# Microwave Remote Sensing Modeling of Ocean Surface Salinity and Winds Using An Empirical Sea Surface Spectrum

Simon H. Yueh
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California, USA
Simon.Yueh@jpl.nasa.gov

*Abstract*— **Active and passive microwave remote sensing techniques have been investigated for the remote sensing of ocean surface wind and salinity. We revised an ocean surface spectrum using the CMOD-5 geophysical model function (GMF) for the European Remote Sensing (ERS) C-band scatterometer and the Ku-band GMF for the NASA SeaWinds scatterometer. The predictions of microwave brightness temperatures from this model agree well with satellite, aircraft and tower-based microwave radiometer data. This suggests that the impact of surface roughness on microwave brightness temperatures and radar scattering coefficients of sea surfaces can be consistently characterized by a roughness spectrum, providing physical basis for using combined active and passive remote sensing techniques for ocean surface wind and salinity remote sensing.**

*Keywords: Sea surface spectrum; microwave radiometer; scatterometer*

## I. INTRODUCTION

Microwave radar and radiometer remote sensing techniques have been routinely applied to the remote sensing of ocean surfaces. Several spaceborne Ku-band (13 GHz) and C-band (5 GHz) scatterometers have been launched to provide global mapping of ocean surface wind velocities. The principle of wind scatterometers is based on the response of microwave radar echoes to wind-generated sea surface roughness. In recent years, the natural microwave emissions from ocean surfaces have also been found to respond to the change of wind speed and direction. The spaceborne multi-frequency (6-37 GHz) polarimetric radiometer on Windsat is operating to demonstrate the feasibility of polarimetric microwave radiometers for global ocean wind measurements.

The other important ocean parameter for climate modeling is the ocean surface salinity. The NASA Aquarius mission, flying an integrated L-band (~1GHz) microwave radar and radiometer, is being implemented for launch in 2008. The Aquarius radiometer will measure the brightness temperatures, which are sensitive to salinity and surface roughness. The purpose of the Aquarius radar channel is to measure the surface roughness for correcting the radiometric brightness temperature. Although there are significant interests on the applications of combined active and passive microwave techniques, there has been a lack of common physical framework for the interpretation of both techniques.

## II. TWO-SCALE SCATTERING MODEL AND SURFACE SPECTRUM

Numerous two-scale sea surface scattering model, have been developed over the years to model the microwave scattering and emission from sea surfaces [1-7]. The improvement in two-scale models has been largely due to the advances in the characterization of sea surface spectrum. The two-scale model has been used to develop a forward radiative transfer model to account for the effects of reflected sky radiation for the wind speed retrieval algorithm using data from 19 and 37 GHz channel radiometers for the Special Sensor Microwave/Imager and to develop the wind speed retrieval algorithm for the Radarsat C-band (5.3 GHz) synthetic aperture radar [3]. However the published sea surface spectra remain inaccurate over a broad range of wind speed and wavenumber, in particular for the L-band microwave frequencies.

We adjusted the sea surface spectrum using the accurate microwave radar backscatter from European Remote Sensing (ERS) and NASA satellite scatterometers and applied the resulting sea surface spectrum to estimate the apparent brightness temperature of sky reflection and surface emissivity. We tested this approach using the CMOD5 geophysical model function (GMF) for the ERS C-band (5.3 GHz) scatterometer and the QSCAT-1 GMF for the NASA SeaWinds scatterometer operating at Ku-band (13.4 GHz). We started with the functional form of the sea surface spectrum proposed by Elfouhaily et al. [5], expressed as an algebraic sum of two terms, including a low wavenumber spectrum ($B_l$) for long gravity waves and a high wavenumber spectrum ($B_h$) for short-gravity and capillary waves. The spectrum parameters include wind speed, direction and wave age. We revised the shape of the spectrum versus wavenumber and wind speed and direction to improve the two-scale model predictions at 5 and 13 GHz frequencies.

