *Hs*, δ, σ_θ are defined following Tolman (2002). Q_p, BFI (Eqs. 1 and 2) are defined as Janssen and Bidlot (2003). We seek to check the parameters that set close relationship with freak wave occurrence and find physically-meaningful factors common to “freakish” sea states.

$$Q_P = 2m_0^{-2}\int_0^\infty \sigma\left[\int_0^{2\pi} F(\sigma,\theta)d\theta\right]^2 d\sigma \qquad (1)$$

$$BFI = k_o m_o^{1/2} Q_p \sqrt{2\pi} \qquad (2)$$

w~~W~~here σ is the relative radian frequency, θ is the wave direction, k_o is the wave number, F is the wave energy density~~frequency~~ spectrum, m_o is the zero order moment of F.

Hs is an important parameter that characterizes the mean sea states. It always takes local extreme value (case1, case3, and case6) or near the extreme value when freak waves occur (Fig. 1). Many in-situ observations have demonstrated that the freak wave occurrence will increase significantly in quite rough seas (Guedes et al., 2003; Liu et al., 2009), so the quasi local extreme value feature is self-consistent to some extent. Case 5 indicates the freak wave events occur when the *Hs* are not the highest locally in continuous time series unlike others’ quasi local extreme value feature (Fig. 1, case5). This means freak waves can also take place relatively far away from local extreme sea states.

Steepness, Spectral bandwidth and directional spreading are fundamental wave indices for freak wave occurrence. BFI has been considered as a good freak wave occurrence indicator (Janssen, 2003), yet it does not work very well for directional ocean waves (Gramstad and Trulsen, 2007; Onorato et al., 2010). Steepness in cases 1 to 6 is always above 0.08 when freak waves happen, which is a relatively large value for ocean waves' statistical characteristics (Fig. 2). Spectral bandwidth is parameterized by frequency peakedness. The temporal change of frequency peakedness (Fig. 3) is often time similar with that of BFI (Fig. 4) for the direct proportion relation between them according to Eq. (2), such as cases 1, 4, 5, and 6. BFIs at freak wave occurrence time are too small to be consistent with experimental and physical conclusions; BFI is supposed to be larger than 1 when freak waves occurs (Janssen, 2003). Similar results are also found by Bertotti and Cavaleri (2008), Burgers et al., (2008). Freak waves are influenced significantly by the directionality of water ocean waves and it is almost impossible to generate freak waves in large directional spreading. As such, the directionality of ocean waves is thought to be responsible for the inconsistency. The directional spreading values among cases 1 to 6 are relatively small and are less than 25° except case2 (37.3°) (Fig. 5). It also demonstrates that the freak waves are not clearly related to any wave parameter's absolute value. In contrast, the freak waves should be more associated with the wave parameter's value relative to before and after during a period of time.

In summary, there are no obvious relationships between single wave parameters and freak wave incidents. Freak wave is more considered as a result of B-F instability, so it should be triggered under multi-conditions rather than one and it is not easy to find any clues from single wave parameters.

Joint distributions of multi-wave parameters that are in close relation with freak wave occurrence are more reasonable representation. Tamura et al., (2009), In et al., (2009) have introduced frequency peakedness-directional spreading joint distribution to explore the freak wave occurrence circumstance. The joint distributions of two freak wave samples that they used in their research show similar visual feature. We find that there are always some abrupt changes in frequency peakedness when the peak number of spectrum varies. For this, the frequency peakedness is not used in the joint distributions. Freak waves are strong nonlinear phenomena, whose occurrences are closely related to ocean waves' directionality. With a consideration of nonlinearity and directionality of ocean waves, wave directional spreading-steepness joint distribution is used to analyze the freak wave incidents in this research.

An obvious visual common feature is shown in six wave directional spreading-steepness joint distributions (Fig. 6). Although it is not obvious in any single parameter, the joint distributions show large steepness and small directional spreading characteristics at freak waves' time. This is quantitatively consistent with experimental and theoretical research conclusions (Gramstad and Trulsen, 2007; Waseda et al., 2009; Onorato et al., 2010). Second, the points are intensive around freak waves' time. It means that large steepness and small directional spreading are continuous over a long period of time. New information given in two characteristics implies certain circumstance that is suitable for triggering freak waves. A continuous sea state with large

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steepness (>0.08) and small directional spreading (<27°) lasting a long time means a "freakish" sea state. Third, the freak wave occurrence time is always near or in the extreme point of joint distribution. It demonstrates the freak wave sea states are near or at the maximum of wave steepness or minimum of directional spreading.

