Group Structure in Random Seas

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ABSTRACT

Markov theory for statistics of runs of high waves in a random sea is extended to include the special case where runs consist of two or more high waves, that is, for the case of wave groups. Expressions are derived for the average number of waves forming the groups, for the relative number of groups expected, and for the average number of waves between the beginnings of groups. Theoretical results are shown to be in good agreement with data determined from laboratory and computer simulations and from field measurements.

1. Introduction

It has long been known among experienced mariners that relatively high waves in heavy seas often come along in groups of two or more high waves, with the high waves followed by a larger number of smaller waves before the next high waves arrive. The group characterization represented by this body of experience is, as indicated, not without exception, as single high waves also come along. But the characterization is noteworthy because it suggests the possible existence of a basic group structure in the higher waves of wind-driven seas.

Whether or not a group structure actually exists in a random sea depends, of course, on whether or not groups of two or more high waves come along more frequently than expected from the laws of chance for independent events. Analysis of wave records, with high waves considered to be those with heights comparable to or greater than the significant wave height, have, in fact, indicated this to be the case. The number of observed single high waves has been observed to be less than that expected from the assumption of random independent events and the number of runs with two or more high waves has, correspondingly, been found to be greater (Goda 1976).

The existence of a distinct group structure in random seas implies, as indicated above, a statistical dependence between the high waves forming the groups. This dependence does not affect prediction of the relative number of high waves arriving at a fixed location, as given by the well-known Rayleigh law (Rayleigh 1880; Longuet-Higgins 1952), but does require additional theory for characterizing the order in which the waves come along. At present, there exist two theories that account, either directly or indirectly, for the statistical dependence. The first may be referred to as envelope theory and is based on statistical properties of the envelope of wave crests, as discussed by Ewing (1973), Goda (1976), Longuet-Higgins (1984), and Ochi and Sahinoglou (1989) among others. Statistical dependence between waves is included indirectly in this theory through dependence on the amplitude spectrum of the sea state. The second theory may be referred to as Markov theory and is based on probability considerations of runs of high waves, taking into account directly the statistical dependence existing between adjacent waves. Details of this theory have been discussed by Kimura (1980) and Longuet-Higgins (1984) among others.

Attention in both theories has been directed mainly toward averages associated with runs of one or more high waves rather than with groups of two or more waves and the associated group structure. An exception is the work of Ochi and Sahinoglou (1989) in which envelope theory was extended to include statistics associated with runs of two or more high waves. Unfortunately, the mathematical complexity associated with this approach is such as to mask any basic description of the group structure that may actually exist.

The applicability of envelope theory to general wave runs and group statistics has been examined experimentally by Dawson et al. (1991) using laboratory and computer simulation measurements. In a recent paper, Dawson et al. (1996) have also examined the applicability of the Markov theory to general wave runs using laboratory and field measurements. In that paper, the simplicity of the theory was emphasized as well as its direct application to wave measurements. The success of this theory in describing general wave runs has prompted a further investigation into adequacy of the theory in describing fundamental aspects of group structure in random seas. Results from this study are presented in the present paper.

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2. Markov description for wave runs

High waves in random seas may be defined, for analytical purposes, simply as those waves having heights equal to or greater than some specified critical wave height. Statistics of such high waves may be investigated using Markov theory for runs (Kimura 1980; Longuet-Higgins 1984). The basic assumption in the theory, justified approximately by measurement (Arhan and Ezraty 1978), is that wave heights are statistically correlated only with immediately preceding ones. Thus, given a high wave, the occurrence of one, two, etc. successive high waves is assumed representative of independent statistical events. Similarly, given a low wave, the occurrence of one, two, etc. successive low waves is also regarded as independent statistical events. We denote by \( P_+ \) the probability that a high wave is followed by a high wave and by \( P_- \) the probability that a low wave is followed by a low wave. The probability of transition from high wave to low wave is then \( 1 - P_+ \), and, similarly, the probability of transition from low wave to high wave is \( 1 - P_- \).

a. General wave runs

General wave runs are defined as runs of high waves where a single high wave occurs or where two or more successive high waves occur. Variables of interest in the study of such wave runs are the number of high waves in a run of high waves \( N_H \) and the number of waves \( N_I \) between the beginnings of such runs. Averages of these variables over sufficient time for representative results have traditionally been used in characterizing runs of high waves in random seas. Such averages will also be employed in the present work.

