

Simulation of Sea Clutter Characters in the Different Duct Environment

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Abstract—The influence of sea clutter can not be ignored in the radar detection. The trapped structure of duct environment can induce exceptional characters of the graze angle and clutter power of sea clutter. This paper analyzes the influence of duct environment on the graze angle and incidence power. Combined with the established calculation model, we put forward the calculation method of the sea clutter characters in duct environment based on the corresponding range method. At last, using this calculation method and the simulated radar parameters, the characters of the sea clutter are simulated in deferent duct environments, in addition, the influences of radar frequency, antenna height and the duct height are analyzed.

Keywords-duct environment; sea clutter characters; corresponding range

1. Introduction

The research of sea clutter characters is the base of the radar detection, and has pivotal impacts on the radar performance. This research has been on for many years but incomplete, and because of the complexity of the ocean surface dispersion, the clutter model is not universal. With the appearance of exceptional sea clutter characters of the modern radar and the research of atmospheric duct, the problems of sea clutter in duct environment are concerned^{[1][2]}.

In abroad, the research of sea clutter in duct environment is profound, and the calculation methods of sea clutter characters in duct environment are applicable. For example, the ray-tracing method can simple combined the duct condition with the calculation of gazing angle and incident energy^[3-5], and the numerical model of electromagnetic wave propagation is used to analyze the distribution characters of gazing angle and incident energy^[6-7], furthermore, others use the dispersion theory in duct environment to amend the Bragg dispersion and get the energy dissipation equation of sea clutter^[8]. But at home, this research is just started; the concerned contents include the estimation of atmospheric refractivity profile from radar sea clutter^[9], and the relation between the sea clutter distribution and the evaporation duct height^[10].

From the view of electromagnetic wave propagation, this paper analyze the influence of duct environment on the sea clutter, consult the experiential model and put forward the calculation methods of the sea clutter characters(grazing angles, sea reflectivity and clutter power) based on the corresponding range method in the duct environment. At last, according to this method and the fixed radar parameters, the sea clutter characters are simulated in the different duct environments, and the influence of radar frequency and duct height is analyzed.

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2. Analyze and Calculation of Sea Clutter Characters in the Duct Environment

Because of the trapped character, the duct environment can induce the curve track of electromagnetic wave, and the exceptional characters of grazing angle, sea reflectivity and sea clutter power.

2.1. Analyze and calculation of grazing angle in the duct environment

Here, the grazing angle refer to the angle of incident energy, and has obvious difference to the geometrical gazing angle in free space and standard environment. The usual calculation methods of gazing angle include ray-tracing method^[3] and spectrum estimation method^[6-7]; both these methods have their strongpoint, but in this paper a compound method of them will be used to calculate the relationship between the grazing angle and the range in duct environment. The compound method means that in the evaporation duct environment ray-tracing method is used to calculate the grazing angle and let the ultimate grazing angle ψ_{lim} substitute for the grazing angle out of the ultimate range. At the same time, in the surface duct environment firstly, ray-tracing method is used to calculate the grazing angle, and the spectrum estimation method is used to calculate in the range out of the first jumping blind area This compound method cans overcome the shortcoming of the ray-tracing method in the range out of the first jumping blind area, and consider the trapped character of surface duct environment. Because of the paper length, more details please refer to [3], [6] and [7].

2.2. Analyze and calculation of sea reflectivity in the duct environment

Sea reflectivity is the representation of the electromagnetic character of the sea surface, and should not include the propagation environment of electromagnetic wave. But, the experienced calculation model of sea reflectivity all includes the propagation environment, for example, the GIT model^[11] also includes the standard environment. So here, the GIT model can be described as:

$$\sigma_{\text{git}}^0(\psi_s(R_s)) = \sigma^0(\psi_s(R_s))F_s^4(R_s) \quad (1)$$

The subscript 's' refer to the standard environment, σ_{git}^0 is the sea reflectivity of CIT model, ψ is the grazing angle, R is the distance, F_s^4 is the two-way propagation loss. According to the direction of the radiation $F_s^4 = [F_{s,o} \cdot f^2(u)]^4$, then:

$$\sigma_{\text{git}}^0(\psi_s(R_s)) = \sigma^0(\psi_s(R_s))F_{s,o}^4(R_s) \cdot [f^2(u)]^4 \quad (2)$$

where $F_{s,o}$ is the two-way propagation factor of the isotropy antenna in standard environment, $f(u)$ is the function of the antenna direction, u is the departure angle with the antenna main direction.