The Case 2 was moderate sea state; the steepness was 0.082 and the directional spreading was 37.3° when the suspected freak wave occurred. The directional spreading in Case 2 is too broad to trigger freak waves according to experimental and numerical research results. But for local characteristic, it is relatively small during seven days period (Fig.6, Case2). The freak wave occurrence point is also on the upper left corner of Fig. 6, which is similar with distribution in other cases. For this, it is thought that freak waves are dependent more on relative~~ly~~ sea states rather than absolute sea states. Some freak wave incidents also occurred in rather low sea states with the scenario of rapidly changing conditions or crossing seas (Toffoli et al., 2004). Joint distribution in Case2 (Fig. 6) shows a rapid change condition in direction spreading, and therefore it may be responsible for the suspected freak waves. The obvious visual commonness of the joint distribution shows local extreme conditions and rapid changes of sea state parameters. It always signifies a considerable increase of freak wave occurrence as wave steepness increases and directional spreading narrows. What's more, the long duration of this combination may be necessary for "freakish" sea states.

4 Conclusions

Both experimental and theoretical approaches suggest that the freak waves are triggered under small directional spreading, large steepness and narrow spectrum bandwidth conditions. The attempt to characterize freak wave sea states from single wave parameters is likely impossible. The characteristics with regard to variability of steepness and directional spreading are shown by joint distributions. There are regions that always mean "freakish" seas, which are situated on the upper left corner of the joint distribution figure. In long duration joint distribution of directional spreading-steepness, "freakish" sea states have a visual common feature that steepness is large and directional spreading is narrow relatively and the state last a long time.

Multi-dimensional evolution of wave parameters contains more information, so it is better suited for more variables analysis. The visual commonness feature would be supposed to be used as a tool to characterize freak wave sea states and can be validated by long time-series observation in the future.

Acknowledgment. ~~We thank Yizhen Li for his contribution to the research.~~ We thank the reviewers for ~~his~~ their valuable comments. We are grateful to the Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the NASA Jet Propulsion Laboratory (JPL) for the CCMP wind. This work is supported by the National Natural Science Foundation of China (Grant No. 41406032, 41206021)

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Caption of figures:

Figure 1. Time series of simulated significant wave height (case1-case6), redlines refer to the freak waves occurrence time.

Figure 2. Time series of simulated wave steepness (case1-case6), redlines refer to the freak waves occurrence time.

Figure 3. Time series of simulated frequency peakedness (case1-case6), redlines refer to the freak waves occurrence time.

Figure 4. Time series of simulated BFIs (case1-case6), redlines refer to the freak waves occurrence time.

Figure 5. Time series of simulated directional spreading (case1-case6), redlines refer to the freak waves occurrence time.

Figure 6. Joint scatter plot of directional spreading and steepness by 1 hour during 7-20 days around the freak waves occurrence time (case1-case6), red star refer to the freak wave occurrence time, green rectangles refer to the start and end time.

