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A study of the statistics of sea clutter in the northern coast of Taiwan

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ABSTRACT

Analyses of sea clutter measured at Taipei Harbour were carried out. Statistical models commonly used by researchers for sea clutter were used to fit measured data. These include the Rayleigh, the Weibull, the lognormal, and the so-called (compound) K- distributions. It is shown that the lognormal distribution results in the best fits among all possible candidates. Possible sources for the misfits of the K-distribution suggested by many researchers were also discussed.

KEY WORDS: Sea clutter; statistical distribution; Rayleigh-, lognormal-, Weibull- and K-distributions.

INTRODUCTION

Sea clutter is the backscattered electromagnetic waves of radar from the sea surface. While they may be considered annoying for the most of time, sea clutters may contain information of the structure of the water surface and are, therefore, considered by oceanographers to be rather useful. It has been shown by many researchers that, valuable information concerning both the wave- and wind-fields can be derived from it (Gommenginger, 1997, see also Gommenginger et al., 2000; Robinson et al., 2000; as well as Lentine, 2006).

Young et al. (1985; Ziemer, 1987; Gangeskar; 2000) have shown that, useful information concerning the wave fields can be extracted from radar image sequences. Using wave heights obtained from the so-called wavenumber-frequency spectrum, Nieto Borge & Guedes Soares (2000; Izquierdo et al., 2004, 2005; Hessner et al., 2006) clearly show that these are in good agreements with on site measurement. Furthermore, it have also been shown that surface current speeds and direction (Senet, 1996), as well as water depth (Outzen, 1998), and information about the wind fields above the water surface (Hatten, 1998; Dankert, 2003) can be inferred from radar images.

Statistical analyses of sea clutter started with the intension of its suppression so that objects other than waves on the sea surface can be detected easily (Ward et al., 1990a, b; Wetzel, 1990). Most commonly used statistical models are, the Rayleigh, Weibull, lognormal, and the so-called K-distributions. Researchers have found that, when the resolution cells are large, and grazing angles are high, the Rayleigh distribution is well situated for describing the sea clutter statistics. However, when the resolution cell is small, and/or the grazing angle low, the clutter statistics gradually develop a “long tail”, and this makes them to deviate from the Rayleigh model.

It was often suggested that, the last model, the K-distribution, should be favoured (Ward et al., 1990a; Antipov, 1998). This is because this model can be considered as the product of two distributions, i.e., the Rayleigh and the gamma. The former is considered to represent the effects of small-scale reflectors on the sea surface, such as capillary waves. The latter, on the other hand, is due to the underlying swell, which may have scales larger than the resolution cell. This argument, however, breaks down when it was found that the K-distribution can also be used in modelling both land- and sea-clutters in radar images (Dong, 2004a), or even speckles in the images of ultrasound echoes (Dutt, 1995; Pesavento, 1999).

The sea surface is a collective result of many interacting factors such as surface currents, waves due both to distance storms, or local winds, nonlinear wave-wave interactions, as well as topographic influences. Since sea clutters are the results of multipath reflections of the sea surface, knowledge of their statistics is important, as the information of the sea state may be contained in it (Trizna, 1991).

The Institute of Harbour and River Engineering of the National Taiwan Ocean University started to study radar images a few years ago. Preliminary results were presented in the ISOPE 2006 conference (Yim et al., 2006). In this article, we discuss some results of our recent studies on the statistics of sea clutter.

The measuring site

The Taipei Port, located in the northern Taiwan, is a new harbour under construction. The Port Authority of Keelung Harbor (PAKH) is responsible for the administrative planning works and procedures. A few years ago, a long-term program to monitor the coastal environments of the Harbour was launched by PAKH. This program has the purpose of gathering all the possible information of the oceanographic processes of the coastal area nearby. The data will then be used for the assessments of possible environmental impacts, as well as for possible further future planning, of the Harbour. The Institute of Harbor and Marine Technology (IHMT), commissioned for the program, has decided to use marine radar as a monitoring device. Our Institute is then responsible for the analyses and interpretations of the radar images.

