

Application of Backscattering Models in Active-passive Microwave Remote Sensing of Ocean Salinity

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Abstract— The program of new type combined active and passive L-band sensor will meet the science needs by providing global ocean salinity distribution. Before the reconstruction of ocean salinity by brightness temperature, surface roughness must be taken into account, which is the leading part of the error sources that influences the brightness temperature. So it is a crucial step to eliminate the excess brightness temperature engendered by roughness. The elimination can be implemented by sea surface backscattering coefficient, which is directly influenced by roughness. In this paper, the sea surface is regarded as a two dimensional isotropic random process and the influence of roughness for backscattering coefficient is discussed. This can be a fundamental way to get pairs of brightness temperature and backscattering coefficient and for better inversion of ocean salinity.

1. INTRODUCTION

Ocean salinity is a key parameter to understand the interplay between the Ocean Circulation, Global Water Circle and Climate Change. The conventional way of acquiring salinity depends primarily on site measurement by ship-borne buoys, which impedes our obtainment of spatial and temporal distributions of ocean salinity. For 125 years by far, over 25% data from salinity observations of sea surface have not been acquired; moreover, the observation periods are less than 10 in almost 73 percent range of sea surface [1].

However, with the rapid development of remote sensing technologies, remote sensors can be an effective way of detecting ocean salinity. From the 1990s, some mission concepts have been proposed to measure the sea salinity from space by L band radiometers. This includes ESA's Soil Moisture and Ocean Salinity (SMOS) mission that has been launched at Nov. 2009 and NASA's Aquarius mission that has been launched at Jun. 2011 [2, 3].

In our program, a combined Passive/Active L-band salinometer has been designed [4], in which the radiometer is used to measure the brightness temperature of the ocean surface and the scatterometer is used to measure the backscattering coefficient. Since the sea surface brightness temperature is a function of SSS (Sea Surface Salinity), SST (Sea Surface Temperature) and SSR (Sea Surface Roughness), we can inverse the salinity through brightness temperature; however, the brightness temperature is influenced by various error sources at the same time, the leading part of which is sea surface roughness. Therefore, a crucial step of the inversion of SSS by brightness temperature is to eliminate the excess brightness temperature engendered by sea surface roughness. The elimination can be implemented by the sea surface backscattering coefficient, which is directly influenced by roughness.

In this paper, we show how the roughness can be described as statistical parameters of the ocean surface that is regard as a two dimensional random process with Gaussian distribution and how the backscattering coefficient is directly influenced by the sea surface roughness. This may be a fundamental way for us to build the relationship between excess temperature and backscattering coefficient and thus the inversion of ocean salinity with brightness temperature can be refined.

2. STATISTICAL DESCRIPTION FOR RANDOM SURFACES

2.1. Surface Height Standard Deviation

Suppose the average height of illuminated area S in x - y plane is $\bar{z}$, then the surface height standard deviation is

$$\sigma = \left(\overline{z^2} - \bar{z}^2 \right)^{1/2}$$

where

$$\bar{z} = \frac{1}{S} \iint_S z(x, y) ds \quad \bar{z}^2 = \frac{1}{S} \iint_S z^2(x, y) ds$$

2.2. Surface Correlation Length

Suppose one-dimensional condition, in the length L , the normalized surface correlation function is

$$\rho(\Delta x) = \int_l z(x)z(x + \Delta x)dx \Big/ \int_l z^2(x)dx$$

let $\rho(L) = 1/e$, then L is the correlation length.

2.3. Surface RMS Slope

The surface RMS Slope is short for the surface root mean square slope for a random process. For instance, we suppose a one-dimensional case, where $z(x)$ is a random process with average zero and standard deviation σ , and then the slope of $z(x)$ is

$$Z_x = \lim_{\Delta x \rightarrow 0} \frac{z(x + \Delta x) - z(x)}{\Delta x}$$

The second order moment of the slope is

$$\langle Z_x^2 \rangle = \lim_{\Delta x \rightarrow 0} \left\langle \frac{z^2(x + \Delta x) - 2z(x)z(x + \Delta x) + z^2(x)}{\Delta x^2} \right\rangle$$

That is

$$\langle Z_x^2 \rangle = \lim_{\Delta x \rightarrow 0} \frac{\sigma^2 - 2\sigma^2\rho(\Delta x) + \sigma^2}{\Delta x^2}$$

To find the limitation, expand $\rho(\Delta x)$ at $\Delta x = 0$, in Taylor series, upon letting $\Delta x \rightarrow 0$, we obtain the variance of the slope, which is

$$\langle Z_x^2 \rangle = \lim_{\Delta x \rightarrow 0} \frac{1 - [1 + \rho''(0)\Delta x^2/2 + \dots]}{\Delta x^2} = -\sigma^2\rho''(0)$$