For standard environment and the isotropy antenna, $f^2(u) \equiv 1$, if the range R_s is equal, the grazing angle $\psi_s(R_s)$ will be equal, and the calculated σ_{git}^0 will be equal too. So the difference between the true sea reflectivity and the σ_{git}^0 is the $F_{s,o}$, and the true sea reflectivity σ^0 is calculated as

$$\sigma^0(\psi_s(R_s)) = \frac{\sigma_{\text{git}}^0(\psi_s(R_s))}{F_{s,o}^4(R_s)} \quad (3)$$

For the duct environment, the received sea reflectivity is integration of the true sea reflectivity σ^0 and the duct environment. So in duct environment the sea reflectivity σ_d^0 is calculated as:

$$\begin{aligned} \sigma_d^0(\psi_d(R_d)) &= \sigma^0(\psi_d(R_d)) \cdot F_d^4(R_d) \\ &= \sigma_{\text{git}}^0(\psi_d(R_d)) \cdot \frac{F_d^4(R_d)}{F_{s,o}^4(R_s)} \end{aligned} \quad (4)$$

The subscript 'd' refer to the duct environment, $F_d^4(R_d)$ is the two-way propagation loss. Here, what need to be explained is that the distance R_d in duct environment and the distance R_s must satisfy the qualification of equal grazing angle i.e. $\psi_d(R_d) = \psi_s(R_s)$. This is the corresponding distance method, which means the grazing angle and sea reflectivity of R_d in the duct environment can always find the corresponding equal ones of R_s in the standard environment. It just because of this 'corresponding range'

method, the sea clutter characters in duct environment can be calculated by the GIT model of standard environment.

2.3. C. Analyze and calculation of clutter power in the duct environment

Another important influence of duct environment on the sea clutter is the exceptional clutter power. According to the equation of radar detection, in the condition of low grazing angle, the clutter power can be calculated as:

$$P_r = \frac{P_t G^2 \lambda^2}{(4\pi)^3 R^4 L_s} \cdot \sigma \cdot F^4 \quad (5)$$

Where P_t is the radiation power, σ is the sea reflectivity, λ is the wavelength, G is the transmit gain, F is the propagation factor, L_s is the system loss, R is the range.

In duct environment, with the influence of the two-way propagation factor and the calculation method of sea reflectivity, the clutter power equation 5 should be amended as:

$$P_c(R) = C_r \cdot \frac{1}{R_d^3} \cdot \sigma_{git}^0(R_d) \cdot \frac{F_d^4(R_d)}{F_{s,o}^4(R_s)} \quad (6)$$

Similarly, in equation 6, $F_{s,o}^4$ is the two-way propagation factor of the isotropy antenna in standard environment, and also satisfy the condition of ‘corresponding range’ i.e. $\psi_d(R_d) = \psi_s(R_s)$. The $F_d^4(R_d)$ and $F_{s,o}^4(R_s)$ need to be calculated in duct and standard environment with the numerical model PEM-SSFA^[12]. In the calculation of F^4 , the calculation height choose the effective wave height h_e which has the relationship of $h_e \approx 0.6h_{av}$ with the average wave height h_{av} ^[6].

3. Simulation and Analyze of Sea Clutter Characters in the Different Duct Environment

3.1. The radar and evaporation duct parameters

According to the theory and statistical characters of the duct environment^[13], the duct profiles set as figures 1, the evaporation duct heights are: 0 2.5,5,10,20,40m(0m stand for the standard environment), and the surface duct heights are: 50,100,200,300m. The sea status suppose as 2 level, including wind rate 5.5m/s, upwind direction UW and average wave height 0.32m.

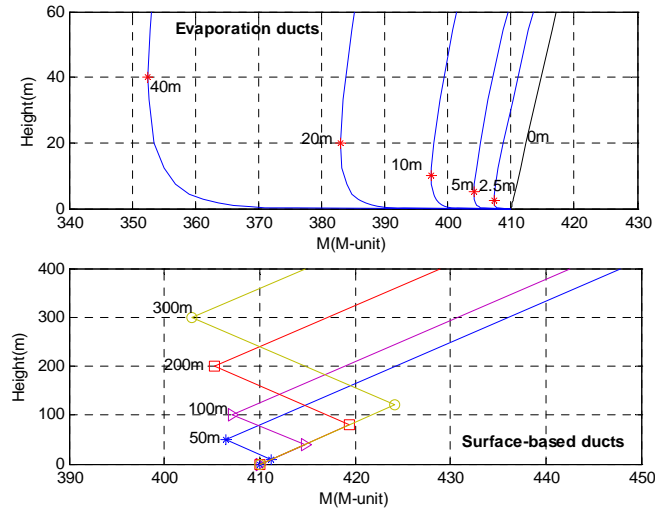


Fig.1. The M- profile of different duct environment

In addition, the radar parameters set as table 1(L:1.5GHz;S:3.0GHz;C:6.0GHz;X:10.0GHz).

