Impact of a New Formula on the Fresnel Reflectance on Microwave Remote Sensing

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Abstract: In microwave remote sensing, the Fresnel reflectance formula is widely used in the sea surface emissivity modeling. As an essential contribution to microwave remote sensing, a new formula on the Fresnel reflectance has been derived based on our understanding of the complex index of refraction and continuity condition of E-M waves at the interface between two mediums. The proposed formula can be used to obtain the emissivity of sea surface, which is useful to retrieve sea surface temperature, sea surface salinity and the brightness temperature. Considering Bragg-resonant scatter, it is useful for the calculation of the normalized radar cross-section, and the retrieval of sea surface wind either.

Keywords: Fresnel Reflectance, Complex Index of Refraction, Microwave Remote Sensing

1. Introduction

In ocean remote sensing, the Fresnel reflectance is required for retrieving the sea surface temperature, salinity, wind speed, and so on[1,2].

At the interface between two mediums, the Fresnel reflectance ρ is defined by

$$\rho = \left|\frac{E_i}{E_r}\right|^2. \tag{1}$$

where E_i and E_r denote the amplitude of incident electric-field intensity and that of reflective one, respectively.

ρ is a function of temperature, salinity, frequency and complex index of refraction (which is described as $n=n'-jn''$). The imaginary component (n'') of the complex index of refraction is completely based upon the attenuation of electro-magnetic (E-M) waves propagating in a medium, but is unconcerned with the phase of E-M waves. In visible light and infrared bands, the attenuation is so little that n'' is negligible; thus the commonly used Fresnel reflectance formula is correct for use in the sea surface emissivity modeling of visible light and infrared bands. For microwave, the attenuation becomes more significant, so n'' cannot be neglected any more. However, the previous investigators have used the Fresnel reflectance formula in the modeling of microwave remote sensing without any correction of it. These investigators confused the physical meaning of n'' in their derivations. Thus, based on our understanding of it and continuity condition of E-M waves at the interface between two mediums, we derived a new formula.

2. The Fresnel Reflectance Formula

1) The Continuity Condition of E-M Waves and the Snell Refraction Law

When the E-M waves arrive the interface of two different mediums, there exists a condition of continuity. The continuity condition of electric-field intensity **E** on both sides of the interface is described as: The sum of tangent components of the electric-field intensity of incident waves and reflective waves, i.e., $\mathbf{E_i}$ and $\mathbf{E_r}$, is equal to that of refractive ones, $\mathbf{E_t}$. The magnetic-field intensity **H** has the same character. The continuity condition concludes two aspects: the continuity of the amplitude, and the continuity of the phase.

From the continuity of the amplitude, we can derive the commonly used Fresnel formula which are described as

$$\begin{cases} \left(\dfrac{E_{0r}}{E_{0i}}\right)_H = \dfrac{\dfrac{n_1}{\mu_{r1}}\cos\theta_i - \dfrac{n_2}{\mu_{r2}}\cos\theta_t}{\dfrac{n_1}{\mu_{r1}}\cos\theta_i + \dfrac{n_2}{\mu_{r2}}\cos\theta_t} \\ \left(\dfrac{E_{0r}}{E_{0i}}\right)_V = \dfrac{-\dfrac{n_2}{\mu_{r2}}\cos\theta_i + \dfrac{n_1}{\mu_{r1}}\cos\theta_t}{\dfrac{n_2}{\mu_{r2}}\cos\theta_i + \dfrac{n_1}{\mu_{r1}}\cos\theta_t} \end{cases}. \tag{2}$$

where subscript H and V denote horizontal and vertical polarization, respectively; subscript i and r denote incident and reflective waves, respectively; θ_i and θ_t are incidence angle and refractance angle, respectively; μ_{r1} and μ_{r2} are the relative permeabilities of medium 1 and medium 2, respectively; n_1 and n_2 are the complex indexes of refraction of medium 1 and medium 2, respectively.