The resulting two-scale model predictions using the modified empirical (EM) spectrum in comparison with the CMOD5 GMF are shown in Fig. 1, together with the model

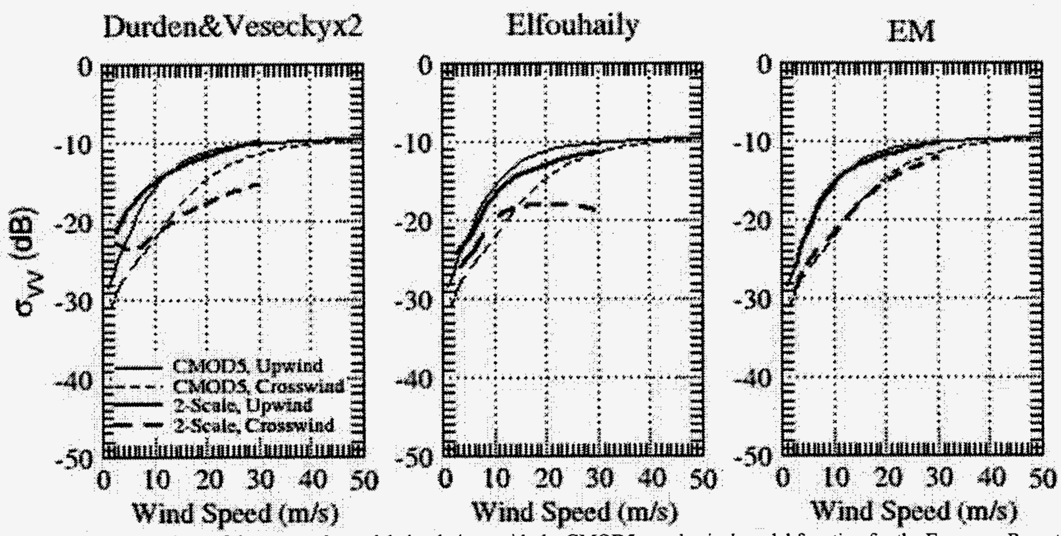

Figure 1. Comparison of the two-scale model simulations with the CMOD5 geophysical model function for the European Remote Sensing Satellite (ERS) scatterometer.

predictions from the Elfouhaily spectrum [5] and the Durden and Vesecky spectrum with a factor of two adjustments [1,2]. The two-scale model using the Durden and Vesecky spectrum with a factor of 2 adjustment (DV2) matches the CMOD5 GMF at 10 m/s wind speed, but overestimates the upwind $\sigma_0$ for lower wind speeds. The crosswind backscatter estimates from the DV2 model are inaccurate except for near 10 m/s wind speed. The 2-scale model estimates using the Elfouhaily spectrum show reasonable agreement with the CMOD5 GMF for upwind observations, but fail to characterize the response of $\sigma_0$ for crosswind direction. Similar conclusions were found from the comparison with the QSCAT-1 GMF at Ku-band frequencies. The deficiencies in the DV2 and Elfouhaily spectra have been essentially corrected near the C- and Ku-band microwave wavenumber for less than 15-20 m/s wind speeds.

We have compared the predictions from the preliminary EM model with the passive microwave measurements at 19 GHz from the JPL WINDRAD measurements [8] and the recent SSM/I analysis [11] regarding the dependence on the wind direction. The wind direction modulations observed from the JPL WINDRAD data agreed well with the theoretical 2-scale model predictions. The results are not included in this paper.

## III. MODEL COMPARISON WITH ACTIVE AND PASSIVE MICROWAVE DATA

We have made a preliminary comparison of the model predictions with the PALS $T_B$-$\sigma 0$ relationship acquired from 2002 flights near Monterey Bay [9]. Using the EM spectrum, we simulated the L-band radar backscatter and emission of sea surfaces over 3 to 21 m/s wind speeds at 2m/s step. Fig. 2 illustrates the simulated vertically polarized brightness temperature Tv against the radar backscatter $\sigma_{HH}$ for horizontally polarized transmit and horizontally polarized receive $\sigma_0$. The model predicts that the L-band ocean Tb increases with increasing radar backscatter for <10 m/s wind speed. The reasonable agreement between the model (black curve) and data supports the approach of using the two-scale model to perform consistent analysis of microwave scattering and emission from sea surfaces.

We have also made a comparison of the model predictions with limited available WISE 2001 data [10]. There was small wind speed dependence in the observed L-band brightness temperatures of sea surfaces. The model predictions agreed reasonably well with the mean characteristics of the data (Fig. 3). However, there was a significant scatter in the data, about 0.5-1K. The scatter could be the result of instrumentation errors, but could be induced by other sea surface parameters, such as the height or slope of long waves [10].