As the construction works of the Taipei Port continues, the original site of the radar measurement become more and more sheltered, and the quality of the images down-graded. It was then decided to move the radar atop of the new building of the Harbour authority, where a relatively clear view of the Port can be guaranteed. Figure 1 shows the locations of the Taipei Harbour and the measuring site schematically.

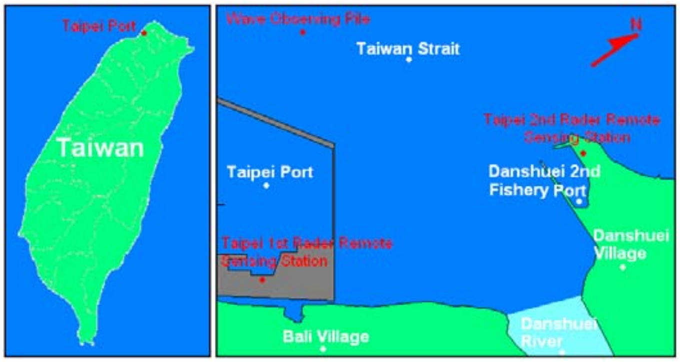

Figure 1. Schematic sketch of the location of Taipei Port and the instrumentations

However, careful inspection of the radar images shows that they are sometimes contaminated (Fig. 2). Several conjectures concerning the possible sources of the contaminations were proposed. Among these, Radio Frequency Interferences (RFI) is considered to be the most possible one. In this paper, we present our results based on a selection of images without such contamination. Studies of the characteristics of the contaminations, along with their possible removal, will be postponed for a later time.

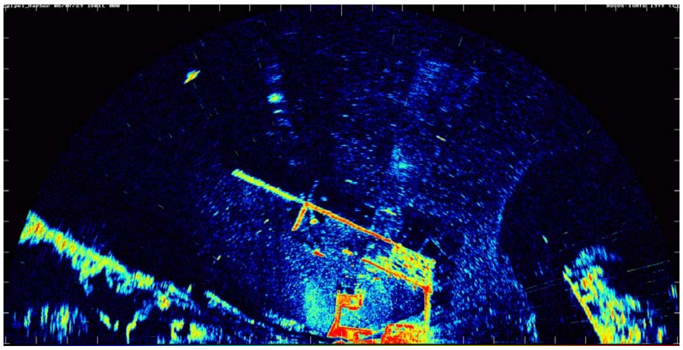

Figure 2. Radar image showing contaminations

The sea surface is monitored by a navigation radar, type FR-8251 from the Furuno Company, Japan. It is situated atop of the administrative building of the Harbour. The measuring range of the radar is set to 1.5 miles. With a rotation speed of 24 cycles per minute, 32 images, having a length of 80 seconds per hour, of the sea states will be imaged and stored for analysis.

The statistical models

A total of five statistical models were used for the fits. These are: the Rayleigh, Weibull, the two- and three-parameter lognormal, and the *K*-distribution. A short description of these models will be given below. More detailed descriptions can be found in text books concerning statistics (Kite, 1988).

a) The Rayleigh distribution

The mathematical form of this distribution can be expressed as:

$$f_R(a)=\frac{2a}{\beta_R^2}\exp\left[-\left(\frac{a}{\beta_R}\right)^2\right] \tag{1}$$

where β_R is a scale parameter for the Rayleigh distribution, and α is the amplitude of the clutter.

b) The Weibull distribution

The Weibull distribution has many different forms. One of the possibilities is:

$$f\left(a;\alpha_W,\beta_W\right)=\alpha_W\beta_W a^{\alpha_W-1}\exp\left(-\beta_W a^{\alpha_W}\right) \tag{2}$$

where α_W and β_W are, respectively, the shape and scaling parameters of the model.

c) The 2-parameter lognormal distribution

$$f(a)=\frac{1}{a\sigma_y\sqrt{2\pi}}\exp\left\{-\frac{\left[\ln(a)-\mu_y\right]^2}{2\sigma_y^2}\right\} \tag{3}$$

where $y = \ln(a)$, and the shape parameter, σ_y, and the scale parameter, μ_y, are, respectively, the standard deviation and mean of the natural logarithms of *a*.

