Research on the Sea Surface Waveguide Inversion of Radar Sea Clutters Based on Five-parameter Method

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Abstract. In this paper, a method for the formation of the oceanic atmospheric refractive index based on Five Parameters, which uses the power information of radar sea clutter. By comparing the surface waveguides measured in some experimental sea areas in China, the feasibility of this method is verified, which is beneficial to overcome the difficulty of directly measuring the atmospheric refractive index profile under harsh conditions at sea.

Keywords: Inversion of radar clutters; Atmospheric refractive index; Five-parameter method.

1. Introduction
There are three types of atmospheric ducts in the ocean environment: evaporation duct, surface conduit and uplift conduit. [1], the OTHER (Over-the-Horizon Radar) can be used to realize the over the horizon detection of the atmospheric duct. To obtain atmospheric pipelines at 300 meters or higher, a hybrid pipeline model should be used for inversion. In order to parameterize these three types of atmospheric ducts, the California Naval Physics Laboratory has proposed a universal five-parameter refractive index model[2]. The model parameters comprises five evaporation duct height (δ), base height of the conduit (Zb), the slope of the mixed layer (C1), the thickness of the surface of the catheter (Zdick) and the surface of the catheter deficit M (Md). The refractive index model is shown in Figure 1.

In this mode, the correction of atmospheric refractive index profile may be determined at the same time given five parameters, it may also be obtained in the case where the air conduit.
Based on this premise, this paper first establishes a nonlinear relationship between radar echo power and atmospheric refractive index distribution. Then, the best parameters of the atmospheric refractive index distribution are searched and matched with the optimization algorithm. The atmospheric distribution of the refractive index corresponding to the optimal parameter is a waveguide distribution.

Figure 1. Model of five-parameter.
2. RFC Technology

A flowchart of the atmospheric refractive index distribution of radar sea clutter (RFC [3]) is shown in Figure 2.

![RFC flowchart](Figure 2)

Radar Sea Clutter discrete power [4]. Extracting clutter from the radar echo power and the relationship between the transmission distance, and then spread over the distance \( r_1, r_2, \ldots, r_N \) to obtain discrete power vector \( P_{\text{obs}}(x) \). And \( P_{\text{obs}}(x) \) as an input parameter.

The model of the waveguide parameters is stable. Suitable establish atmospheric environment model refractive index profile, the refractive index parameter determines the number of dimensions. There are five parameters, include \( c_1, z_b, z_{\text{thick}}, M_d \).

The model of radar beam propagation is stable. The \( M_d \) and PE, the calculated power radar clutter received, and decomposition \( P_e(x) \).

Choice of objective function \( f(x) \). The model parameters can be modified by comparing the observed data of the radar echo with the simulated radar echo power. The inversion of radar echo power is achieved by genetic simulated annealing [5]. And immune optimization algorithms. The degree of matching between the simulation curve of radar echo power \( P_e(x) \) and the relaxation curve of radar echo power \( P_{\text{obs}}(x) \) can be evaluated by determining the objective function \( f(x) \) [6].

\[
f(x) = (P_{\text{obs}}(x) - P_e(x))(P_{\text{obs}}(x) - P_e(x))^T \tag{1}
\]

Function optimization. The inversion algorithm is used to optimize the waveguide parameter space globally. Currently, there are many algorithms that can be used to calculate waveguide parameters, including genetic algorithms, maximum posterior algorithms, ant colony algorithms [7], and Kaman filtering algorithms, PSO algorithms [8,9].

3. Model Parameters Optimization

When there are evaporation tubes and surface tubes, the functions of refractive index and height are shown below.

\[
M(z) = M_0 + \begin{cases} 
M_0 + c_0 \left( z - \delta \log \frac{z}{z_0} \right) & z < z_d \\
c_1 z & z_d < z < z_b \\
c_1 z_b - M_d \frac{z - z_b}{z_{\text{thick}}} & z_b < z < z_f \\
c_1 z_b - M_d + c_2 (z - z_f) & z_f < z
\end{cases} \tag{2}
\]

The parameters in Formula (2) was:
The coordinate of height \( z \); roughness factor \( z_0 \). The experience parameter of refractivity profile of centrospheres \( c_0 \) [10]. The height of duct \( \delta \).
The mixed layer slope \( c_1 \). The average of all data \( c_2 \). This is a sensitive parameter because the contour is refracted upwards.

\( z_d \) is defined as follow:

\[
z_d = \begin{cases} 
\frac{\delta}{1-c_1/c_0} & 0 < \frac{1}{1-c_1/c_0} < 2 \\
\frac{2\delta}{1-c_1/c_0} & \text{else}
\end{cases}
\]  

(3)

The value range of \( z_h \) is \([0,500]\).
and the range of thickness \( z_{\text{thick}} \) is \([0,100]\). \( z = z_h + z_{\text{thick}} \), \( M_0 = 330 \). \( M_d \) is M-deficit, and the value range is \([0,100]\).

Of all these parameters, the five most important parameters are \( \delta, c_1, z_h, z_{\text{thick}}, M_d \). The maximum and minimum values are listed in Table 1.

| Parameter           | Min | Max |
|---------------------|-----|-----|
| Evaporation duct height \( \delta \) | 0   | 40  |
| Mixed layer slope \( c_1 \) | -1  | 0.4 |
| Base height \( z_h \) | 3   | 300 |
| Thickness \( z_{\text{thick}} \) | 0   | 100 |
| M-deficit \( M_d \) | 0   | 100 |

4. Experiment Research

The profile of the mixed duct was retrieved by fitting data measured in the ocean, and the results are shown in Fig. 3, Fig. 4 and Fig. 5. According to the results, the data fitting of the contour of the evaporation tube is perfect because the evaporation tube is the main factor affecting the wind direction. During the inversion process, the sea clutter's exploration characteristics and sea clutter power are related to the height of the evaporation tube. The fitting of the data of the rising pipe profile shows a separation phenomenon, because the rising pipe has little effect on the low-altitude target.

\[ \text{Figure 3. Sounding experiment with the ball} \]

\[ \text{Figure 4. Comparison result between two ducts} \]
Figure 5. Power between two clutters.

Table 2. The analyze results.

|   | inversion | measurement | Relative error |
|---|-----------|-------------|----------------|
| $\delta$ | 14.9      | 15          | 0.87%          |
| $c_1$   | 0.35      | 0.3         | 16.3%          |
| $c_1$   | 135.7     | 150         | 9.56%          |
| $z_{thick}$ | 38.4    | 50          | 23.24%         |
| $M_d$   | 34.7      | 30          | 15.73%         |

5. Conclusions
Five-parameter analysis of the application of the algorithm in RFC. The five-parameter algorithm can not only obtain the refractive index profile of the multi-tube atmosphere, but also the atmospheric refractive index profile of higher altitudes. According to the results of experimental inversion, this algorithm is suitable for the calculation of RFC. However, due to the complex parameters, the optimization algorithm should be modified to improve the accuracy of the inversion.

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