From the continuity of the phase, the Snell refraction law was derived. It is described as

$$\frac{\sin\theta_t}{\sin\theta_i}=\frac{n_1'}{n_2'}\,. \tag{3}$$

where n_1' and n_2' are real components of complex index of refraction of medium 1 and medium 2, respectively.

However, authors of the literature[2~5] described the Snell refraction law as

$$\frac{\sin\theta_t}{\sin\theta_i}=\frac{n_1}{n_2}\,. \tag{4}$$

In visible light and infrared bands, the attenuation is so little that n'' is negligible, and Eq. (4) is correct. But for microwave, the attenuation becomes more significant, and n'' cannot be neglected. The investigators ignored the attenuation of E-M waves, and confused the concepts of the amplitude and the phase when applying to the continuity condition. So in this case, the Snell refraction law given by them is not correct any more.

2) The Fresnel Reflectance Formula

According to Eqs. (1), (2) and (3), the new formula on the Fresnel reflectance ρ is

$$\rho_{H1}=\left|\frac{\cos\theta_i-\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\left(\frac{n_2}{n_1}\frac{n_1'}{n_2'}\right)^2\sin^2\theta_i}}{\cos\theta_i+\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\left(\frac{n_2}{n_1}\frac{n_1'}{n_2'}\right)^2\sin^2\theta_i}}\right|^2\,. \tag{5}$$

$$\rho_{V1}=\left|\frac{(\varepsilon_{r2}/\varepsilon_{r1})\cos\theta_i-\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\left(\frac{n_2}{n_1}\frac{n_1'}{n_2'}\right)^2\sin^2\theta_i}}{(\varepsilon_{r2}/\varepsilon_{r1})\cos\theta_i+\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\left(\frac{n_2}{n_1}\frac{n_1'}{n_2'}\right)^2\sin^2\theta_i}}\right|^2$$

Eq. (4) was used in the literature [2~5], so ρ is described as

$$\rho_{H2}=\left|\frac{\cos\theta_i-\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\sin^2\theta_i}}{\cos\theta_i+\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\sin^2\theta_i}}\right|^2\,. \tag{6}$$

$$\rho_{V2}=\left|\frac{(\varepsilon_{r2}/\varepsilon_{r1})\cos\theta_i-\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\sin^2\theta_i}}{(\varepsilon_{r2}/\varepsilon_{r1})\cos\theta_i+\sqrt{(\varepsilon_{r2}/\varepsilon_{r1})-\sin^2\theta_i}}\right|^2$$

where ε_{r1} and ε_{r2} are the relative dielectric capacitance of medium 1 and medium 2, respectively. Subscript "1" of ρ in Eq. (5) denotes the Fresnel reflectance we have derived, and subscript "2" in Eq. (6) denotes the Fresnel reflectance in the literature[2~5].

3) Comparisons

What the paper concerns is the application of the Fresnel reflectance in ocean remote sensing. Hence we only study the cases where the two mediums are the air and sea water, respectively.

a) The E-M waves propagating from the air (the medium sparse for E-M waves), to the sea water (the medium dense for E-M waves)

For visible light and infrared radiation propagating in the air, we have $n_1\approx1$, $\varepsilon_{r1}\approx1$, $n_2''<<n_2'$, and n_2'' is approximatively equal to 0 which can be neglected. Thus $(n_2n_1'/n_1n_2')^2\approx1$. Therefore the results calculated from Eqs. (5) and (6) are equal in numerical values, and we can consider them equivalent.

For microwave, the range of frequency is from 0.3GHz to 300GHz. Study shows that the difference between Eqs. (5) and (6) becomes more significant with increase of the incidence angle. However, this difference is very small. Although the difference is not very large, what must be emphasized is that Eq. (6) is not correct.

b) The E-M waves propagating from the sea water to the air

Fig.1 shows the difference between Eqs. (5) and (6) on the Fresnel reflectance ρ with sea surface temperature of 20 ℃, the salinity of 35‰, and the frequency of 39GHz.The word "new" denotes ρ calculated from Eq. (5). The word "old" denotes ρ calculated from Eq. (6).

