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Wave Climate in the Northeast of Taiwan

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ABSTRACT

Characteristics of the wave climate in the northeast of Taiwan are discussed here in this paper. Yim et al. (2004) and Huang et al. (2004) have carried out separate studies concerning the wave climate in this region. It was found by Yim et al. that several extreme value distributions can be used to model the long-term statistical properties of wave heights recorded at the measuring station Long-Dong. These include, the two- and three-parameter lognormal, the gamma, the Fisher-Tippett Type I (Gumbel), the Pearson Type III, the Generalized Extreme Value (GEV), and the Weibull distributions. However, since wave heights are recorded hourly at this station, it is found that the use of the whole data set for the analysis would violate the assumption of independence, and thereby, invalidate the results. In this paper we have adopted the concept of "*sea storm*" due to Boccotti (2000) to study the possible distribution(s) of extreme waves in this region. It is shown that only four of the models used can fit the "storm waves". These are, the two- and three-parameter lognormal, the Gumbel, and the GEV distributions.

KEY WORDS: wave climate, statistical models, sea storm

INTRODUCTION

Coastal regions in the northeast Taiwan are famous for their nature beauty. The shore in this region consists of coral reef, interrupted with sandy beaches. Water depth can reach 60 m. For coastal/ocean engineers, the region is of interest for two reasons. In the first place, although the beautiful coastal regions have attracted thousands of tourists in holidays, the regions are often plagued by erosion as well as sedimentation. A strategy for sustainable development is therefore desperately needed. In the second place, a nuclear power plant is under construction in this region. Knowledge concerning both the wind- and wave-climates in this region can be helpful in assessing the possible environmental impact(s) of the effluents emitted by the plant.

One of the major problems in studying wave and/or wind climates is that there is just no sufficient data available. Another well-known problem is that there is simply no theoretical justification that any of the available models should be preferred. This is especially true for the study of wave climate. As a result, researchers have proposed a variety of models that can be used to model the long-time statistical distribution of wave heights. Models of extreme value distributions, such as, the two- and three-parameter lognormal distributions, the Weibull, and the Fisher-Tippett Type I (Gumbel), among others, were often used. A short review of this was given by Yim & Chou (2004). They used, in addition to those mentioned above, also the gamma, and the generalized-extreme value (GEV) distributions to fit the data. It is shown that, among the models considered, only the two lognormal distributions as well as the GEV can fit the empirical peak of measured data set.

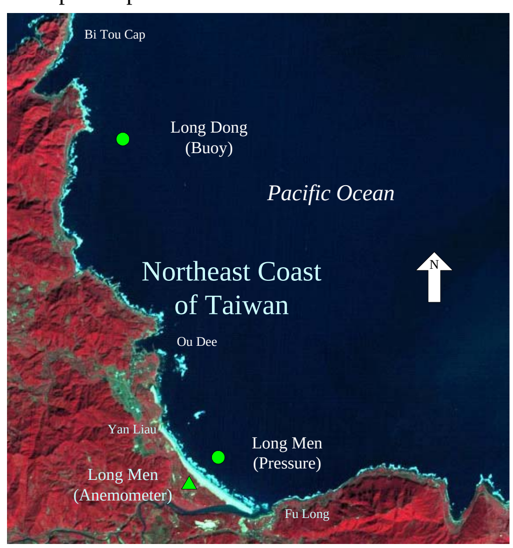

Fig. 1. The locations of the measuring stations

However, since the data used in that paper are of sequential nature, with time intervals of one- or two-hours, it is considered that the assumption of independence could be violated. In this paper, we, therefore, use the concept of "sea storm" due to Boccotti (2000) to study possible fits of the models. The present paper is arranged as follows. In the following, we discuss shortly the nature of the wave data, as well as the models used for the analyses. Presentation and discussion of the results then follow, and with a short conclusion we then close this paper.

