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Study on the Characteristics of the Coastal Wind Fields in Keelung

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ABSTRACT

Using wind records measured near the coast of Keelung, the short-term statistical properties of the wind fields were studied. Statistical models found in the literature were used to model the possible distributions of the wind speeds and temperature. It was found that both the mean and maximum wind speeds can be modelled using either a lognormal or a Weibull distribution. On the other hand, the distributions of the temperature are highly concentrated and can only be roughly approximated with the Gaussian model.

KEY WORDS: Wind speeds distributions, probability models

INTRODUCTION

Knowledge of the characteristics of a wind field near the coast is important for many reasons. Coastal engineers may need the information to estimate ocean surface winds (Lo et al., 1994), which, in turn, may be used for the estimation of the wave condition (Hedges et al., 1991; Plant, 1982; Toba & Ebuchi, 1992). It has been shown that erroneous estimate of the winds can have a strong influence on wave hindcast results (Holthuijsen et al., 1993).

The characteristics of the wind field are also important in other aspects. It has been shown that the distribution of wind directions and speeds can severely affect navigation maneuvers in a harbour. Furthermore, harbour facilities are to be designed to sustain possible extreme wind forcing during their lifetime. All these factors should be considered in the planning stage of a harbour. It is also argued that, in order to study and/or model the spread of pollutants over land, environmental engineers need to know the standard deviations of all the three-dimensional velocity components of a turbulent wind field (Weber, 1998).

In June 1998, the Department of Harbour and River Engineering, National Taiwan Ocean University, has started to study the characteristics of wind fields near the coast of Keelung. Data recording continued till the present day. Yim et al. (2000) have studied the statistical properties of the short-term records. All the three turbulent fluctuating velocity components, and that of the temperature, were fitted with probability models found in the literature. They have found that the of probability distributions of the three turbulent fluctuating velocity components are better to be described by the Edgeworth's form of the type A Gram-Charlier series expansion. The distributions of the turbulent temperature fluctuations, on the other hand, are roughly Gaussian-distributed.

In this paper, we will concentrate ourselves on the statistical properties of the mean and maximum wind speeds and temperature measured near the coast of Keelung. In the following, we further divide the rest of the paper into four parts. In Section II, we briefly describe the measuring site and the instrumentation. The methodology we adopted for the analyses will be explained in Section III. Results, together with discussion, are presented in Section IV. With a short summary of the present findings in Section V we then close this paper.

THE MEASURING SITE AND INSTRUMENTATION

The Institute building has a distance of appropriately 150 meters from the coast. A 3-D ultrasonic anemometer of type TJ-61B from KAIJO Corporation was mounted on a mast atop of the building. The total height of the anemometer is appropriately 26 meters above ground. A sampling rate of 20 Hz was used to record the variations of the wind speeds and temperature. Recorded data were separated on an hourly basis by the name according to their measuring date. A file thus contains 72,000 data points. A more detailed description concerning the measuring site and the general properties of the anemometer can be found in Yim et al. (2000).

THE MODELS APPLIED

A total of 21 months of hourly mean and maximum values of the velocity components and temperature is available. They were stored in separate files named after the month and the year. To study their probability distributions, the following statistical models were used:

a). The Gaussian distribution

$$p(x',\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{(x'-\mu)^2}{2\sigma^2}\right] \quad (1)$$

where $x' = \frac{x}{\bar{x}}$, $x = (U, V, W, \theta)$, with $\bar{x} = \mu$ the mean of the series and σ is the standard deviation. They are sometimes called, respectively, the location and the scale parameter (Hahn & Shapiro, 1967). The Gaussian distribution is the most frequently used statistical model. It can be used whenever the phenomenon under consideration is the cumulative result of many independent influential factors (Thiébaux, 1994).

b). The Rayleigh distribution

$$p(x;\sigma) = \frac{x'}{\sigma^2} e^{-\frac{x'^2}{2\sigma^2}} \tag{2}$$

It can be shown that under the assumption of a narrow-band Gaussian process with zero mean and variance σ^2, the amplitude of the process is Rayleigh distributed (Ochi, 1992).

c). The Weibull distribution

$$f(x';\alpha,\beta) = \alpha \beta x'^{\alpha-1} \exp(-\beta x'^{\alpha}) \tag{3}$$

where α is the shape, and β is the scale parameter. Unlike the Rayleigh distribution, the Weibull distribution is an empirical distribution.

d). The two-parameter log-normal distribution

$$f(x';\mu,\sigma) = \frac{1}{\sigma x\sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma^2}(\ln x' - \mu)^2\right] \tag{4}$$

where the parameters μ and σ are often called, respectively, the scale and the shape parameters. The lognormal distribution can be used to describe phenomena that resulted from multiplication of many independent factors.

e). The exponential distribution

$$f(x';\lambda) = \lambda e^{-\lambda x'} \tag{5}$$

The parameters of the respective distributions were estimated through the method of maximum likelihood. The χ^2-goodness-of-the-fit tests were performed for each distribution. As a further check, the Kolmogorov-Smirnov goodness-of-fit test was also carried out. All calculations were performed on an IBM-compatible computer with a Pentium III processor.

