The Analysis of Sea Clutter Statistics Characteristics Based On the Observed Sea Clutter of Ku-Band Radar

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Abstract- **The model of GTI，TSC，NRL distribution the most fundament characteristic of sea clutter, as used in radar performance evaluation. The model of Rayleigh，LogNormal，Weibull and K distribution radar clutter are analyzed and modeled and some kinds of radar clutter，such as ground，weather，chaff and sea clutter are modeled and simulated. The analysis focuses on amplitude characteristic of sea clutter. The analysis would contribute to designing and implementation of radar filter and increasing the ability of suppressing sea clutter and ensuring the detection ability of radar itself.**

I. INTRODUCTION

Ideally, the accurate modeling of sea clutter should include both temporal and spatial characteristics and may ultimately require probabilistic descriptions. The most important characteristic of sea clutter, however, is its average reflectivity defined in the dimensionless unit of square-meters of radar cross section per square-meter of surface area illuminated by the radar, often denoted by σ_0 . Some amount of smoothing of experimental errors leads to a need for empirical models, which, while supported by experimental data, allows computations to be performed over a continuum of parameter values. Radar environmental clutter plays an important role in the simulation of radar environment，statistical characterization of which can be described by the scattering coefficient model.

II. THEORY FORMULAS

A. Average scattering coefficient model of sea clutter

The radar designer requires estimates of the range of different clutter characteristics likely to be encountered. Empirical models for these are also available. The study of average scattering coefficient model of sea clutter is mainly about the average scattering coefficient of sea clutter with the change of grazing angle and the variation of parameters of the marine environment. It plays an important role for radar range performance prediction.

Internationally, typical semi-empirical model of sea clutter average scattering coefficient are GIT model, TSC model and the NRL model.

GIT model [1] is a function which describes the sea clutter backscatter coefficient of three factors: (1) interference factor G_i ; (2) wind factor G_u ; (3) wind factor G_w .

GIT model sea clutter scattering coefficient is:

$$\sigma_{HH}^0 = 10\log_{10}\left[3.9\times10^{-6}\lambda\phi_{gr}^{0.4}G_iG_wG_u\right] \tag{1}$$

$$\sigma_{VV}^0 = \begin{cases} \sigma_{HH}^0 - 1.05\ln\left(h_{av}+0.015\right)+1.09\ln\left(\lambda\right)+ \\ 1.27\ln\left(\phi_{gr}+0.0001\right)+9.7, \\ 3GHz < f < 10GHz \\ \sigma_{HH}^0 - 1.73\ln\left(h_{av}+0.015\right)+3.76\ln\left(\lambda\right)+ \\ 2.46\ln\left(\phi_{gr}+0.0001\right)+22.2, \\ f < 3GHz \end{cases} \tag{2}$$

where λ is the radar wavelength (m), ϕ_{gr} is the grazing angle (radians), h_{av} is average wave height (m).

TSC model [2] is a function which describes sea clutter backscatter coefficient of three factors: (1) small grazing angle factor G_A ; (2) wind factor G_u ; (3) wind factor G_w .

TSC model sea clutter scattering coefficient is:

$$\sigma_{HH}^0 = 10\log_{10}\left[1.7\times10^{-5}\phi_{gr}^{0.5}G_AG_wG_u/\left(\lambda+0.5\right)^{1.8}\right] \tag{3}$$

$$\sigma_{VV}^0 = \begin{cases} \sigma_{HH}^0 - 1.73\ln\left(2.507\sigma_z+0.05\right)+ \\ 3.76\ln\left(\lambda\right)+2.46\ln\left(\sin\left(\phi_{gr}\right)+0.0001\right) \\ +19.8,\ \ f<2GHz \\ \sigma_{HH}^0 - 1.05\ln\left(2.507\sigma_z+0.05\right)+ \\ 1.09\ln\left(\lambda\right)+1.27\ln\left(\sin\left(\phi_{gr}\right)+0.0001\right) \\ +9.65,\ \ f>2GHz \end{cases} \tag{4}$$

where λ is the radar wavelength (m), ϕ_{gr} is the grazing angle (radians), σ_z is the sea surface height standard deviation.