The following discussion of general wave runs includes recent developments by Dawson et al. (1996) and provides perspective for the subsequent treatment of wave groups.

We consider a representative wave record from a sea state of interest and designate the total number of runs of high waves revealed by this record by \( n_\text{r} \), with runs of high waves defined to be those cases where a single high wave occurs, or where two or more successive high waves occur. We also note that the average number of high waves in a run \( \bar{N}_H \), is expressible as the ratio of the total number of high waves in the record to the total number of runs, and that the average number of waves between the beginnings of high runs \( \bar{N}_I \), is expressible as the ratio of the total number of all waves in the record to the total number of runs. The total number of high waves in the record is thus given by the product \( n_\text{r} \bar{N}_H \), and the total number of waves in the record is given by the product \( n_\text{r} \bar{N}_I \).

The transition probability \( 1 - P_+ \) from a high to a low wave may be expressed as the ratio of the number of such transitions to the total number of high waves considered. The total number of these transitions is equal simply to the total number \( n_\text{r} \), of runs of high waves, and the total number of high waves is equal to the product \( n_\text{r} \bar{N}_H \). We accordingly have the ratio

\[
1 - P_+ = \frac{n_\text{r}}{n_\text{r} \bar{N}_H}.
\]

which, on solving for \( \bar{N}_H \), provides the fundamental relation (Kimura 1980)

\[
\bar{N}_H = \frac{1}{1 - P_+}.
\]

Similarly, the transition probability \( 1 - P_- \) from a low wave to a high wave may be represented by the ratio of the total number of such transitions to the total number of low waves in the record. The number of transitions from low to high waves is the same as the number from high to low, namely, the number of runs \( n_\text{r} \). In addition, the total number of low waves is equal to the difference between the total number of waves in the record and the total number of high waves. From the above considerations, this may be expressed as \( n_\text{r} \bar{N}_I - n_\text{r} \bar{N}_D \). We thus have the ratio

\[
1 - P_- = \frac{n_\text{r}}{n_\text{r} \bar{N}_I - n_\text{r} \bar{N}_D}.
\]

Solving this relation for \( \bar{N}_I \) and using Eq. (2), we then have the additional fundamental relation (Kimura 1980)

\[
\bar{N}_I = \frac{1}{1 - P_+} + \frac{1}{1 - P_-}.
\]

We note that the expressions for \( \bar{N}_H \) and \( \bar{N}_I \) are not independent but, rather, are related by the equation \( P = \frac{\bar{N}_D}{n_\text{r} \bar{N}_I} \), that is, by

\[
P = \frac{\bar{N}_D}{n_\text{r} \bar{N}_I},
\]

where \( P \) denotes the probability of a high wave. When, as in the present work, high waves are defined as those with heights equal to or greater than a critical wave height, say \( H_C \), this probability is that given by the Rayleigh probability law in the form

\[
P = \exp\left(-\frac{2H_C^2}{H_s^2}\right),
\]

where \( H_s \) denotes the significant wave height of the sea state. Interestingly, if high waves were defined in terms of crest amplitudes rather than wave heights, this last relation would have to be modified to include nonlinear Stokes effects, causing crest amplitudes to increase and trough amplitudes to decrease, but leaving wave heights essentially unchanged (Dawson et al. 1996).

On combining Eqs. (2), (4), and (5), we may next establish the following relations between the transition probabilities and the Rayleigh probability:

\[
1 - P_+ = C(1 - P), \quad 1 - P_- = CP,
\]

where \( C \) is a constant.
gives rise to longer runs of high waves. Theoretical results of Longuet-Higgins (1984) and consis-
terations can be seen to be in general agreement with the-
creases in this same order, so that the coefficient vari-
bias decreases as attention shifts first from the Bret-
scheider sea to the Jonswap 3.3 and then to the
Jonswap 7 sea. Spectral width for these seas also de-
creases in this same order, so that the coefficient vari-
tions from measurements of Bretschneider, Jonswap 3.3, and
Jonswap 7 seas by Dawson et al. (1996). These values
Table 1 also gives results of calculations of \( \bar{N}_p \) and
\( \bar{N}_g \) from Eqs. (8) and (9) for the Bretschneider and Jon-
swap sea states, based on the indicated coefficient values
and assuming high waves to be defined as those with
heights equal to or greater than the significant wave
height. The probability of occurrence of such high
waves is determined from Eq. (6), with \( H_c = H_s \), as \( P = 0.135 \).
It is of interest to compare the values in Table 1 with
results that would apply if complete statistical indepen-
dence existed between high waves. For this situation,
the coefficient \( C \) is unity in Eqs. (8) and (9), as noted
earlier, and the resulting values are \( \bar{N}_p = 1.16 \) and \( \bar{N}_g = 8.55 \). The average number of waves in a high run in
a Bretschneider sea is thus predicted to be about 6%
greater than if statistical independence existed. In con-
trast, the predicted increases are about 22% and 34%,
respectively, for the Jonswap 3.3 and Jonswap 7 sea
states.

