

Effects of Ocean Wind, Foam/Spray and Atmosphere on Four Stokes Parameters in Passive Polarimetric Remote Sensing of the Ocean Based on Numerical Simulations and Analytic Theory

Leung Tsang, Vikram Jandhyala, Lin Zhou and Chi-te Chen
Department of Electrical Engineering
Box 352500, University of Washington
Seattle, WA 98195

Phone: (206) 685-7537 fax: (206) 543-3842 email: tsang@ee.washington.edu

Award Number: N00014-99-1-0190

ABSTRACT

The research last year consisted of three parts:

- A. Emission, absorption and scattering by foam;
- B. Polarimetric passive microwave remote sensing of foam covered ocean;
- C. Brightness temperature of ocean with wind based on paralleled code of SMCG and PBTG.

A: EMISSION, ABSORPTION AND SCATTERING BY FOAM

Emissivities of ocean surfaces are affected by the presence of foam. Recently, field experiments have been conducted to study the foam emissivity as a function of polarization, observation angle and frequencies between 10 GHz to 37 GHz. The measurements exhibit interesting frequency dependence. The results are not explained by simple mixing formulae nor past empirical models. In particular, the emissivities at 10 GHz are observed to be higher than or comparable to that of 37 GHz. Foam is a mixture of air bubbles and sea water. The bubbles range from sizes of hundreds of microns to millimeters. We conduct theoretical modeling based on modeling the microstructure of foam taking into account bubble size and fractional volume of water to rigorously study the emission, absorption and scattering properties and to account for the observed frequency dependence and polarimetric dependence of emissivities. In a previous paper, we used the model of air bubbles coated with a water layer. The absorption and emission are calculated by using the dense media radiative transfer theory to account for the observed emissivities. Recently, to study the effect of foam, we used Monte Carlo simulations of exact solutions of Maxwell equations. In the Monte Carlo simulations, we calculated the stochastic Green's function. We model foam as densely packed non-absorptive particles (air bubbles) in an absorptive background (sea water). Maxwell equations are put in the form of dipole interactions. Up to one or two thousand bubbles are used in the simulations. We use the Monte Carlo simulations to calculate the absorption coefficient, effective permittivity, scattering rate and phase matrix. We then use Monte Carlo simulations to calculate the absorption rate and effective propagation constant. After solving the absorption and effective propagation constant, we can further calculate the emissivities from the medium and compare with the measurements.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 30 SEP 2001		2. REPORT TYPE		3. DATES COVERED 00-00-2001 to 00-00-2001	
4. TITLE AND SUBTITLE Effects of Ocean Wind, Foam/Spray and Atmosphere on Four Stokes Parameters in Passive Polarimetric Remote Sensing of the Ocean Based on Numerical Simulations and Analytic Theory				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Electrical Engineering,,Box 352500, University of Washington,,Seattle,,WA, 98195				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

B: POLARIMETRIC PASSIVE MICROWAVE REMOTE SENSING OF OCEAN WIND VECTORS WITH FOAM-COVERED ROUGHENED OCEAN SURFACE

In the past, we succeeded in formulating an electromagnetic scattering model of foam by treating the foam as densely packed sticky air bubbles coated with a thin seawater coating. We apply electromagnetic scattering theory and dense media radiative transfer theory to analyze the effects of foam on the passive microwave remote sensing [3].

In this work, we further investigate the polarimetric passive remote sensing of wind-generated sea surfaces combined with foam. The second-order small perturbation method (SPM) is applied to the Stokes vectors of thermal emission from foam and random rough dielectric surfaces described by anisotropic directional spectra.

Consider thermal emission from a layered medium with coated dielectric particles embedded in a background medium, as indicated in Fig.1. The layer consisting of coated particles (in region 1) covers an ocean (region 2). Between region 1 and region 2 is the small-scale sea surface described by an empirical sea surface spectrum proposed by Durden and Vesecky. In solving the radiative transfer equations [1, 2], the iterative approach is convenient for the case of small albedo or small layer thickness. It can give physical insight into the multiple scattering processes since there is a one-to-one correspondence between the iterative order and the order of multiple scattering. The final results of 4 Stokes parameters and comparisons with experiments will be presented soon.

C: BRIGHTNESS TEMPERATURE OF OCEAN WITH WIND BASED ON PARALLEL CODE OF SMCG & PBTG

With recent advances in computational electromagnetics and available computer resources, we calculate 3-dimensional Maxwell equation solutions with 2-D rough surfaces for practical remote sensing applications. Highlights of our numerical approach are: (i) The sparse-matrix canonical grid method (SMCG) and the physics-based two-grid method (PBTG) are used. (ii) An algorithm has been implemented for parallel computing. We use a Beowulf cluster that consists of 32 processors connected by a 100 Base TX Ethernet switch. The workloads of computing the sparse-matrix-vector multiplication corresponding to the near interactions and the fast Fourier transform (FFT) operations corresponding to the far field interactions in MOM can be easily distributed among all the processors. (iii) Dense discretization of the surfaces is used because of high permittivity and an energy conservation check is verified.

The results for ocean surfaces at 19 GHz are presented [4]. All results are based on the energy conservation check, which gives acceptable values of energy conservation errors. They are shown in Table I and Table II, which are calculated by parallel computing. 1024 points/ λ^2 of discretization of surface in simulation is used in Table I, and 4096 points/ λ^2 of discretization is used in Table II.

