PHENOMENOLOGICAL APPROACH

TO SCATTEROMETER DATA INTERPRETATION

by

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ABSTRACT

This paper proposes a graphic method of analyzing radar scatterometer sea clutter data leading to linear relations between scattering cross sections and tan angle of incidence of the radiation. This relation permits formulation of simple analytic relations without reference to the ocean surface spectrum. Parameters introduced depend on the wavelength of the incident radiation and its polarization, and on wind and sea states. The simplicity of the expressions derived suggests a corresponding simplicity in the physical mechanism of radar sea clutter return.

INTRODUCTION

The complicated character of expressions derived in the theories of the analysis of scattering of electromagnetic waves from rough surfaces has been mentioned frequently (e.g., references 1 and 2). As a consequence, physical interpretation of the theories' predictions is difficult, and approximations must be made if explicit and useful results are required (references 2 and 3). Applied to ocean scatterometry, these theories often begin with doubtful assumptions about the nature of the ocean's surface and with Kirchhoff's approximation; thus, even the complicated initial results of the theory are questionable.

The history of physical research demonstrates that insight into the nature of physical processes can be gained by beginning with the experimental data (rather than with electromagnetic field theory as in reference 1, for example) and attempting to find simple relations between the experimental parameters. These relations then become the basis of a provisional and uncomplicated theory featuring the trends and correlations summarized in the empirical expressions; this procedure permits a minimum number of assumptions about the physical mechanisms involved. Consequently, there is more certainty about whatever details of the physical processes are assumed in order to derive the theory. Such a theory is characterized as "semi-empirical" or "phenomenological", since the experimental data is of primary importance and the theoretical structure is taken to follow from this, rather than the converse. Although the validity of the theory is no greater than that of the data available, the value of this approach has been amply demonstrated in many connections: one outstanding example is the discovery of the Balmer series in spectroscopy, later the basis of the Bohr theory of the hydrogen atom. Another example is met in the study of radioactive decay, where a theory had to be constructed to explain an observed exponential decay law. In both the above cases, plotting the data against log-log scales to obtain a linear variation was found to be a useful device in data analysis.

In the analysis of scatterometer data from several sources, the writer has found that a considerable simplication in description of the data can be obtained by plotting the data against log-log scales in the tradition mentioned above. Since the data do not include measures of precision or accuracy, the latter technique will appear, in effect, as a mode of fitting the data by lines or curves of regression. It is found that simple analytic expressions can be derived inductively from the data so displayed, and since the data is dependent on wind and ocean conditions, analysis of relations between these factors appears possible by the technique suggested. Again, the expressions are only as accurate as the data from which they were derived.

Relations between scattering cross section, angle of incidence, wavelength of incident radiation, and wind velocity can be derived in the manner described.

ASSUMPTIONS

The following discussion relates only to radar return from the ocean surface.

Several alterations were made in the usual method of representing scatterometer data; these were made to conform the more customary physical kind of approach emphasized above.

1. The scattering cross section per unit area N of the ocean's surface was used, rather than the derived quantity σ_0 measured in decibels. The latter quantities are related by

$$\sigma_0 = 10 \log_{10} N \tag{1}$$

   A major reason for using N rather than σ_0 lies in the fact that relation (1) implies a distortion of the scale of the cross section when N is less than unity, and hence may lead to incorrect interpretation of the physical character of the ocean surface.

2. To a first approximation, as suggested by Beckman and Spizzichino (reference 4) and by Spetner and Katz (reference 5), we assume that the scattering cross section for radar return from the ocean surface is a function of the radiation's angle of incidence θ through the function $\tan\theta$ alone. Reference 5 arrives at the latter conclusion by assuming that wave facets specularly reflect energy back to the receiver.

3. In order to expose any dependence of N on a power of the argument $\tan\theta$, the experimental data for N versus $\tan\theta$ are plotted on logarithmic scales.

The value of the assumptions will depend on the simplicity and fruitfulness of the conclusions derived from them.

RESULTS

By replotting two typical curves from Figure 18.4, p. 406, reference 4, we obtain Figure 1. It is seen that two straight line segments are obtained; for each such segment

$$N \propto (\tan \beta_0/\tan \theta)^m \tag{2}$$

($m > 0$ and $\tan \beta_0$ is a mean ocean wave slope). The validity of the straight line approximation for one of the segments over more than three decades of variation in N (for θ between approximately 15° and 45°) testifies to the remarkable persistence of the dependence (2) for fixed m and σ_0. Indeed, the linear relation is independent of any choice of $\tan \beta_0$; for simplicity we would write, for example

$$N \propto (1/\tan \theta)^m \tag{3}$$

Once having obtained the hoped-for linear relation, this property of the data can be utilized in a variety of ways:

1. Each straight line segment illustrates a dependence on θ through the function $\tan \theta$ alone. Hence the manner in which radar energy is reflected back to the receiver, assumed by Spetner and Katz (assumption 2 above), gains credibility.