### b. Extension to wave groups

We now wish to extend the above theory so that it
applies strictly to wave groups, with wave groups de-
ined in the manner of Ochi and Sahinoglou (1989) as
runs involving two or more high waves. Of interest in
this regard is the relative number of high waves that
occur in a sea state that are followed by one or more high
waves, that is, the probability, or fraction, that a
general wave run is a wave group. Also of interest are
variables describing the number of high waves in the
groups \( N_{DG} \) and the number of waves \( N_{HG} \) between the
beginnings of the groups and, in particular, their average
values \( \bar{N}_{DG} \) and \( \bar{N}_{HG} \). In terms of a representative wave
record, \( \bar{N}_{DG} \) is determined by the ratio of the number of
high waves in groups to the number of groups in the
record, and \( \bar{N}_{HG} \) is determined by the ratio of the total
number of all waves to the number of groups in the
record.

Within the framework of the Markov representation,
the extension to wave groups is relatively simple and
involves mainly a reconsideration of the transition prob-
ability from high to low waves. Because of the statistical
independence associated with runs of high waves fol-
lowing the first high wave, the transition probability
given by Eq. (1) will remain unchanged if we consider
transitions from high to low waves associated only with
runs of two or more waves. This is equivalent to ig-
noring the first high wave in all runs of one or more
high waves. Thus, if \( n_g \) denotes the number of runs, or
groups, of two or more high waves, the number of tran-
sitions from high to low waves is now \( n_g \) and the number
of high waves, or opportunities for transition, is now
\( n_g \bar{N}_{DG} - n_g \). We may accordingly write the relation

\[
1 - P_+ = \frac{n_g}{n_g \bar{N}_{DG} - n_g}.
\]
On comparing Eqs. (1) and (10), we then have the simple relation \( N_{DG} = 1 = N_D \) or, equivalently,
\[
N_{DG} = N_D + 1,
\]
which gives us the expression for the average number of waves in wave groups in terms of the average number existing in general runs of high waves.

With this last result before us, we may next consider the relation for the ratio of the number of groups \( n_g \) in a representative wave record to the number of runs \( n_o \). We have observed earlier in connection with Eq. (1) that the total number of high waves in all runs of high waves is expressible as \( n_g N_D \). This total may also be written as \( n_g N_{DG} + n_s - n_o \), where the product \( n_g N_{DG} \) denotes the number of high waves in groups and the difference \( n_s - n_o \) denotes the number of high waves in runs of one wave only. Thus, we may write the equation
\[
n_g N_{DG} + n_s - n_o = n_s N_D
\]
and solve, with the help of Eq. (11), for the ratio \( n_s/n_o \), in the form
\[
n_s/n_o = \frac{N_D - 1}{N_D}.
\]

Finally, we may determine the relation for the average number of waves \( N_{DG} \) between the beginnings of wave groups. Since the total number of waves in a representative wave record is expressible both as \( n_g N_s \) and as \( n_g N_{DG} \), we have the equation
\[
n_g N_{DG} = n_s N_s
\]
which may be solved, with the help of Eq. (13), to find the simple relation
\[
N_{DG} = \frac{N_s N_D}{N_D - 1}.
\]

Equations (11), (13), and (15) provide remarkably simple expressions characterizing group structure in random seas in terms of averages for general wave runs. Interestingly, they apply both for random seas with Markov dependence among waves as well as for seas with complete independence, the difference between the two cases resting in the values of \( N_s \) and \( N_D \).