We examined one year of the nominal significant wave heights (SWH) measured by the NDBC buoy 46002 with the calculations using the EM spectrum over a range of parametric amplitudes for long wind-driven waves. The measured SWH data had a rather larger scatter beyond the contributions from the wind-driven EM spectrum. We conducted a preliminary sensitivity analysis on the impact of long waves. A spectral parameter, representing the amplitude of the long wave spectrum (still wind-driven), was changed from 0.002 to 0.005. The resulting change of L-band brightness temperature is about 0.5 to 1 K (Figure 3), which correspond to about 1 to 2 psu error if not corrected for salinity retrieval. The response of model Tb to long wave height seems to cover the scatter of the limited WISE data. It is important to conduct a more detailed analysis to fully explore the geophysical sources responsible for the observed scatter in Fig. 3.

## IV. SUMMARY

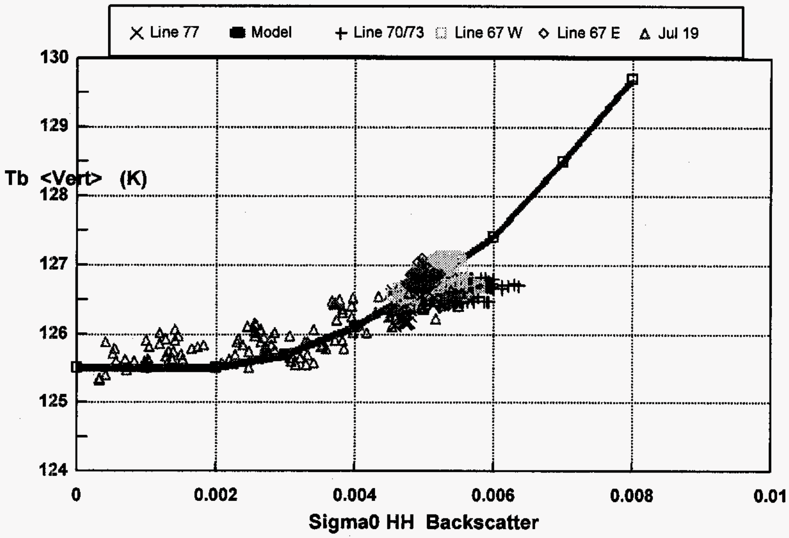


Figure 2. Comparison of the two-scale model simulations using the improved EM spectrum with the PALS L-band radiometer versus radar data. 2-scale model simulations (solid curve). Crosses, squares, pluses, diamonds, and triangles for the PALS data acquired in 2002.

We examined the possibility of using the 2-scale model to provide consistent interpretation of active and passive microwave observations of sea surfaces. The sea surface spectrum required for the 2-scale modeling was tuned using the C-band and Ku-band geophysical model functions from the ERS and NASA SeaWinds scatterometers. The two-scale scattering model with the empirical surface spectrum was used to simulate the polarimetric brightness temperatures at L to Ka-band frequencies. The wind directional modulations of the simulated passive data show good agreement with the measurements acquired by the JPL aircraft polarimetric microwave radiometers. Using the empirical sea surface spectrum expressed in an analytic form, we varied the long wave component of the spectrum to examine the sensitivity of L-band brightness temperature to the height of long waves with wavelength greater than 1m. The results indicate consistency with the brightness temperature model published by the European Soil Moisture Ocean Salinity (SMOS) team. Our analysis suggests that microwave radar and radiometer observations of sea surfaces share a common set of scattering mechanisms. The improved sea surface spectrum derived from the active microwave measurements have potential applications to model and remove the impact of various ocean surface features on ocean brightness temperatures to enable accurate measurements of ocean surface winds and salinity from microwave remote sensing data.

## ACKNOWLEDGMENT

The research carried out in this paper is performed by the Jet Propulsion Laboratory under a contract with the National Aeronautics and Space Administration.

## REFERENCES

[1] Durden, S. L., and J. F. Vesecky, A physical radar cross-section model for a wind-driven sea with swell, IEEE J. Oceanic Eng., Vol. OE-10, No. 4, 445-450, 1985.

[2] Yueh, S. H., Modelling of wind direction signals in polarimetric sea surface brightness temperatures, IEEE Trans. Geosci. Remote Sensing, Vol. 35, No. 6, 1400-1418, 1997.