Then the surface RMS slope is defined as

$$\sigma_s = \langle Z_x^2 \rangle^{1/2} = [-\sigma^2\rho''(0)]^{1/2}$$

2.4. Surface Spectrum

The surface spectrum is the two dimensional Fourier transforms of the surface correlation coefficient $\rho(x, y)$, which is:

$$W(k_x, k_y) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \rho(x, y) e^{-jk_x x - k_y y} dx dy$$

For polar coordinates:

$$W(\kappa, \varphi) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \rho(r, \phi) e^{-j\kappa r \cos(\varphi - \phi)} r dr d\phi$$

where $\kappa = \sqrt{k_x^2 + k_y^2}$, $\cos \varphi = k_x/\kappa$, $\sin \varphi = k_y/\kappa$.

3. BACKSCATTERING FROM SEA SURFACES

3.1. Backscattering Models

The scattering coefficient of an extended target in a given direction is the ratio of the total scattered power from an equivalent isotropic scatter which generates the same scattered power density in the direction to the total incident power on the illuminated area. Mathematically, the scattered coefficient can be written as [5]:

$$\sigma_{pq}^0 = \frac{4\pi R^2 \text{Re} \left\{ \left\langle |\vec{E}_{pq}^s|^2 \right\rangle / \eta_s^* \right\}}{A_0 \text{Re} \left\{ |E_0|^2 / \eta^* \right\}}$$

The two most commonly used models for random surface scattering are Kirchhoff Approximation (KA) and Small Perturbation Model (SPM). The KA is assumed that the total field at any point on the surface can be computed as if the incident wave is impinging upon an infinite plane tangent to the point. It turned out that the surface correlation length and the curvature radius must greater than a wave length. Mathematically, that is:

$$kl > 6 \quad l^2 > 2.76\sigma\lambda$$

Here k is the wave number, σ is surface height standard deviation and l is surface correlation length. After this assumption, it is still hard to obtain the analytic results; therefore there are two simplifications: Stationary Phase Approximation of incoherent scattering for large surface height standard deviation; and Scalar Approximation with Surface RMS Slope less than 0.25 for small surface height standard deviation, which includes both coherent and incoherent scattering. In the condition when both the surface standard deviation and correlation length are smaller than the wave length, KA is not valid.

SPM is assumed that the scattered field can be represented by the superposition of the plane waves with unknown amplitudes propagating away from the interface. The unknown amplitudes can be calculated by boundary conditions. In the calculations, the unknown field amplitudes are expanded in a perturbation series and taken a first-order approximation. In fact, the first order approximation is exactly the mirror reflecting contribution from the target points, which is the mechanism of Bragg Resonance. Therefore, SPM requires the surface standard deviation to be less than about 5 percent of the electromagnetic wave length. Mathematically, that is:

$$k\sigma < 0.3 \quad \sigma/l < 0.3 \quad k^3\sigma^2l \ll 1$$

It can be summarized that KA is high frequency approximation while SPM is low frequency approximation in solving the scattered field. Since L band is used in the ocean surface detection, we next turn our attention on SPM. Mathematically, the backscattering coefficient of SPM can be written as [5]:

$$\sigma_{pq}^r = 4k^4\sigma^2 \cos^4\theta |\alpha_{pq}|^2 W(2k \sin\theta, 0) \Big/ \pi$$

where

$$\begin{aligned} \alpha_{hh} &= R_{\perp} \\ \alpha_{vv} &= (\varepsilon_r - 1) \frac{\sin^2\theta - \varepsilon_r (1 + \sin^2\theta)}{\left[\varepsilon_r \cos\theta + \sqrt{\varepsilon_r - \sin^2\theta} \right]^2} \end{aligned}$$

This form is assumed that the random surface is isotropic in horizontal direction with Gaussian height distribution. Then the random process becomes one dimensional and for different correlation functions the surface spectra would be different. For example, the surface spectrum of Gaussian correlation function is $W(2k \sin\theta, 0) = \pi L^2 \exp[-(kL \sin\theta)^2]$. The cross polarization omitted here would be zero if only first-order approximation is considered while that would be a complex integral if we carry out to second order.

3.2. Performance of Statistical Parameters of Sea Surface

The ocean surface fluctuates when wind blows and the roughness may change. The change of surface roughness is equivalent to the variation of the surface standard deviation, surface correlation length, surface spectrum and other statistic descriptions. Then we analyzed the variation of backscattering coefficient with these parameters.