TABLES AND FIGURES

Table I. Emissivity and brightness temperature with various values of k_U , for 3-D ocean scattering problem. $k_L = 100$ rads/m, surface area $64 \lambda^2$, 1024 points/ λ^2 for dense grid.

Polar.	k_U (rads/m)	emission	Energy cons.	Emission of flat surface	T_B (K)	ΔT_B (rough-flat surface)
TE	400	0.30667	0.99763	0.28728	86.79	5.49
TE	1000	0.31120	0.99813	0.28728	88.07	6.77
TE	4000	0.31230	0.99887	0.28728	88.38	7.08
TM	400	0.54289	0.99997	0.55927	153.64	-4.63
TM	1000	0.54469	1.0025	0.55927	154.15	-4.12
TM	4000	0.54303	1.00078	0.55927	153.67	-4.60

Table II. Emissivity and brightness temperature with various values of k_U , for 3-D ocean scattering problem. $k_L = 100$ rads/m, surface area $64 \lambda^2$, 4096 points/ λ^2 for dense grid.

Polar.	k_U (rads/m)	emission	Energy cons.	Emission of flat surface	T_B (K)	ΔT_B (rough-flat surface)
TE	400	0.29788	1.00140	0.28728	84.30	3.00
TE	1000	0.29844	0.99792	0.28728	84.46	3.16
TE	4000	0.29645	0.99740	0.28728	83.90	2.60
TM	400	0.56973	1.00230	0.55927	161.23	2.96
TM	1000	0.55058	0.99970	0.55927	155.81	-2.46
TM	4000	0.53216	0.99740	0.55927	150.60	-7.67

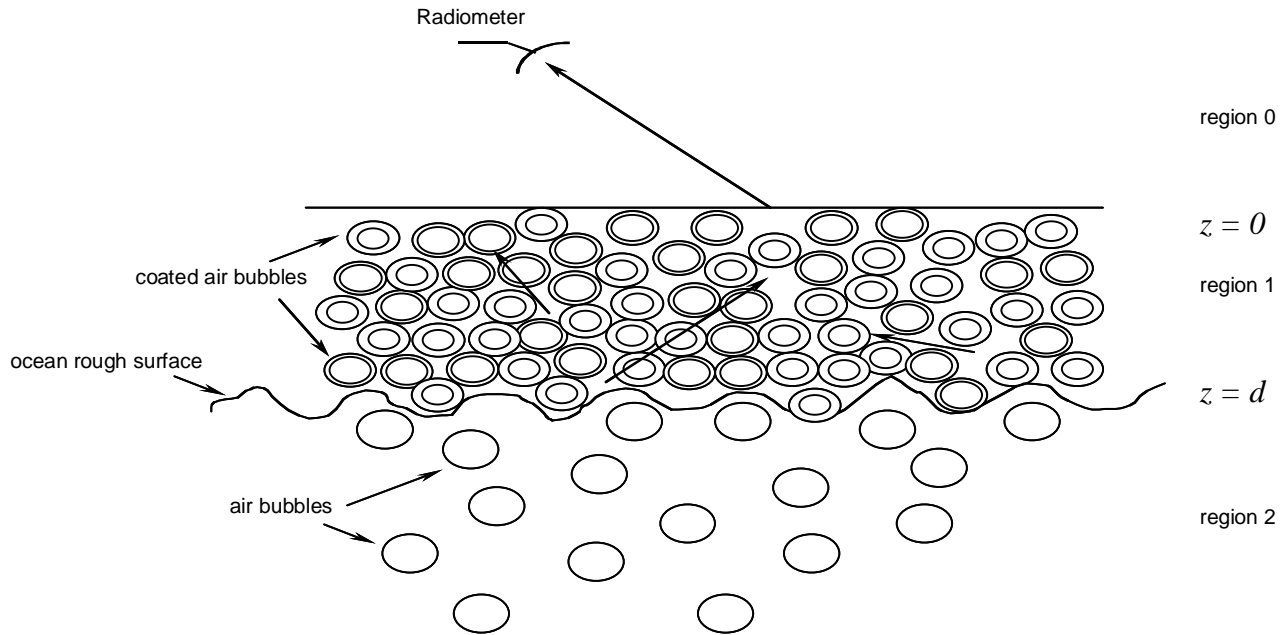


Fig. 1. Geometrical configuration for thermal emission from a foam-covered ocean rough surface.

REFERENCES

- [1] L. Tsang, J.A. Kong, and K.H. Ding, *Scattering of Electromagnetic Waves: Theories and Applications*, Wiley-Interscience, vol.1, New York, 2000.
- [2] L. Tsang, J.A. Kong, *Scattering of Electromagnetic Waves: Advanced Topics*, Wiley-Interscience, vol.3, New York, 2001.
- [3] J. Guo, L. Tsang, *Fellow, IEEE*, W. Asher, K.H. Ding, and C.T. Chen, "Applications of Dense Media Radiative Transfer Theory for Passive Microwave Remote Sensing of Foam Covered Ocean," *IEEE Trans. on Geoscience and Remote Sensing*, Vol.39, No.5, May 2001.
- [4] L. Zhou, Q. Li, L. Tsang, *Fellow, IEEE*, J. Shi, V. Jandhyala, K.S. Chen, S.Q. Li, and C.H. Chan, "Emissivities and Back-scattering Coefficients of Random Lossy Dielectric Rough Surfaces at Microwave Frequencies Based on 3-Dimensional Numerical Simulations," *Proceedings of IGARSS' 2001*, July, 2001.