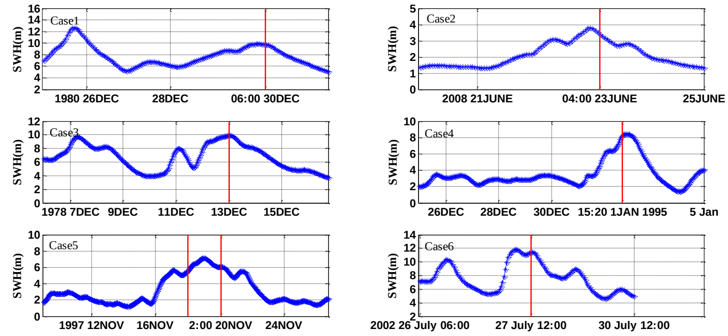

Figure 1

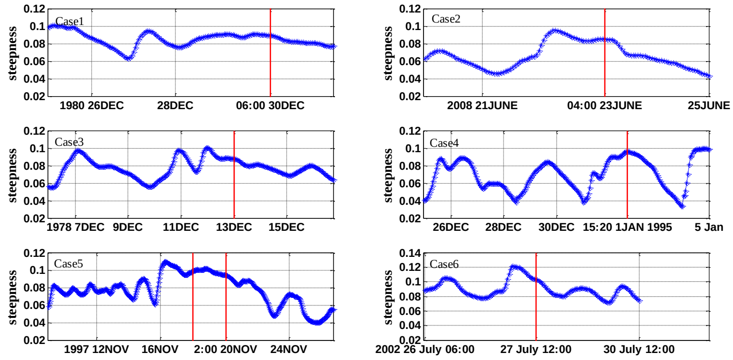

Figure 2

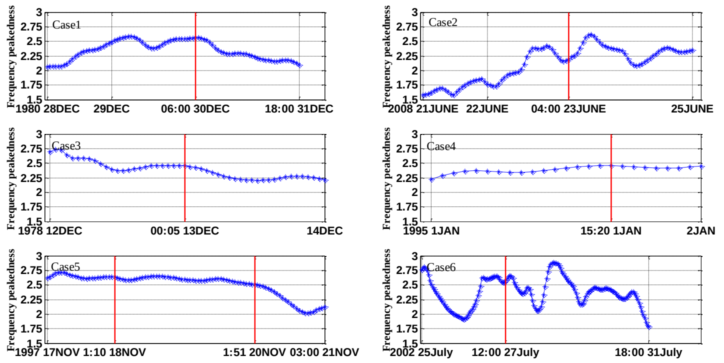

Figure 3

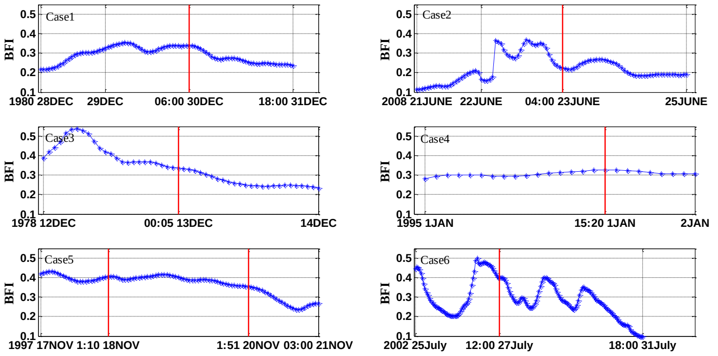

Figure 4

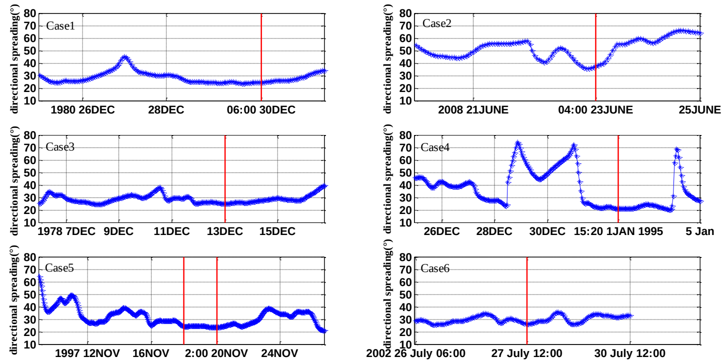

Figure 5

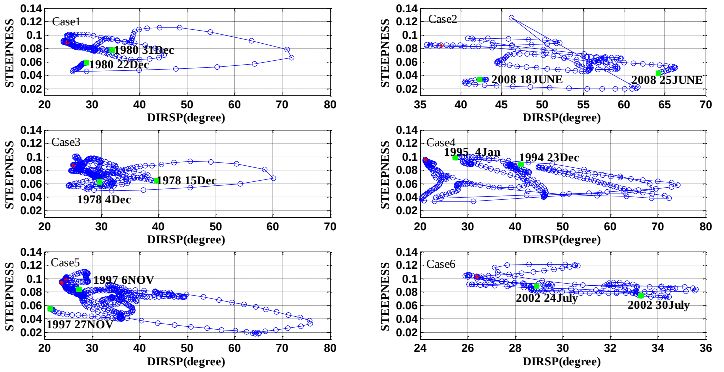

Figure 6