FOAM EMISSIVITY MODELS FOR MICROWAVE OBSERVATIONS OF OCEANS FROM SPACE

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Increasing demands for accuracy in satellite-based geophysical retrievals of environmental variables from passive radiometric measurements at frequencies from 1 to 37 GHz necessitates forward geophysical models capable of adequate accounting for the foam effect [1], [2]. In addition, the direct and indirect involvement of whitecaps in numerous air-sea interaction and climate processes justifies work on parameterizing the high variability of whitecap coverage [3]. As a result there is a rekindled interest in measuring [4] and modeling [5] the microwave emissivity of sea foam.

While sea foam can be defined broadly to include bubble plumes in the water, foam layers at the surface, and, in some cases, sea spray suspended closely above, the skin depth at microwave frequencies narrows the remote sensing investigations of the sea foam to its surface expression. Surface layer foam has a specific mechanical structure [6] comprising densely packed bubbles whose dimensions gradually change within the layer depth. Large, thin-walled bubbles in the upper part of the foam layer contain little seawater and form dry foam. As the bubbles become smaller and thick-walled in depth, air content decreases making the foam wet. Direct consequence of this vertical stratification of the foam structure is that all foam characteristics acquire a wide range of values.

Modeling the foam vertical stratification calls for the use of a vertical profile for the mechanical and dielectric properties of the sea foam, such as of the foam void fraction (defined as the fraction of a unit volume of seawater that is occupied by air) and foam complex dielectric constant. For the foam void fraction, a continuous profile should be preferred compared to constant or layered model. For the foam dielectric constant, scattering and dipole interaction between densely packed bubbles should be considered. The question is how to achieve these two formidable tasks yet keep the model computationally efficient for use in operational retrieval algorithms or for processing large data sets.

In this study we evaluate two models which address the specifics of a vertically structured foam layer comprising densely packed bubbles in different ways.

The macroscopic foam-spray model [7] represents the sea foam as a multilayer dielectric structure by applying an iterative numerical method, which is based on consecutive calculations of the complex Fresnel reflection coefficients. The continuous foam dielectric profile is approximated with a large number of elementary layers (n), each characterized with a specific complex dielectric constant and thickness $\{\varepsilon_n, h_n\}$. For regions of dry and wet foam, the effective complex dielectric constant is calculated with the Maxwell Garnett and the modified Lorentz-Lorenz formula, respectively. Using the latter, model [7] accounts for the scattering and absorption within the foam layer.

The radiative transfer model (RTM) [8] uses a continuous void fraction profile to represent the foam vertically and accounts for various contributions to sea foam emissivity by applying the so-called incoherent approach [6], which is suitable for weakly scattering medium. The effective complex dielectric constant of the sea foam is calculated with the Refractive (quadratic) model [6], which ignores scattering. The rational for the simplification obtained by ignoring the scattering is based on the conclusion that scattering in foam is weak [6].

Running model [7] once without and then with the spray layer included, we had found that spray droplets were generally not important for wind speeds less than 10-12 m/s, depending on incidence angle and frequency. Thus we focus our current investigation on the surface foam layer. We present foam emissivity obtained with these two models as a function of frequency (1 to 100 GHz, H and V polarizations) at several foam layer thicknesses (1 to 10 cm) at water temperature (10 °C), salinity (34 psu) and incidence angle (53°). The results of the two models are compared to experimental [4] and theoretical [5] data. The contributions of various elements of these two models to differences in predicting the foam emissivity are investigated and quantified in terms of absolute bias and percent difference. Specifically, we assess how the results from the two models differ due to choice of the emissivity model (layered medium versus incoherent approach of solving RTM in foam) and including or ignoring of the scattering in foam. We find that the largest differences are due to the choice of emissivity model rather than including or ignoring scattering. For frequencies below 37 GHz, the two models provide comparable results, especially for think foam layers (above 3 cm). For thinner layers (e.g., 1 cm) the two models show significant differences at low frequencies (below 6 GHz). Predictions of the brightness temperature due to foam obtained with the two models are compared to those measured with WindSat sensor in three characteristic regions of the world ocean, namely North Atlantic in winter; North Pacific in spring; and Southern Ocean in summer.

REFERENCES

[1] Bettenhausen, M.H., C.K. Smith, R.M. Bevilacqua, N.-Y. Wang, P.W. Gaiser, and S. Cox, "A nonlinear optimization algorithm for WindSat wind vector retrievals," *IEEE Trans. Geosci. Rem. Sens*., 44, pp. 597-610, Mar. 2006.

[2] Camps, A., et al., "Determination of the sea surface emissivity at L-band and application to SMOS salinity retrieval algorithms: Review of the contributions of the UPC-ICM," *Radio Sci*., 43, RS3008, doi:10.1029/2007RS003728, 2008.

[3] Anguelova, M.D., and F. Webster, "Whitecap coverage from satellite measurements: A first step toward modeling the variability of oceanic whitecaps," *J. Geophys. Res*., 111, C03017, doi:10.1029/2005JC003158, Mar. 2006.

[4] Rose, L. A., W. E. Asher, S. C. Reising, P. W. Gaiser, K. M. St Germain, D. J. Dowgiallo, K. A. Horgan, G. Farquharson, and E. J. Knapp, "Radiometric measurements of the microwave emissivity of foam," *IEEE Trans. Geosci. Remote Sens*., 40, pp. 2619– 2625, Dec. 2002.

[5] Chen, D., L. Tsang, L. Zhou, S.C. Reising, W.E. Asher, L.A. Rose, K.-H. Ding; C.-Te Chen, "Microwave emission and scattering of foam based on Monte Carlo simulations of dense media," *IEEE Trans. Geosci. Rem. Sens*., 41, pp. 782 – 790, Apr. 2003.

[6] Anguelova, M.D., "Complex dielectric constant of sea foam at microwave frequencies," *J. Geophys. Res*., 113, C08001, doi:10.1029/2007JC004212, Aug 2008.

[7] Raizer, V., "Macroscopic Foam–Spray Models for Ocean Microwave Radiometry," *IEEE Trans. Geosci. Rem. Sens*, vol.45, no.10, pp.3138-3144, Oct. 2007.

[8] Anguelova, M.D., M.H. Bettenhausen, and P.W. Gaiser, "Passive remote sensing of sea foam using physically-based modes," *IEEE Proceed. Geosci. Rem. Sens Symp.* (IGARSS'06), 7, pp. 3676–3679, 2006.