TABLE I. THE RADAR PARAMETERS

Frequency	L,S, C,X	Evaluation	0 deg
Peak power	1Mw	Antenna gain	45dBi
Polarization	VV	Impulse accumulation	30
Plane beam angle	0.7 deg	Noise coefficient	4.5dB
Impulse breadth	2 μs	Antenna height	18/25m
Vertical beam angle	0.7 deg	System loss	4.5dB
Impulse repeat	600Hz	Antenna type	GAUSS

3.2. Characters of grazing angle with the range in the evaporation duct

The characters of gazing angle with the variety of the range are showed as fig 2, in evaporation duct environment(a) the radiation heights are 18m and 25m and in evaporation surface environment(b) the radiation heights is 25m.

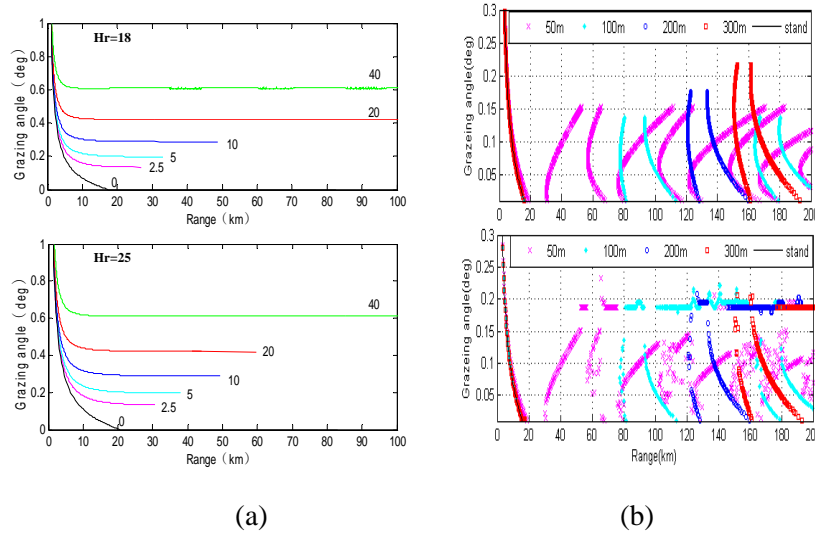


Fig.2. The variational characters of grazing angle with range in different duct environment

Fig 2 illuminates the conclusions as follow. ①The grazing angle characters vary with the evaporation duct environment, and in the region of big grazing angle and little distance, the grazing angles are almost same in evaporation duct environment and stand environment. This same phenomenon also exists in surface duct environment. ② In the same duct environment, the grazing angles of different radiation heights have difference. And in the same duct environment, the characters of the grazing angle change with the antenna height H_r . ③ In fig2(b), the different surface duct environment can form different characters of jumping blind area, and the grazing angle is not exist when use the Ray-tracing model(upside of fig 2b)and exist when use the compound method of this paper(downsides of fig 2b). ④ In the surface duct environments the grazing angles are very little and most are less than 0.3 deg. And For the lower radiation height near the ocean surface, the difference of the corresponding grazing angles in different environments is little.

3.3. characters of sea reflectivity with the range in the evaporation duct

Use the calculation model of chapter 2.2; the characters of sea reflectivity are simulated with four kinds of frequency and six kinds of evaporation duct environments. The conclusion show as fig 3, from fig 3a to 3d the frequency is L,S,C and X.

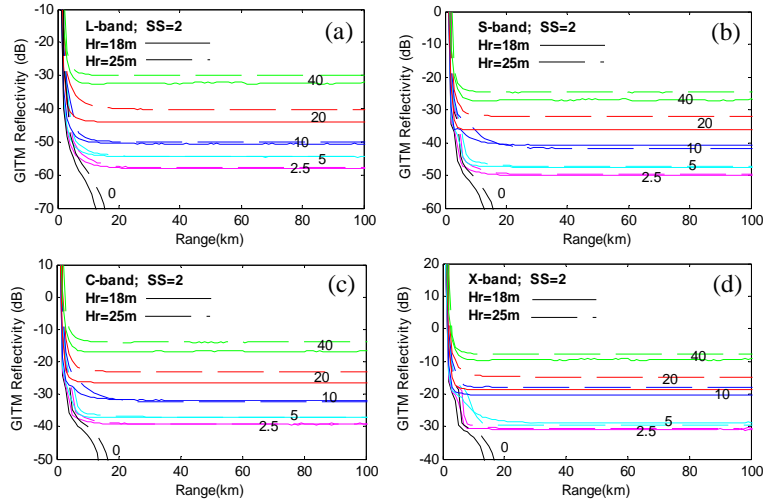


Fig.3. The variational characters of sea reflectivity with range in evaporation duct environment