It is instructive to calculate results from the above theory for the standard Bretschneider and Jonswap sea states considered earlier. With high waves defined as those with heights equal to or greater than the significant wave height, the data given in Table 1 may be used for this purpose. Results from these calculations are given in Table 2.

<table>
<thead>
<tr>
<th>Sea state</th>
<th>( n_o/n_s )</th>
<th>( N_{DG} )</th>
<th>( N_{DG} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bretschneider</td>
<td>0.19</td>
<td>2.2</td>
<td>49</td>
</tr>
<tr>
<td>Jonswap 3.3</td>
<td>0.29</td>
<td>2.4</td>
<td>36</td>
</tr>
<tr>
<td>Jonswap 7</td>
<td>0.36</td>
<td>2.6</td>
<td>32</td>
</tr>
</tbody>
</table>

Of particular interest in the above results is the prediction of the relative number of runs of high waves that consists of groups of two or more waves, that is, the values of ratio \( n_s/n_o \). This may be interpreted as the relative number of high waves, following one or more low waves, that come along and are followed, in turn, by one or more high waves. For complete statistical independence, we see that out of, say, 100 high waves that come along, each after one or more low waves, only 14 will be followed by one or more high waves. In contrast, for Bretschneider seas, the predicted number is 19; for Jonswap 3.3 seas, the number is 29; and for Jonswap 7 seas, the number is 36. Actual seas are therefore indicated to have appreciably more high-wave grouping than an idealized sea with statistical independence existing between all high waves. These results are, of course, in agreement with the general observations of experienced mariners, noted at the beginning of this paper. It remains to examine the predictions from the theory in terms of detailed measurements.

3. Comparison with measurements

a. Laboratory simulations

Wave-run and group statistics associated with standard Bretschneider and Jonswap seas have been determined from wave records derived from laboratory simulations of these seas. General procedures employed in the laboratory work have been described in an earlier paper (Dawson et al. 1991).

The specific sea states considered in the laboratory work were scaled versions of full-scale heavy seas having significant wave height of 10 m and peak spectral frequency of 0.067 Hz. Scaling ratios were based on Froude's scaling law. The length-scale ratio employed was 1/68 = 0.0147, thus requiring a laboratory-scale significant wave height of 14.7 cm and a peak spectral frequency of 0.55 Hz.

The laboratory simulations were made using a wave tank of length 116 m and width 7.9 m, with nominal water depth of 4.9 m. Random waves corresponded to deep-water conditions for both full-scale and laboratory waves so that no specific dependence on water depth existed. Waves were generated at one end of the tank by a computer-driven wavemaker. The wavemaker commands were formed by dividing the desired amplitude spectrum into increments, of width 0.025 Hz, and determining amplitudes for the midfrequency of each.
These amplitudes were next used to define sinusoidal wave components with random phases. The sum of all such components was then used to provide direction for the wavemaker through an appropriate transfer operation. Iterative procedures were used to achieve the desired amplitude spectrum at a wave probe, located approximately 30 m from the wavemaker. Relatively long composite wave records, involving more than 2200 waves, were developed for each sea state using several shorter experimental runs in order to minimize effects from end reflections.

In analyzing the experimental records, waves were defined to be those disturbances between successive upcrossings of the mean water level by the water surface. Also, as earlier, high waves were defined as waves with heights equal to or greater than the significant wave height.

Table 3 gives the experimentally determined average values \( \bar{N}_o \) and \( \bar{N}_\varnothing \) for general wave runs associated with the sea states of interest. Comparison with the theoretical results in Table 1 indicates excellent agreement between the two sets of results, consistent with the chosen values for the empirical coefficients.

Corresponding experimental results for group properties are listed in Table 4. Comparison with theoretical results in Table 2 shows good general agreement, within about 15% maximum error, between theory and measurement. It is, however, interesting to observe for all three sea states that the relative number of groups indicated by the measurements is somewhat larger than the theoretical prediction and that the average number of waves in the measured groups is somewhat smaller than the theoretical predictions. This indicates, perhaps, that a few more groups of two waves exist in the laboratory waves than expected from strict adherence to the Markov assumption of wave dependence only with immediately preceding waves.

### b. Computer simulations

Computer simulations of the Jonswap 3.3 sea state have been made in order to provide independent data for comparison with the theory and for the purpose of assessing the likely variability of data associated with wave records of the length used in the laboratory work just described. Of particular interest is whether the differences, noted above, between theory and laboratory measurements can be attributed to variability in records, or whether they indicate a fundamental limitation on the theory and the laboratory measurements.