RESULTS AND DISCUSSION

Figure 1 shows the result of fitting the mean longitudinal wind speed components with the statistical models mentioned earlier. It can be seen that the measured distribution is skewed to the right, and this is well described by the exponential, the lognormal, and the Weibull distributions. The data were for July 1998. In Taiwan, winds in summer are rather weak, whereas in winter seasons the dominant northeast winds are relatively strong. To ascertain that the result shown in Figure 1 is not due to relatively low wind speeds, we have shown in Figure 2 the result of the fitting for the month December. Figure 2 shows the result of fitting the vertical wind speed components with these models. It can be seen that the results are similar to Figure 1. In fact, both the exponential and the lognormal distributions can be considered superior than the Weibull distribution due to their better fits at the origin. The probability distribution of the lateral wind speed components is similar to that of Figures 1 & 2, and will not be presented here.

Distributions of the mean temperature are shown in Figure 3. It can be seen from this figure that the temperature fluctuations is highly concentrated around the normalized mean value, $\frac{\theta}{\bar{\theta}} = 1$. Either the exponential or the Rayleigh distribution failed to fit the distribution. Notice that the curves of the lognormal and the Gaussian distributions are almost identical. Notice also that in an attempt to fit the peak on the right of the dimensionless temperature, $\frac{\theta}{\bar{\theta}} = 1$, the curve of the Weibull distribution is skewed toward left.

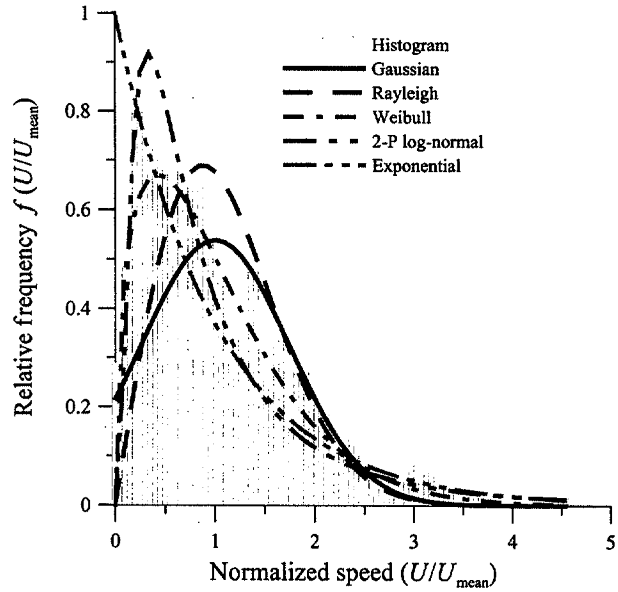

Figure 1. Probability distribution of the mean longitudinal wind speeds fitted with five statistical models. Data source: July 1987.

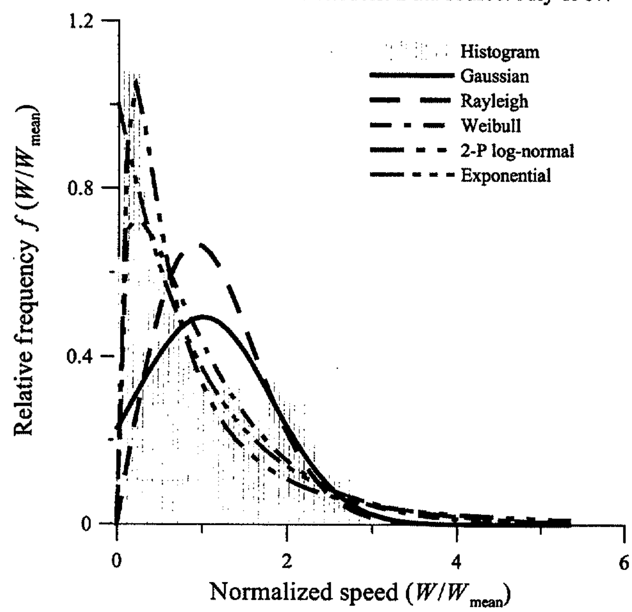

Figure 2. Probability distribution of the mean vertical wind speeds fitted with five statistical models. Data source: December 1999