d) The 3-parameter lognormal distribution

This is a generalization of the two-parameter log-normal distribution with an extra location parameter γ:

$$f(a)=\frac{1}{(a-\gamma)\sigma_y\sqrt{2\pi}}\exp\left\{-\frac{\left[\ln(a-\gamma)-\mu_y\right]^2}{2\sigma_y^2}\right\} \tag{4}$$

e) The *K*-distribution

According to Dong (2004a) there are at least two versions of the *K*-distribution, one for the statistical distributions in the intensity domain, and one for the amplitude. The latter can be expressed as:

$$f_K(a)=\frac{2c}{\Gamma(\nu)}\left(\frac{ca}{2}\right)^{\nu}K_{\nu-1}(ca) \tag{5}$$

where c is a scale parameter and ν is a shape parameter, $\Gamma(z)$ is the gamma function; and $K_{\nu-1}(z)$ is the modified Bessel function of the second kind of order ν-1.

Expressions for the parameters of the first four statistical models can be derived though the method of maximum likelihood (Kite, 1988). There is, however, no closed form solution for the parameters of the *K*-distribution. Various methods to obtain an estimate of the parameters for this distribution were proposed (Raghavan, 1991; Joughin et al., 1993, Blacknell, 1994; Lombardo & Oliver, 1994; Iskander & Zoubir, 1996, 1999; Roberts & Furui, 2000; Chung et al., 2005). Antipov (1998) compared the results obtained from four estimating methods, and concluded that method based on second and fourth sample moments (Watts, 1985) can yield best results. In this paper, we used this method to estimate the parameters of the *K*-distribution.

Defining the *r*-th sample moment, m_r, as:

$$m_r = \frac{1}{N}\sum_{i=1}^{N} a_i^r \tag{6}$$

where *N* is the total number of samples, a_i is the amplitude of *r*-th radar return. The parameters of the *K*-distribution can be approximated as:

$$\hat{\nu} \approx \frac{1}{\left(\dfrac{m_4}{2m_2^2}-1\right)} \tag{7}$$

and

$$\hat{c} \approx 2\sqrt{\frac{\nu}{m_2}} \tag{8}$$

where $\hat{\nu}$ and $\hat{c}$ are, respectively, the estimates of the shape and scale parameters ν and *c* of the *K*-distribution.

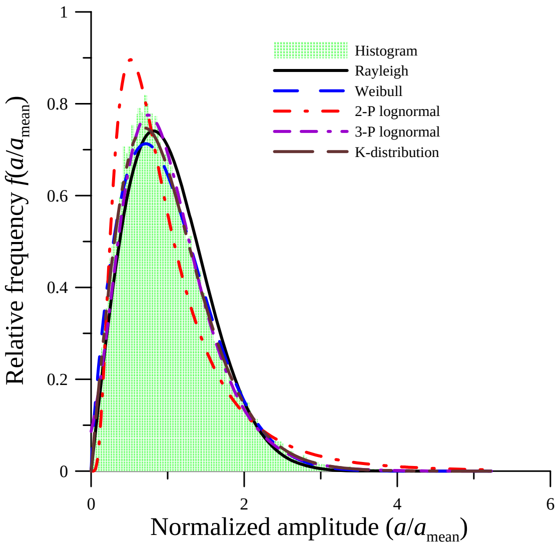

Figure 3. Results of fitting the five statistical models to simulated data

Results and discussion

Figure 3 shows the results of fitting simulated data with the five statistical models. Generally speaking, all the five models used in this paper can fit the data quite satisfactorily. However, the curve of the two-parameter lognormal distribution is seen to deviate from the data more those of the other four models. Among the four, the three-parameter lognormal distribution can be considered as to yield the best result in fitting the data. It should also be pointed out that in all our simulated results, not shown here, that this model can always fit the data more adequately than other models. The results seem to contradict conclusions obtained by other researchers. More studies are needed to verify this.