NRL model [3] of the sea clutter scattering coefficient is:

$$\sigma^0_{HH,VV} = c_1 + c_2 \cdot \log_{10}\left(\sin\left(\phi_{gr}\right)\right) + \frac{\left(c_3 + c_4 \cdot \phi_{gr}\right) \cdot \log_{10}\left(f\right)}{\left(1 + c_5 \cdot \phi_{gr} + c_6 \cdot s\right)} + c_7 \cdot \left(1+s\right)^{1/\left(2 + c_8 \cdot \phi_{gr} + c_9 \cdot s\right)} \quad (5)$$

where ϕ_{gr} is the grazing angle (degrees), s is the sea state, f is the radar operating frequency (GHz).The parameter of NRL model is in table I.

TABLE I
PARAMETER OF NRL MODEL

	Estate of Polarization	
Parameter	HH-pol	VV-pol
c1	-72.76	-48.56
c2	21.11	26.30
c3	24.78	29.05
c4	4.917	-0.5183
c5	0.6216	1.057
c6	-0.02949	0.04839
c7	26.19	21.37
c8	0.09345	0.07466
c9	0.05031	0.04623

B. Average distribution model of sea clutter amplitude

Sea clutter amplitude distribution characteristics have a great significance to the radar target detection, simulation and system design and performance evaluation. The main sea clutter amplitude distribution models are Rayleigh-distribution model[4], lognormal-distribution model[5], Weibull-distribution model [6] and K-distribution[7-10] model.

The probability density function (PDF) of Rayleigh-distribution is:

$$p(E) = \frac{2E}{x}\exp\left(-E^2 / x\right) \quad (6)$$

Cumulative probability density function (CDF) of Rayleigh-distribution is:

$$P(E) = 1 - \exp\left(-E^2 / x\right) \quad (7)$$

N-order moments of Rayleigh-distribution is:

$$M_n = x^{n/2}\Gamma\left(1 + n/2\right) \quad (8)$$

where x is the average square value of the amplitude of the clutter, E is the instantaneous value of the clutter amplitude, $\Gamma\left(\cdot\right)$ is gamma function.

The probability density function (PDF) of Lognormal-distribution is:

$$p(E) = \frac{1}{E\sqrt{2\pi\sigma^2}}\exp\left(-\frac{\left[\ln(E/m)\right]^2}{2\sigma^2}\right) \quad (9)$$

Cumulative probability density function (CDF) of Lognormal-distribution is:

$$P(E) = 1 - \frac{1}{2}erfc\left(\frac{\ln\left(E-m\right)}{\sqrt{2\sigma^2}}\right) \quad (10)$$

N-order moments of Lognormal-distribution is:

$$M_n = \exp\left(n\ln(m) + (n\sigma)^2\right) \quad (11)$$

where $\mathrm{erfc}\left(\cdot\right)$ is the residual error function, m is the average noise amplitude, σ^2 is the variance of $\ln E^2$.

The clutter probability density function (PDF) of Weibull-distribution is:

$$p(E) = \beta\frac{E^{\beta-1}}{\alpha^\beta}\exp\left(-\left(E/\alpha\right)^\beta\right) \quad (12)$$

Cumulative probability density function (CDF) of Weibull-distribution is:

$$P\left(E\right) = 1 - \exp\left(-\left(E/\alpha\right)^\beta\right) \quad (13)$$

N-order moments of Weibull-distribution is:

$$M_n = \alpha^n\Gamma\left(1 + n/\beta\right) \quad (14)$$

where β is the shape parameter, α is the scale parameter.

The clutter probability density function of K-distribution is:

$$p\left(E\right) = \frac{4b^{(v+1)/2}E^v}{\Gamma(v)}K_{v-1}\left(2E\sqrt{b}\right) \quad (15)$$

Cumulative probability density function (CDF) of K-distribution is:

$$P(E) = 1 - \frac{2}{\Gamma\left(v\right)}\left(E\sqrt{b}\right)^v K_v\left(2E\sqrt{b}\right) \quad (16)$$

N-order moments of K-distribution is:

$$M_n = b^{-n/2}\frac{\Gamma\left(1+n/2\right)\Gamma\left(v+n/2\right)}{\Gamma\left(v\right)} \quad (17)$$

where b is the scale parameter, v is the shape parameter, $K_v\left(\cdot\right)$ is v^{th} -order Bessel modified function of second kind.

III. ANALYSIS OF EXPERIMENTAL DATA AND RESULTS OF EXPERIMENTSS

The following experimental data is collected in Qingdao on July 23, 2011 and July 24, 2011.