Details of the computer simulations are as follows: The Jonswap 3.3 amplitude spectrum was assumed, with target significant wave height of 15 cm and peak spectral frequency of 0.55 Hz. The spectrum was divided into increments, each of width 0.025 Hz as in the laboratory cases, and amplitudes determined for midfrequencies of each. Sinusoidal wave components were defined with these amplitudes and with random phases, the phases being changed every \( 1/0.025 = 40 \) s in order to prevent duplication. The sum of the components was formed and then used to generate a random wave record, with length of 4000 s, at a sampling rate of 50 Hz. The record consisted of approximately 2700 waves, consistent with the laboratory record for the Jonswap 3.3 case. High waves were defined, as earlier, as those with wave heights equal to or greater than the measured significant wave height. Wave run properties \( \bar{N}_{n_o} \), \( \bar{N}_n \), etc. were determined from the record. The entire process was repeated a large number of times, 788 times to be exact, and the average of the averages of each record and the associated standard deviation for the many records determined. Results are listed in Table 5.

The last column in Table 5 lists ratios of the standard deviation to the mean value for the statistics considered. When multiplied by 100, these represent percentage maximum errors, from the mean, expected roughly in two-thirds of the records, and when doubled they represent virtually the maximum error expected in all individual records. Thus, the maximum error indicated in the table is about 9% (for the ratio \( n_o/n_{n_o} \)), and twice this is 18% in the range of error reported for the laboratory measurements with respect to theory. Considered in terms of the results from the laboratory simulations, we thus see that the differences between theory and measurement for these data are explainable simply in terms of the variations expected from consideration of a single wave record.

With respect to the mean values from the computer simulations, we also can see that agreement between

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**Table 3. Measured wave-run properties from laboratory simulations.**

<table>
<thead>
<tr>
<th>Sea state</th>
<th>( \bar{N}_o )</th>
<th>( \bar{N}_\varnothing )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bretschneider</td>
<td>1.2</td>
<td>9.2</td>
</tr>
<tr>
<td>Jonswap 3.3</td>
<td>1.4</td>
<td>10.4</td>
</tr>
<tr>
<td>Jonswap 7</td>
<td>1.6</td>
<td>11.5</td>
</tr>
</tbody>
</table>

**Table 4. Measured group properties from laboratory simulations.**

<table>
<thead>
<tr>
<th>Sea state</th>
<th>( n_o/n_{n_o} )</th>
<th>( \bar{N}_{n_o} )</th>
<th>( \bar{N}_n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bretschneider</td>
<td>0.22</td>
<td>2.1</td>
<td>42</td>
</tr>
<tr>
<td>Jonswap 3.3</td>
<td>0.33</td>
<td>2.3</td>
<td>32</td>
</tr>
<tr>
<td>Jonswap 7</td>
<td>0.42</td>
<td>2.3</td>
<td>27</td>
</tr>
</tbody>
</table>

**Table 5. Results from computer simulations of Jonswap 3.3 sea state.**

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Mean</th>
<th>Std dev</th>
<th>Std dev/mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{N}_o )</td>
<td>1.39</td>
<td>0.039</td>
<td>0.028</td>
</tr>
<tr>
<td>( \bar{N}_\varnothing )</td>
<td>10.2</td>
<td>0.342</td>
<td>0.034</td>
</tr>
<tr>
<td>( n_o/n_{n_o} )</td>
<td>0.291</td>
<td>0.027</td>
<td>0.093</td>
</tr>
<tr>
<td>( \bar{N}_{n_o} )</td>
<td>2.34</td>
<td>0.067</td>
<td>0.029</td>
</tr>
<tr>
<td>( \bar{N}_n )</td>
<td>35.4</td>
<td>2.73</td>
<td>0.077</td>
</tr>
<tr>
<td>( P )</td>
<td>0.136</td>
<td>0.003</td>
<td>0.022</td>
</tr>
<tr>
<td>( C )</td>
<td>0.834</td>
<td>0.023</td>
<td>0.028</td>
</tr>
</tbody>
</table>
theory and measurement is excellent when the earlier values of $C = 0.82$ and $P = 0.135$ are used. For example, $\bar{N}_o$ and $\bar{N}_i$ are determined theoretically as 1.41 and 10.4, in comparison with the respective measured average values of 1.39 and 10.2. Similarly, $n/s_o, N_{DG}$, and $N_{IO}$ are determined theoretically as 0.291, 2.41, and 36, in comparison with measured average values of 0.291, 2.34, and 35, respectively.