THE WAVE DATA

Wave records from two measuring stations are available for the analysis. These are the records from wave measuring stations of Long-Dong and Long-Men. In the following, we will use the abbreviations of LD for data from the measuring station Long-Dong and LM for Long-Men. Fig. 1 is a scheme showing the relative locations of these two measuring stations. Also shown in this figure is the weather station at Long-Men. Water depths at these two stations are, respectively, 32 and 14 meters. Wave measuring station LD is maintained by the Central Weather Bureau (CWB) and the recording started from October 13, 1998 to the present day. On the other hand, the measuring station LM is only project-oriented and started from April 23 2002 and ended on July 4 2003.
The recorded data of the two stations are also of different types. While the data from LD contains only the significant wave heights, $H_{1/3}$, and is recorded every two hours, those from LM contains, besides the significant wave heights, also the mean, H_{mean}, the maximum wave heights, H_{max}, as well as $H_{1/10}$, with an interval of 1 hour.

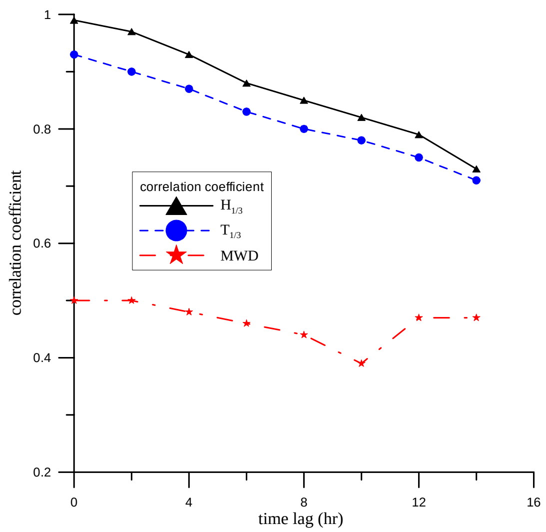

Fig. 3. The correlation coefficients of wave heights ($H_{1/3}$), significant wave periods ($T_{1/3}$), and mean wave directions (MWD) for the measuring stations LD and LM (Huang et al., 2004)

Huang et al. (2004) studied the possible correlations of wave heights, periods, and the mean wave directions recorded by these two measuring stations. Fig. 2 is taken from Fig. 3 of their paper. As can be seen from this figure, the wave heights are highly correlated, with a correlation coefficient of 0.99. This is quite nature, considering the relative short distance between these two measuring stations. It can also be seen that, the correlations of significant wave periods of LD & LM follow the trend of wave heights. Mean wave directions of these two measuring stations are, in contrast to wave heights and periods, less correlated. This can be explained with the different geographical locations of the stations. As can be in from Fig. 1, while measuring station LM is located in a bay, where wave scattering from nearby coasts can be severe; LD, on the other hand, has to face the Pacific Ocean.

Yim et al. (2004) have studied the long-term statistical properties of wave heights of these two records. They used models of extreme value distribution to fit the data set. The mathematical expressions for all the models used by them can be found in textbooks concerning flood frequency analyses (see, e.g., Haan. 1991; Kite, 1988; Rao & Hamed, 2000), and will not be repeated here in this paper for brevity. One of their results is depicted in Fig. 3. As can be seen from Figure 3, a couple of extreme-value distribution models can be used to model the data from LD. These include: the two- and three-parameter lognormal, the gamma, the Gumbel, the Pearson Type III, the Generalized Extreme Value (GEV), and the Weibull distributions.

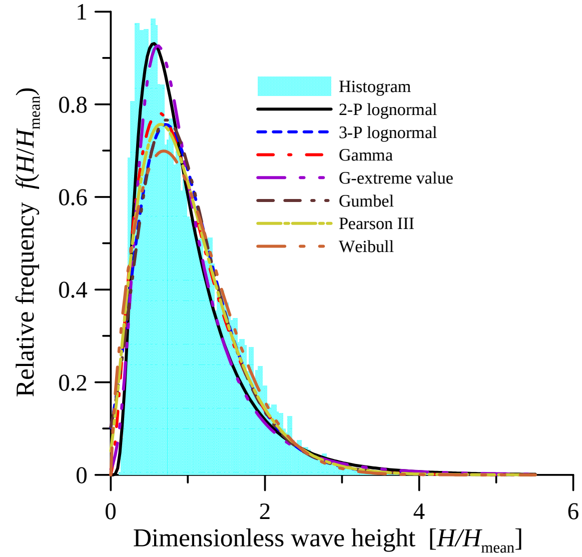

Fig. 3. Results of fitting the statistical models for measured significant wave heights of LD.