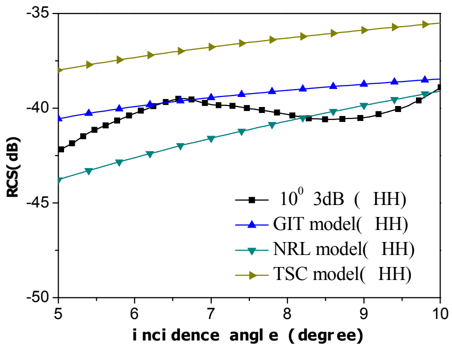

Figure 1 comparison with data of scattering coefficient model and the experimental data

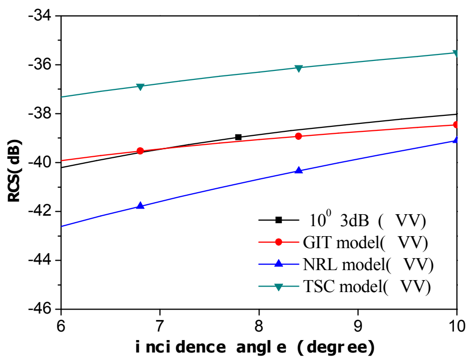

Figure 2 comparison with data of scattering coefficient model and the experimental data

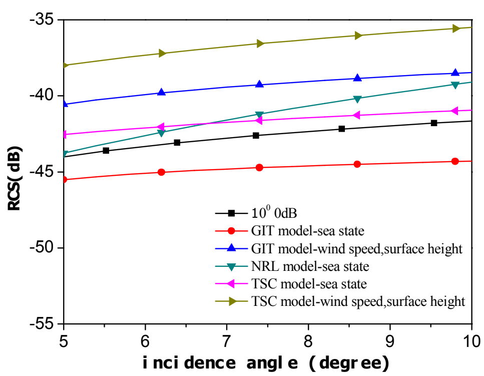

Figure 3 comparison with data of scattering coefficient model and the experimental data

Figure 1 and Figure 2 shows the comparison with the sea clutter data and the experimental data of GIT, TSC and NRL model. In Figure 1, the incidence angle of the data is 10 degree 3dB, HH polarization. In Figure 2, the incidence angle of the data is 10 degree 3dB, HH polarization. As comparison is shown in Figure 1 between the GTI, NRL and TSC sea clutter model and data for horizontal. While the agreement with NRL model at 8-10 degree is reasonable good, the agreement with GTI model at 6.5 degree is good. As comparison is shown in Figure 2 between the GTI, NRL and TSC sea clutter model and data for vertical. The agreement with GTI model at 6-10 degree is reasonable good.

Figure 3 shows the comparison with the sea clutter data and the experimental data of GIT, TSC and NRL model. The incidence angle of the data is 10 degree 0dB. The parameters of GIT model are wind speed, wave height and sea state level. TSC model also have two parameters. The comparison is shown in Figure 3 between the five sea clutter models. The agreement with TSC model with parameter of sea state level at 5-10 degree is reasonable good.

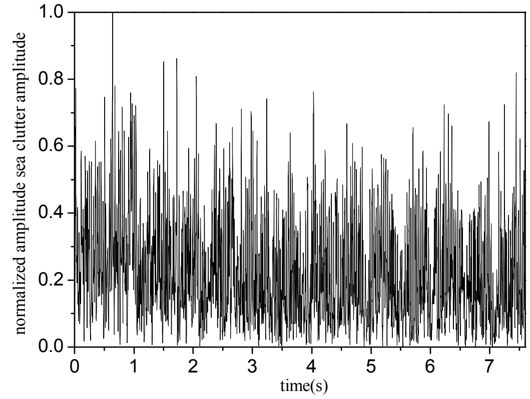

Figure 4 normalized sea clutter amplitude of time series

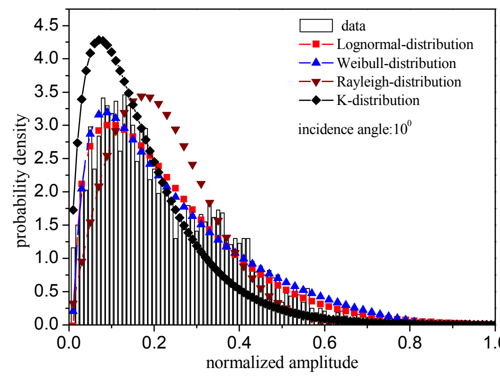

Figure 5 normalized amplitude of the probability density distribution

Figure 4 is the normalized sea clutter amplitude of time series. Figure 5 is the normalized amplitude of the probability density distribution of Figure 4. The incidence angle is 10 °, the wind speed is 3.2 m / s. As comparison is shown in Figure 5, the agreement with Weibull-distribution model is reasonable good; the agreement with Lognormal-distribution model is less good.