Figure 4 shows the results of fitting measured sea clutter amplitude with the five statistical models. The sea clutter data are obtained from a radar image taken at 11:00 AM, on 16th Dec. 2005. As can be seen from the figure, the Weibull model failed to fit the data. On the other hand, contradictory to our simulated results, it can also be seen that, among the other remaining four models, the two-parameter lognormal is seen to follow the trend of the data more closely than the other models.

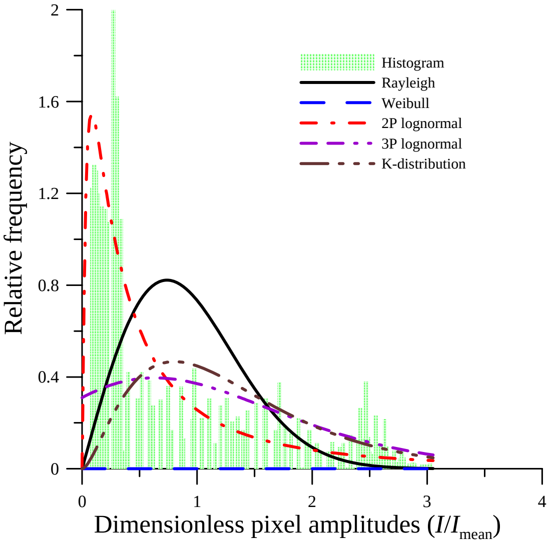

Figure 4. Results of fitting the statistical models to sea clutter data. Data acquired at 11:01 AM, 16th Dec. 2005.

As was mentioned earlier, many researchers have found that the clutter data can be fitted more appropriately using the *K*-distribution. Our results in Figure 4 show that the two-parameter lognormal distribution should be considered as being more suitable for our data. However, it should be noted that most researchers studied the clutter data in the time domain (Antipov, 1998, 2001). Dong (2004b) studied the clutter spatial distribution and also found that the lognormal distribution should be favoured.

However, there are cases where a large quantity of positive amplitudes can be found in the images. One of such cases studied is shown in Figure 5. As can be seen from Figure 4, there is an abnormal amount of large dimensionless pixel amplitudes at approximately $a/a_{\text{mean}} \approx 2.6$. The exact reason for the presence of this is not clear at present. It is conjectured that this is probably due to RFI effects mentioned in the beginning of this article. More studied are needed to clarify this.

Conclusion

Analyses of the characteristics of sea clutter were carried out. In this article, we present some preliminary results of our studies. Five statistical models were used to fit the data. Among these popular models used by researchers, the two-parameter lognormal distribution is found to fit the data more closely than the other four. However, we must stress that the present result is not conclusive. This is because our data seem to be contaminated. Among the possible candidates that can degrade the quality of the clutter data, the Radio Frequency Interference (RFI) is considered to be the most possible one. Nevertheless, the rigorous check of this possibility has not been carried out for the present.

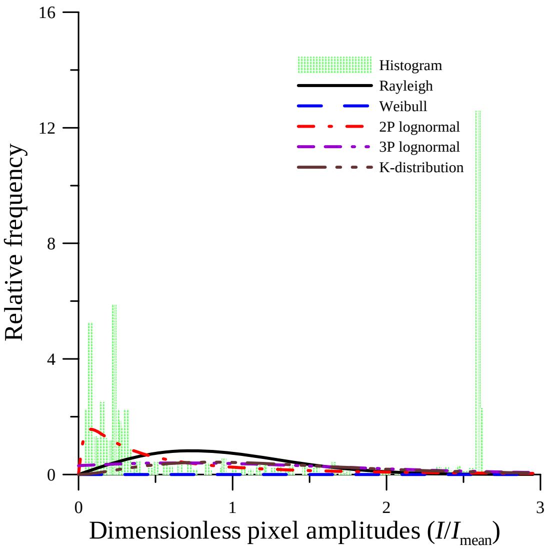

Figure 5. Results of fitting the statistical models to sea clutter data. Data acquired at 11:02 AM, 16th Dec. 2005.

Thermal noise could be another disturbing factor that affects the quality of the data (Antipov, 2001). Furthermore, the clutter on the radar images may also be correlated, and this can also change the statistical nature of the clutter. It is hoped that a somewhat more conclusive result can be presented in the near future.

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