Fig 3 illuminates the conclusions as follow. ① In the sight range or the least range region, sea reflectivity σ^0 decreases with the range clearly, and the difference is very little. With the range increasing, the difference decrease, and change to stabilization in the evaporation duct environment. ② In the sight range, the sea reflectivity σ^0 increase with the duct height h_r . And in the standard environment, according to the meaning of ultimate range R_{lim} , out of the sight range the sea reflectivity σ^0 is not concerned. ③ Compared with the characters of different frequencies, in the evaporation duct environment, the sea reflectivity σ^0 of the same range increase with the radiation frequency. ④ The different characters of the sea reflectivity σ^0 in the different antenna height h_r is the display of the trapped effect of the evaporation duct, and with the antenna height decrease, the calculation value of σ^0 increase.

For the four kinds of surface duct environment, the fig4 show the variational characters of sea reflectivity with range. From fig4a to fig4b the height is 50m,100m, 200m and 300m.

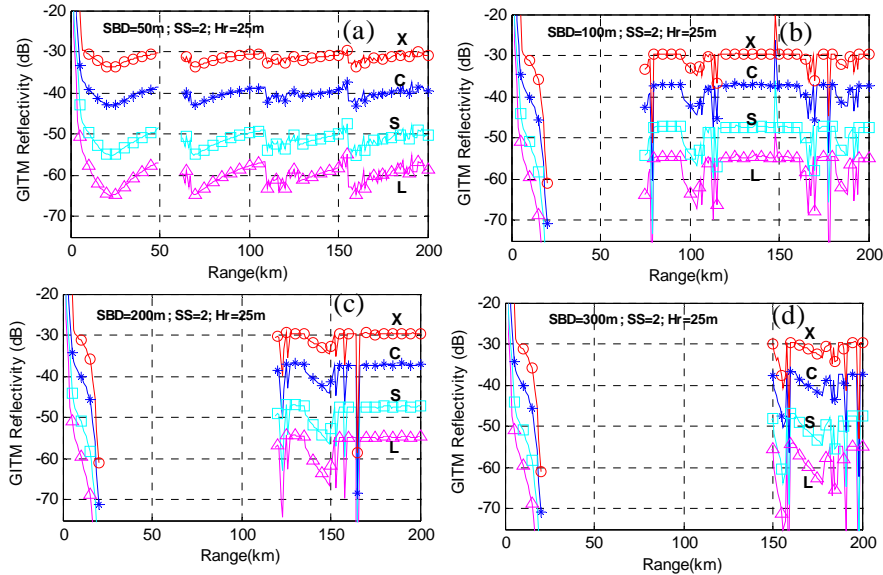


Fig.4. The variational characters of sea reflectivity with range in surface duct environment

Fig 4 shows the conclusions as follow. ① In the sight range and the surface duct environment of higher height, the difference of grazing angle characters is little between the stand environment and the surface duct environment, and the σ^0 is consistent with the stand environment, for example fig4b, fig4c and fig4d. But in the surface duct environment of lower heights, these characters vary just as them of the evaporation duct environment, for example fig4a. ② In the first jumping blind area out of sight range, the electromagnetic

energy is very little and the calculation of grazing angle can be ignored, and the σ^0 is not concerned. ③ In the range out of the jumping blind area, the σ^0 is bigger and fluctuant, not consistent with the characters in the evaporation duct and vary with the duct height. ④ In same surface duct environment, when the frequency is higher the σ^0 also is bigger.

3.4. Characters of clutter power with the range in the evaporation duct

Use the method of chapter 2.3, according to the fig 3, the corresponding characters of sea clutter power with the range is showed as fig 4.