2. Attention is focused on features of the straight lines such as slopes and intercepts; indeed we can readily use the straight line law (insofar as it is found to continue to be valid) for data smoothing and rejection.

3. The sharp change in straight line behavior at the angles shown indicates a similar rapid change in the reflectivity properties of the ocean surface for these angles.

4. We need no prior knowledge of the structure of the ocean surface to pursue this mode of analysis.

5. Another implication of Figure 1 for other theories is a contradiction to a deduction of Beckman and Spizzichino (reference 4, p. 405, formula 9). The text asserts that

$$N \propto e^{-(\tan \theta / \tan \beta_0)^2} \tag{4}$$

or (in decibels)

$$\sigma_0 \propto -(\tan \theta / \tan \beta_0)^2 \log_{10} e \tag{5}$$

provided that the population of ocean wave slopes is represented by a Gaussian distribution. But relation (4) contradicts relation (2), since (2) implies that

$$N \propto (1/\tan \theta)^m \tag{6}$$

or (in decibels)

$$\sigma_0 \propto -m \log_{10} \tan \theta \tag{7}$$

Thus, we deduce from experimental evidence exhibited in the manner suggested herein that the population of the ocean wave slopes is not described by a Gaussian distribution over a range of angles from about 10° to 70°. The directness of this analysis is an argument for its adoption.

The validity of relations (2) and (3) is verified by data derived from other experimenters, although it is found that the exponent m may depend on the wavelength of the radiation. For example, in Figure 2 (reference 6) we display the variation with wavelength of the scattered radiation's energy (vertically polarized in both transmission and reception). There is a remarkable constancy of slopes in the straight line segments exhibited for small angles of incidence (about 10° to about 30°), but the slopes ($-m$) of the line segments vary monotonically in a well-defined manner with wavelength between 30° and 85°. The latter variation is indicated in Figure 3. Since no limits for the precision of the measurements were given in the reports consulted, the curve was interpolated midway between points to indicate the average trend. An independent verification of at least one point on the curve in Figure 3 is obtained from the averaged curve of N versus tan θ derived from observations of sea clutter at 13.3 GHz for vertically polarized radiation made by the National Aeronautics and Space Administration (Manned Spacecraft Center, Houston). The slope of a corresponding line segment agrees with the prediction of the curve in Figure 3.

The behavior of the scattering cross section N for horizontally polarized and received radiation is radically different than for vertically polarized radiation, but the fundamental feature of the straight line variation pointed out above remains (Figure 4).

The effect of wind speed variation is indicated in Figure 5 (reference 7). It is seen that the straight line remains a reasonable approximation for the variation of N with tan θ for 8 to 12 knot winds, as well as for 46 to 48 knot winds. In the latter case, for a smaller percent variation in wind speed, the points adhere more closely to the straight line than for the former case. It appears that variation in wind speed leads to a displacement of the straight lines parallel to the abscissa in the representation adopted. This feature agrees with an asserted dependence of the scattering cross section N upon a power of the wind speed (reference 4, p. 413).

CONCLUSIONS

1. The persistence of the function dependence [relation (2) or (3)] argues a similar persistence of the physical mechanism causing it, and resultant simplicity of any physical model corresponding to the mechanism.

2. That the linear behavior of the plotted data is preserved for both vertically and horizontally polarized radiation suggests that the physical mechanism is similar in both cases.

3. The ability of the analysis described earlier to deliver useful results without prior knowledge of the nature of the ocean surface (e.g., as in the approximate analyses reported in reference 8, depending on various hypotheses about the ocean surface) suggests its usefulness.

5. Variation in wind speed (other factors remaining unchanged) is reflected in a translation of the linear graphs parallel to one another and to the abscissa on which tan θ is plotted.

5. Theories based on electromagnetic field theory and an assumed structure for the ocean surface must agree with the empirical relations derived wherever the latter are valid.

SUMMARY

We have shown (in accord with historical precedent in the development of physical theory) how the introduction of suitable alterations in the scale of plots of experimental values of radar sea clutter cross section versus angle of incidence can result in simplified linear representation of the data. In turn, the latter results suggest a similar simplicity in analysis of the physical mechanism leading to the observed sea clutter return. A variety of conclusions are drawn which indicate the usefulness of the approach and the value of further investigations using this technique.

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