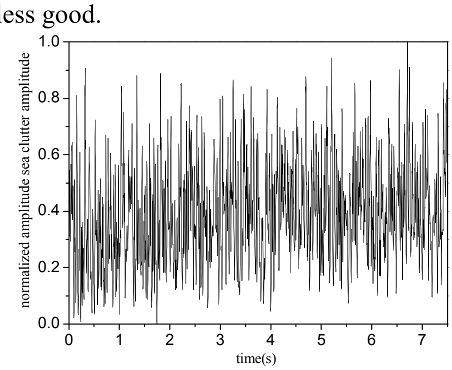

Figure 6 normalized sea clutter amplitude of time series

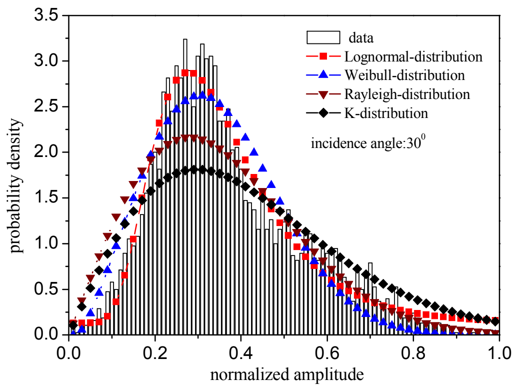

Figure 7 normalized amplitude of the probability density distribution

Figure 6 is the normalized sea clutter amplitude of time series. Figure 7 is the normalized amplitude of the probability density distribution of Figure 6. The incidence angle is 30°, the wind speed is 8.1 m/s. As comparison is shown in Figure 7, the agreement with Lognormal-distribution model is reasonable good; the agreement with Weibull-distribution model is less good.

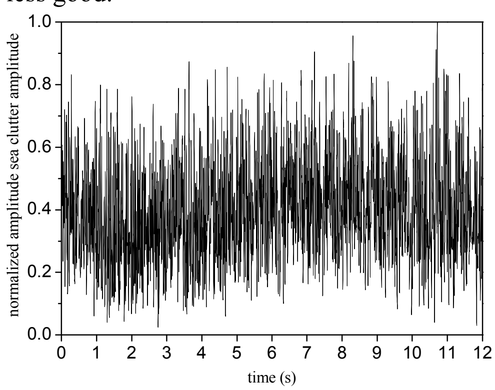

Figure 8 normalized sea clutter amplitude of time series

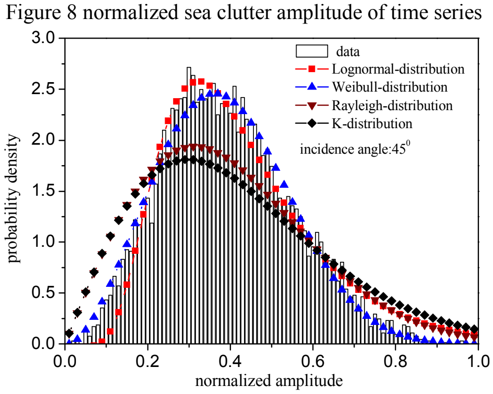

Figure 9 normalized amplitude of the probability density distribution

Figure 8 is the normalized sea clutter amplitude of time series. Figure 9 is the normalized amplitude of the probability density distribution of Figure 8. The incidence angle is 45°, the wind speed is 6.3 m / s. As comparison is shown in Figure 9, the agreement with Lognormal-distribution model is reasonable good; the agreement with Weibull-distribution model is less good; the agreement with Rayleigh-distribution is not that good.

IV. Conclusions

Three kinds of scattering coefficient sea clutter models and four kinds of distribution model of sea clutter amplitude are introduced in this paper comparing with the experimental data. This paper analysis the scattering coefficient model and amplitude distribution model of sea clutter, based on the observed sea clutter of Ku-band Radar. This analysis would help to design the radar filter and increase the ability of suppressing sea clutter.

Acknowledgment

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