However, as pointed out by many researchers, hourly-recorded wave heights may not be independent, and the use of them for the extreme value analysis may not be valid. We have, therefore, decided to adopt the concept of "*sea storm*" due to Boccotti (2000), and to reanalyze the remaining data here in this paper. According to Boccotti, a sea storm is defined as "*a sequence of sea states in which $H_s(t)$ exceeds a fixed threshold h_{crit}, and does not fall below this threshold for a continuous time interval greater than 12 hours*". As h_{crit}, a value of 1.5 times the annual mean significant wave height, $\overline{H}_s$, was suggested by Boccotti. In the following, we present results only from wave station LD, since the data from LM is too scarce to be statistically meaningful.

RESULTS AND DISCUSSIONS

Table 1. Some basic statistical properties of wave heights.

Statistical properties / Category	Mean [m]	Variance	Skewness	Kurtosis
Whole record	1.26	0.60	0.52	1.61
Sea storm	3.82	0.34	0.34	0.76

295 wave heights out of a total of 21541 waves were selected following the criterion of Boccotti. Table 1 compares the first four statistical properties of this sea storm with those from the whole record. As can be seen from Table 1, the wave heights of the so-called sea storm are less scattered, and they are more evenly distributed around the mean of $\overline{H}_s$ = 3.82 m. Furthermore, they have a less pronounced peak, as compared with that of the total data set.

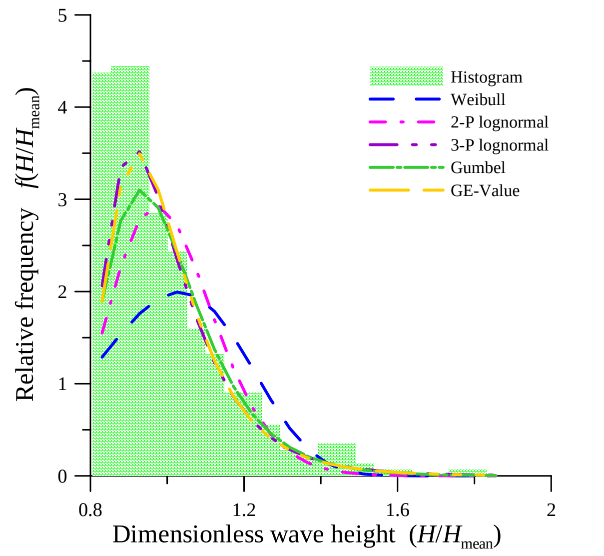

Fig. 4. Result of fitting the statistical models of "sea storm" of LD.

These wave heights were then normalized by their mean value, and models from extreme value distribution were then applied to seek for possible fit(s). Fig. 4 shows the results, where only the curves of those models that have passed the χ^2 goodness-of-fit test are plotted.

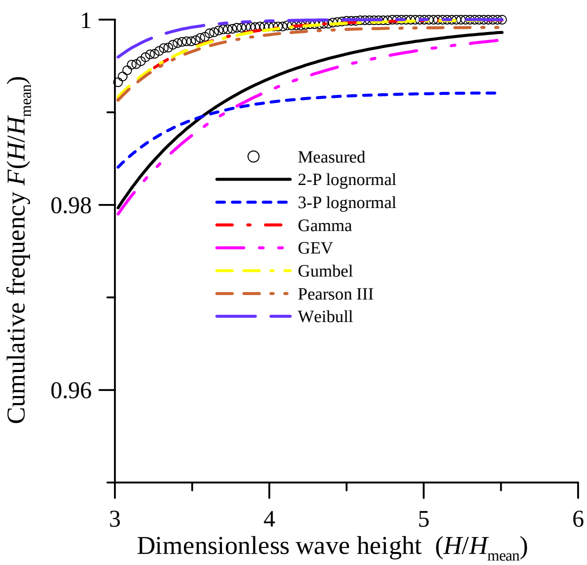

Fig. 5. Comparison of the empirical and fitted cumulative probability distributions for the original data of LD (Yim et al., 2004).

It can be seen from Fig. 4 that, besides the Weibull distribution, only 4 of the extreme value distribution models can fit the data. These are, the 2- and 3-parameter lognormal, the Gumbel, and the GEV distributions. It is also seen that the Weibull distribution is less satisfactory than the other four models. Boccotti suggests using this model for the distribution of sea storms. However, our result shows that this model is not as suitable as other models for our data. Since wave heights from only one measuring station is used here, this result could be due to sampling variability. No definite conclusion can be drawn at the moment.