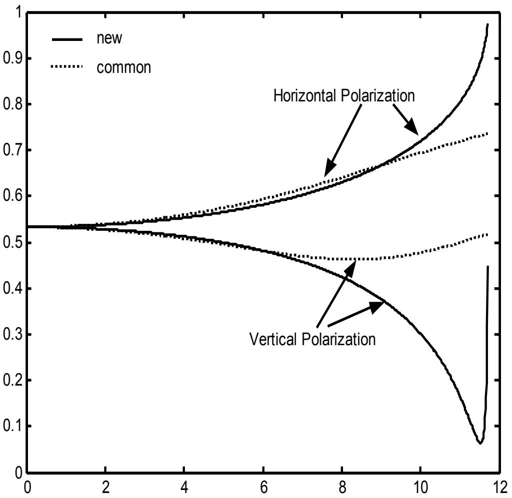

Fig.1. The Fresnel Reflectance versus the Incidence Angle

From Fig.1 we can see that Eq. (5) clearly demonstrates the existence of Brewster's angle θ_B (when $\theta_i=\theta_B$, if $\varepsilon_r''=0$, then $\rho_V=0$; if $\varepsilon_r''\neq0$, ρ_V reaches the minimum value.), while Eq. (6) cannot clearly demonstrate such phenomenon. Fig. 1 is the result of theoretical calculation. It is difficult for the result to be verified in laboratory, because the sea water intensely absorbs microwave.

3. Conclusions

(1) The concepts of the amplitude and phase are seriously confused in previous literature, and the continuities of them aren't differentiated. Accordingly,

the application of continuity condition is not reasonable. Thus, it is not feasible to apply the Eq. (4) directly to the whole E-M waves bands.

(2) For ocean remote sensing within visible light and infrared bands, $n_2'' << n_2'$, and $n_2'' \approx 1$, which makes $(n_2 n_1' / n_1 n_2')^2 \approx 1$. Therefore the Fresnel reflectance calculated from Eqs. (5) and (6) are equal, and we can consider them equivalent. For ocean remote sensing within microwave bands, when the E-M waves propagate from the air to the sea water, there exists difference between Eqs. (5) and (6), and Eq. (6) is not correct. But this difference is not large. When the E-M waves propagate from the sea water to the air, Eq. (6) can't clearly reflect the existence of Brewster's angle (see Fig. 1).

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References

[1] Liu, Y., X-H. Yan, W.T. Liu, and P.A. Hwang, 1997. The probability density function of ocean surface slopes and its effects on radar backscatter. *Journal of Physical Oceanography*, 27: 782-797.

[2] Paul Lorrain, and Dale R. Corson, 1988. Electromagnetic fields and waves. New York, Freeman, pp. 532-551.

[3] Robert G.Reeves, 1975. Manual of Remote Sensing. Falls Church, Va.: American Society of Photogrammetry, pp. 76-81.

[4] Stewart, R.H., 1984. Methods of Satellite Oceanography. University of Califonia Press, pp. 80-94.

[5] Ulaby, Fawwaz T., Richard K. Moore, and Adrian K. Fung, 1986. Microwave Remote Sensing: active and passive. Volume 1, Microwave Remote Sensing Fundamentals and Radiometry. Addison-Wesley Pub.Co., pp. 64-79

[6] Ellison W. et al., 1998. New permittivity measurements of seawater. *Radio Sci.* 33: 639-648.

[7] Liu, Y., M-Y. Su, X-H. Yan, and W.T. Liu, 2000. The mean-square slope of ocean surface waves and its effects on radar backscatter. *Journal of Atmospheric and Oceanic Technology*, 17: 1092-1105.