For Figure 1, we use SPM model with Gaussian distribution and Gaussian correlation function. The correlation length is 5 cm; the dielectric constant is calculated by the method of Ulaby [6] at $f = 1.4$ GHz, $T = 20^\circ\text{C}$ and $S = 30$ psu, which is $73.07 + j59.03$. We can see that the backscattering coefficients for both VV and HH polarization increases with the surface standard deviation. This is because with the increase of surface height standard deviation, it is prone to incoherent scattering and there is a higher possibility of backscattering.

For Figure 2, note that the backscattering coefficient increases with correlation length until the angle reaches about 40 degree and then decreases with the correlation length. This is because when correlation length is large, it is dominated by coherent scattering which is greatly influenced by the incident angle; when the correlation is short, the scattering is dominated by incoherent scattering which is not as sensitive as it is before.

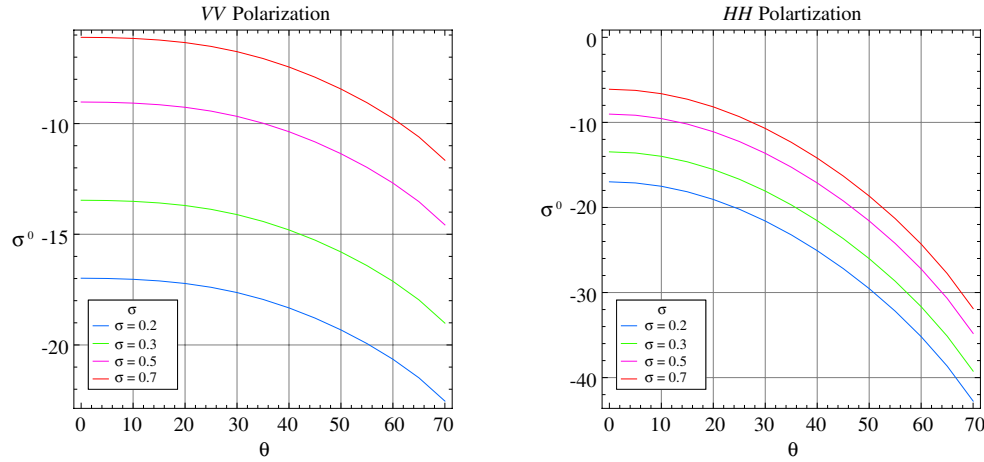


Figure 1: $L = 5$ cm, $SSS = 30$ psu at a frequency of 1.4 GHz with Gaussian correlation function.

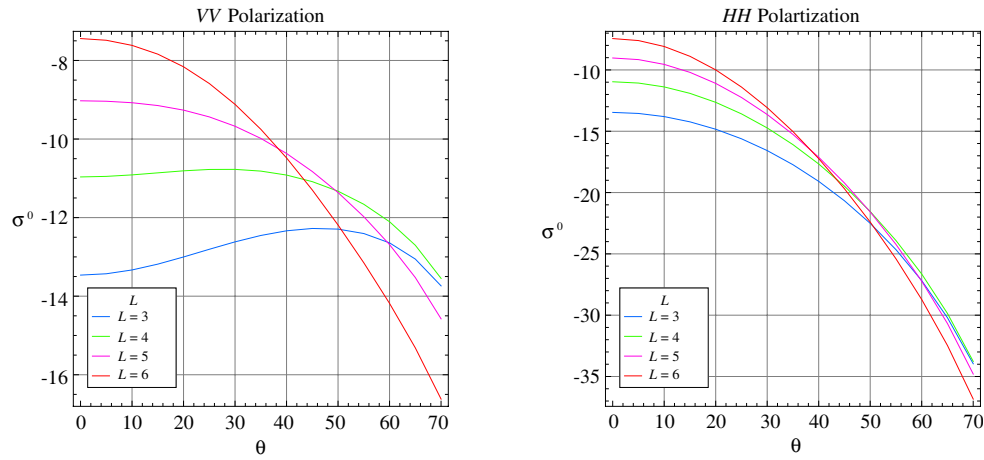


Figure 2: $\sigma = 0.25$ cm, $SSS = 30$ psu at a frequency of 1.4 GHz with Gaussian correlation function.

4. CONCLUSION

The inversion of ocean salinity by brightness temperature is impaired by the error engendered by surface roughness. The error can be eliminated by the backscattering coefficient, which is directly influenced by surface roughness. In this paper, we regard the ocean surface as an isotropic two dimensional random process and discussed the performance of backscattering coefficient with different statistical parameters which represents roughness. This can be a fundamental way for further study of building the relationship between brightness temperature and backscattering coefficient and refine the inversion of ocean salinity.

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