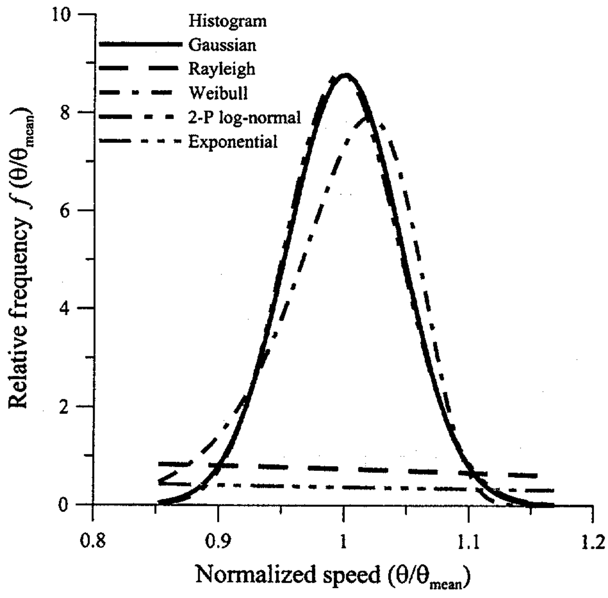

Figure 3. Probability distribution of the mean temperature fitted with five statistical models. Data source: August 1999.

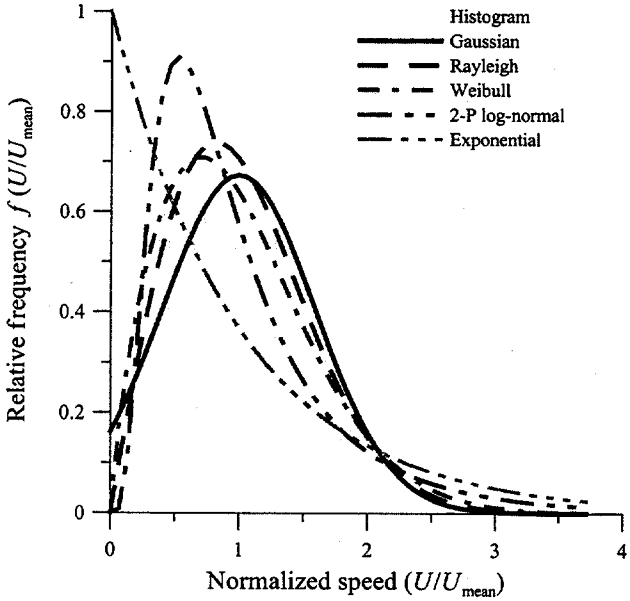

Figure 4. Probability distribution of the maximum longitudinal velocity components fitted with five statistical models. Data source: March 2000.

The distributions of the three maximum velocity components are also skewed to the right. However, unlike those for the mean values, which have their peaks centered around a value of $x' \approx 0$, the peaks of the dimensionless velocity have move toward a value of approximately $x' \approx 0.5$. Figures 4 and 5 show, respectively, the distributions of the hourly maximum longitudinal and lateral velocity components. It is also interesting to note that the curve of the Rayleigh distribution almost coalesces with that of the Weibull. Generally speaking, the Weibull distribution can be considered to be more flexible due to its two parameters that are data adaptive. It has the Rayleigh distribution as a special case. The coalescence of these two curves thus seems to indicate that the underlying could in reality be a Rayleigh distribution. More studies are needed in order to clarify this. On the other hand, it can also be seen that both the Gaussian and the exponential distribution have failed to fit the empirical distribution. The former due to its symmetrical form, and the latter due to its peaks at the origin, both of these features are not in correspondence with the data. It should also be mentioned that the results presented here are not unique, almost all our data show the same results. The results of fitting the distributions of hourly maximum temperature are similar to those for the mean temperature, and will not be presented here.

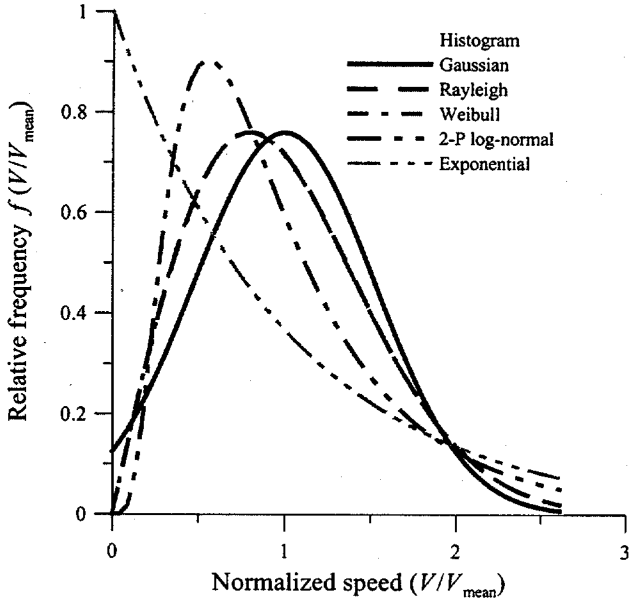

Figure 5. Probability distribution of the maximum transverse velocity components fitted with five statistical models. Data source: April 1999.