It was shown by Yim et al. (2004) that, among the models used, the gamma, the Gumbel, the Pearson III, and the Weibull distributions can fit the tail of measured large wave heights. The result is depicted here as Fig. 5. However, as shown earlier in Fig. 4, the gamma and the Pearson III distributions failed to result in reasonable fits for sea storm wave heights. The empirical cumulative distribution of the sea storm wave heights is plotted together with the curves of statistical models in Fig. 6 for comparison. As can be seen from Fig. 6, the GEV, the three-parameter lognormal, and the Gumbel distributions can follow the trend of the data quite reasonably.

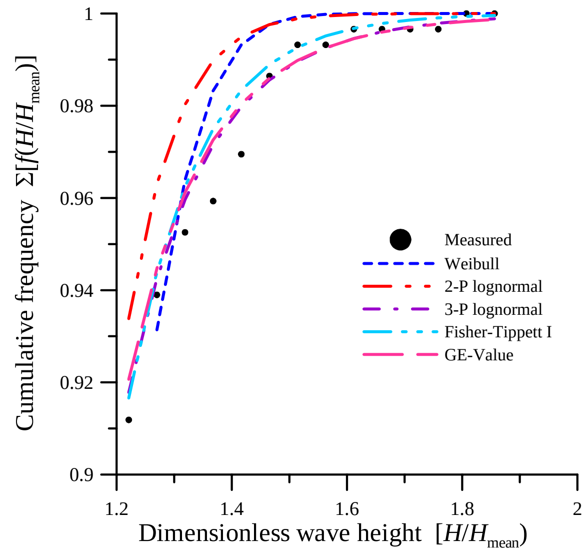

Fig. 6. Comparison of the empirical and fitted cumulative probability distributions for the sea storm of LD.

Bobée & Ashkar (1991) have pointed out that a distribution model should have at least two or three parameters to be flexible in fitting the empirical data. The GEV was considered here due to its three adjustable parameters. Comparing Figs. 5 and 6 shows that, while this model fails to follow the tail of the whole data set, it can fit the high waves of sea storm rather reasonably.

On the other hand, the Pareto distribution also has three parameters. Rao & Hamed (2000) have pointed out that, when certain criterion is satisfied, this model can be used to describe the distribution of random variables exceeding a threshold value. This can be the case, e.g., wave heights obtained from the so-called POT (Peaks-Over-Threshold) method (Ferreira & Guedes Soares, 1998). Since the '*sea storm*' is defined as waves having heights larger than $1.5\,\overline{H_s}$, this is basically equivalent to the POT method. However, as can be seen from Fig. 6, our results showed that this model failed to fit the sea storm proposed by Boccotti. In fact, it also failed to fit the whole data set of LD, as can be seen in Fig. 5. The Pareto distribution, nevertheless, was found to model the distribution of wave heights measured at LM, which has a length of a little more than one year (Yim et al., 2004). The reason for this result is not clear at present. More studies are needed.

CONCLUSIONS

Studies of wave climate in the northeast Taiwan have been carried out recently. Wave records from two measuring stations, namely, LD and LM, were used. Some results were presented in the PACOMS conference. It was shown that, both the wave heights and wave periods of these two measuring stations were highly correlated. It was also shown that the wave heights measured at LD can be fitted with a number of models from extreme value distribution. Models like the two- and three-parameter lognormal, the gamma, the Fisher-Tippett Type I (Gumbel), the Pearson Type III, the Generalized Extreme Value (GEV), and the Weibull distributions can be used to fit the distributions of measured wave heights. Some of the results are depicted here in this paper.

Since it can be argued that the use of hourly wave heights might violate the (basic) assumption of independence, we have here adopted the concept of 'sea storm' due to Boccotti, and reanalyzed the data. It was found that,

1. No reasonable fits can be found for the gamma and the Pearson III distributions for the case of sea storm wave heights.
2. As far as the tail of the high wave is considered, only the GEV, the three-parameter lognormal, and the Gumbel distributions can follow the trend of the data quite reasonably.

Judging from the results, it is suggested that the long-time distribution of wave heights in the northeast of Taiwan can be modelled with one of the three extreme value distributions, namely, the GEV, the three-parameter lognormal, and/or the Gumbel distribution.

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