c. Field measurements

As a final check on the Markov theory for wave groups, we consider results from wave records taken in the Gulf of Mexico during late summer of 1992 when Hurricane Andrew dominated sea conditions in the region. The wave records, kindly supplied by Shell Development Company, Houston, Texas, were made from a fixed platform, located off Louisiana in approximately 300 m of water. The records have been discussed previously by Dawson et al. (1996). They involve three 1-h periods, immediately before, during, and after peak storm conditions. In all, approximately 1200 waves were recorded during the three periods. Significant wave heights during these periods were approximately 7.1, 7.4, and 7.0 m, respectively, all with a corresponding peak spectral frequency of approximately 0.07 Hz. Amplitude spectra for these three periods were similar in shape and resembled a Jonswap 3.3 spectrum, with the exception of a secondary peak at a frequency of about 1.1 times the main peak frequency.

Average wave-run values $\bar{N}_o$ and $\bar{N}_i$ from the field measurements are listed in Table 6 for high waves defined not only for critical height $H_c = H_o$, but for two other values, as indicated. Theoretical values are included in parentheses, based on an average coefficient $C = 0.83$, as determined from these measurements. The agreement between measurement and theory can be seen to be consistently good, thus indicating applicability of a single coefficient for this range of data.

Corresponding group averages are given in Table 7, with theoretical predictions included in parentheses. Agreement between theory and measurement can be seen to be excellent for these measurements.

From all of the above results, we see that laboratory simulation provides excellent agreement with theoretical predictions for average wave-run properties but only approximate agreement with average group properties. In contrast, extensive computer simulation and field data provide excellent agreement with theory for both general wave runs and wave groups. A possible explanation is that group statistics from a single laboratory simulation are subject to some error because of the sensitivity to the finite wave components chosen to describe the sea state. With averages from extensive computer simulation, as well as with actual seas where all components are present, no such limitation exists and much closer agreement between theory and measurement is found to exist.

4. Physical basis for wave groups

The physical explanation for wave groups dates from the time of Stokes, Reynolds, and Rayleigh (see Lamb 1924) when it was first recognized, or noted in any case, that two wave components of identical amplitude and slightly different frequency would produce a modulated wave train with runs of high waves followed regularly by runs of lower waves. The validity of this argument, in general terms, remains sound even today, and the general explanation for wave groups remains that of wave–wave interaction between the components of a random sea.

The modern view of actual wind-driven seas involves the concept of many wave components making up the random sea. The present work demonstrates that these many components also produce wave groups, although in a stochastic rather than regular manner. If a high wave comes along at a fixed location, the chances are better than those for independent events that the next wave along will also be a high wave, and so forth, with the resulting sequences forming wave groups. The chances for wave group formation also improve as the amplitude spectrum of the sea state becomes narrower, as indicated by the present work. The noteworthy feature demonstrated here is that the average properties of wave groups, as well as wave runs, are captured by the simplifying Markov assumption that statistical wave dependence exists only with immediately preceding waves. Limits must, of course, exist on the applicability of the Markov description for wave runs and wave groups (see Elgar et al. 1984), but they have not yet been established.

5. Summary and conclusions

The present paper has extended the Markov description of general runs of high waves to include the special case of wave groups, that is, runs of two or more high waves.
waves. The basic assumption of the description is that waves are statistically correlated only with immediately preceding waves. Theoretical results have indicated significant wave grouping in standard Bretschneider and Jonswap seas, in comparison with an idealized sea where complete statistical independence exists between waves. The results have been confirmed with laboratory and computer simulations of these sea states. Results have also been confirmed with field data derived from wave records made in the Gulf of Mexico during 1992 when Hurricane Andrew dominated conditions in the region.

The general conclusions from this work are 1) that significant wave grouping exists in wind-driven Bretschneider and Jonswap seas and in hurricane-driven seas in the Gulf of Mexico, and 2) that this grouping is well represented by Markov theory and its attendant assumption that statistical wave dependence exists only with immediately preceding waves.

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