Yang (2000) studied the characteristics of the wind field in some detail. He has used the Gaussian-, the Rayleigh-, the Weibull-, the exponential-, and the gamma distributions as possible models for the probability distributions of the three velocity components and the temperature. It is interesting to note that he found that the Weibull distribution can be used to model all the three velocity components, both for the mean and maximum values. The results shown here in this paper demonstrate that the lognormal distribution can also be considered as a possible candidate for the mean and maximum wind speed distributions.

Tables 1 and 2, taken from Yang, show the values of the parameters of the Weibull distribution estimated from the whole data set. As mentioned earlier the Weibull distribution is rather flexible due to its two adjustable parameters. This is reflected in the values of the shape parameter, α, shown in Tables 1 and 2. It can be seen from these two tables that:

1. For both the transverse and the vertical mean velocity components, the values of the shape parameters $\alpha \approx 1$. It is well known that as $\alpha \approx 1$, the curve of the Weibull distribution approximates that of the exponential distribution. Judging however from the rather large value of the standard deviation for the transverse velocity component, it seems at least safe to conjecture that the hourly mean values of the vertical wind velocity component are exponentially distributed. This fact can also be seen from Figure 3 of this paper.

2. It has been mentioned that the Rayleigh distribution is a special case of the Weibull distribution with $\alpha = 2$. From Table 2, it can therefore be concluded that the distributions of the hourly maximum wind speeds for all three components are approximately Rayleigh distributed.
3. With increasing values of the shape parameter, the peak of the Weibull distribution shifts progressively to the right of x-axis. Notice the extreme large values of the shape parameter, α, for both the mean and maximum values of the dimensionless temperature in Tables 1 and 2. The large value of α leads to the skew-to-the-left behaviour of the curve of the Weibull distribution for dimensionless temperature shown in Figure 3.

Table 1. The mean values and standard deviations of the parameters of the Weibull distribution for 21 months of hourly mean values of the wind velocity components and temperature (Yang, 2000).

Parameters / Components	Mean α	Mean β	Standard deviation α	Standard deviation β
Longitudinal (u)	1.49	0.87	0.24	0.04
Transverse (v)	0.99	0.86	0.54	0.05
Vertical (w)	1.02	0.99	0.11	0.04
Temperature (θ)	14.40	0.63	0.67	0.02

Table 2. The mean values and standard deviations of the parameters of the Weibull distribution for 21 months of hourly maximum values of the wind velocity components and temperature (Yang, 2000).

Parameters / Components	Mean α	Mean β	Standard deviation α	Standard deviation β
Longitudinal (u)	1.98	0.79	0.34	0.03
Transverse (v)	1.93	0.80	0.34	0.04
Vertical (w)	1.94	0.80	0.31	0.03
Temperature (θ)	12.00	5.46	4.96	21.60

Originally, statisticians considered Weibull distribution as a model for the asymptotic distribution of minimum values. It has, however, also been used successively to model the distribution of maximum values. Researchers have found that Weibull distribution can be used to describe the probability distributions of wind speeds records measured in some US weather stations (Simiu & Filliben, 1976, 1980; Yim et al., 1999); as well as that of the extreme winds (Chen & Ma, 1991). It was also found to describe the distribution of wave heights, either hurricane-generated (Forristall, 1978, 1984), or in a groin field (Sundar et al., 1993). It is therefore concluded that the distributions of both the mean and maximum wind speeds in Keelung can be modeled through Weibull distribution.

CONCLUSIONS

Using wind records measured near the coast of Keelung, the short-term statistical properties of the wind fields were studied. We have used model equations found in the statistical textbook to model the probability distributions of the three velocity components and the temperature. Both hourly mean and maximum values were used in this study. The present findings are summarized as follows:

1. The distribution of the mean wind speeds for all three velocity components can be modelled using the exponential, the lognormal, and the Weibull distribution. On the average, the shape parameters of the Weibull distribution for both the lateral and the vertical velocity components, v and w, are close to 1 for 21 months of wind data. Since with the value of the shape parameter α approaching 1, the shape of the Weibull distribution bears close resemblance to that of the exponential distribution, we therefore propose to use the latter to model the distributions for these two velocity components near the coast of Keelung.
2. As a first approximation, all the three models, i.e., the lognormal, the Weibull and the Rayleigh, can be used to model the statistical distributions of the hourly maximum winds. This is true for all the three velocity components of the wind field in Keelung. However, since for all the three velocity components the mean values of the shape parameter α are close to 2, it is suggested that the Rayleigh distribution be used as a first approximation.
3. The values of the hourly mean and maximum temperature are highly concentrated. Among the five models used in this paper, no suitable one can be found to be completely satisfactory. They can only be approximated through the Gaussian model.

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