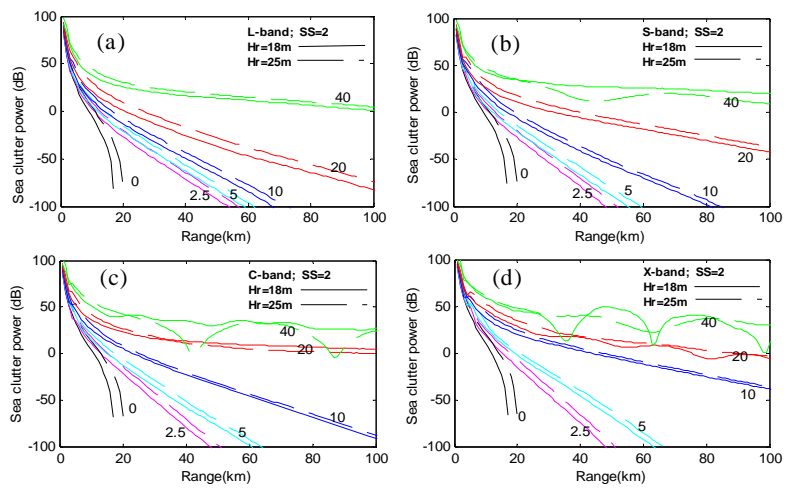


Fig.5. The variational characters of sea clutter power with range in evaporation duct environment

Fig 5 shows the conclusions as follow. ① With the range increasing, the value of sea clutter power decrease. And the attenuation of the clutter power correlate with the duct height. The attenuation velocity of clutter power is lower in the evaporation duct environment than in the standard environment, but in the region of least range nearly equal. ② Compared with the standard environment, the evaporation duct can increase the value of the clutter power, form the exceptional characters out of the range of sight, and with the trapped effect increasing, the attenuation velocity of clutter power become slowly. ③ In the condition of lower antenna height, because of the trapped effect, interference will influence the radar detection and form some vibrational character. These characters relate to the frequency and the duct height, for example, the vibrational character of X frequency is more obvious than others in the fig 5.

For the four kinds of surface duct environment, the variational characters of sea clutter power with range corresponding to the fig4 show in fig6, and the characters in the first jumping blind area are not calculated in the fig 6b, 6c and 6d.

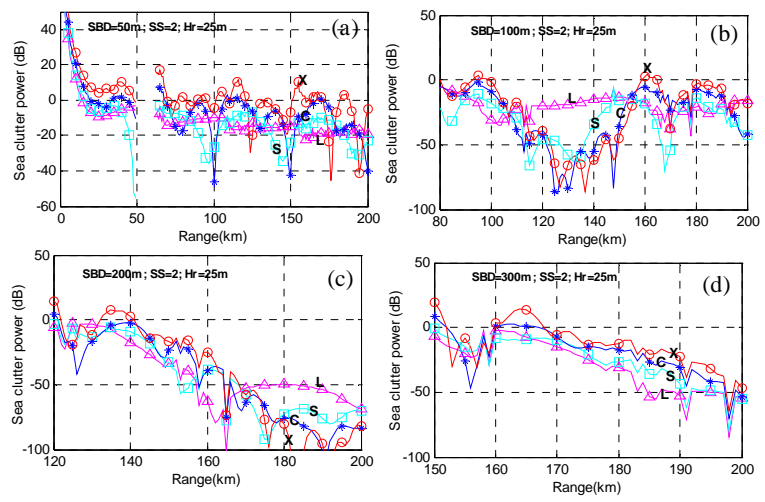


Fig.6. The variational characters of sea clutter power with range in surface duct environment

Fig 6 shows the conclusions as follow. ①In the sight range and the surface duct environment of lower height, the characters of sea clutter power is similar with them in evaporation duct environment, for example fig6, and in the surface duct environment of higher height is similar with them in standard environment. ②In the range of first jumping blind area, the propagation factor F is very little, so the sea clutter power also is ignored; and in the range out of the jumping blind area, sea clutter power is as high as the power in the sight range of little grazing angle and still has some obvious fluctuation. ③The sea clutter power increases by degrees of frequency, but the difference is not absolute because of the fluctuation out of the sight range.

4. Conclusion

In the view of electromagnetic wave propagation, this paper analyzes the influence of the duct environment on the characters of sea clutter, and simulates the result. The research and conclusion show that: ①The different characters of sea clutter between standard and duct environment come from the trapped structure influence on the electromagnetic wave propagation. ②In the duct environment sea clutter power clearly swells, and the attenuation with range become more slowly than in the standard environment. ③In the duct environment sea clutter characters out of the sight range come forth in the lower grazing angle, and there are no characters or few characters in the jumping blind area of surface duct environment. ④Different sea states, antenna height and frequency all affect the sea clutter characters, but apparently, the influence of the duct environment is more obvious, and can not be ignored, especially the evaporation duct environment with high occurrence probability.

5. References

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