[3] Wackermann, C. C., P. Clemente-Colon, W. G. Pichel, X. F. Li, "A two-scale model to predict C-band VV and HH normalized radar cross section values over the ocean," Canadian J. Remote Sens., Vol. 28, pp. 367-384, June 2002.

[4] Apel, John, "An improved model of the ocean surface wave vector spectrum and its effects on radar backscatter," J. Geophys. Res., Vol. 99, No. C8, pp. 16,269-16,291, August 15, 1994.

[5] Elfouhaily, T., B. Chapron, K. Katsaros, and D. Vandemark, A unified directional spectrum for long and short wind-driven waves, J. Geophys. Res., Vol. 102, No. C7, 15,781-15796, July 15, 1997.

[6] A. K. Fung, and K. K. Lee, "A semi-empirical sea-spectrum model for scattering coefficient estimation," IEEE J. Oceanic Eng., Vol. OE-7, No. 4, 166-176, 1982.

[7] M. A. Donelan and W. J. Pierson, "Radar scattering and equilibrium ranges in wind-generated waves with applications to scatterometry," J. Geophys. Res., Vol. 92, No. c5, 4971-5029, May 15, 1987.

[8] Yueh, S. H., W. J. Wilson, S. J. Dinardo, F. K. Li, Polarimetric Microwave Brightness Signatures of Ocean Wind Directions, IEEE Trans. Geosci. Remote Sensing, Vol. 37, No. 2, 949-959, 1999.

[9] W. J. Wilson, S. H. Yueh, S. J. Dinardo, S. Chazanoff, A. Kitiyakara, F. K. Li, and Y. Rahmat-Samii, Passive Active L- and S-band (PALS) Microwave Sensor for Ocean Salinity and Soil Moisture Measurements, *IEEE Trans. Geosci. Remote Sensing,* 39, 1039-1048, 2001.

[10] Camps, A., J. Font, M. Vall-lossera, C. Gabarro, I. Corbella, N. Duffo, F. torres, S. Blanch, A. Aquasca, R. Villarino, L. Enrique, J. Miranda, J. Arenas, A. Julia, J. etcheto, V. Caselles, A. Well, J. Boutin, S. Contardo, R. Niclos, R. rivas, S. C. Reising, P. Wursteisen, M. Berger, and M.

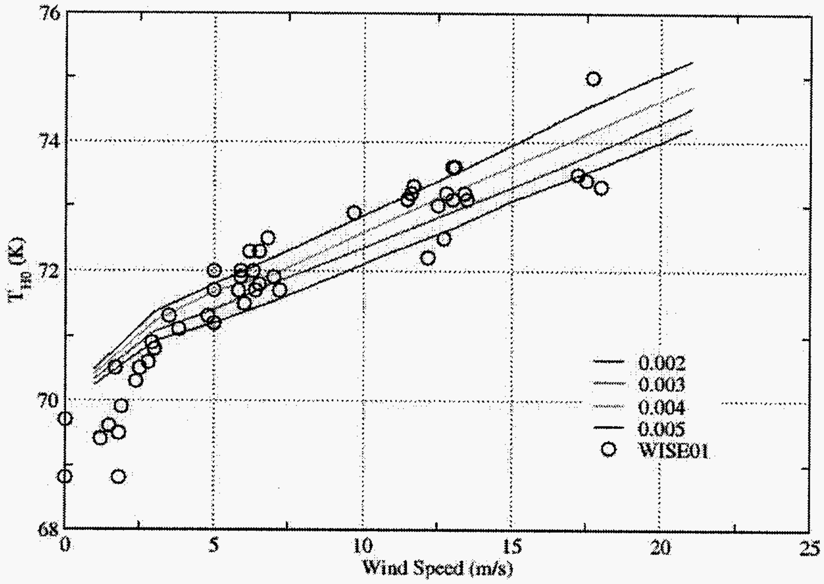


Figure 3. Comparison of the two-scale model simulations using the improved EM spectrum with the WISE01 data. Calculations were performed for four amplitude levels for the low wavenumber spectrum. The significant wave height varies from 2.5 m (legend 0.002) to 3.5 m (legend 0.005) at 10 m/s wind speed.


Martin-Neira, "The WISE 2000 and 2001 Field Experiments in support of the SMOS Mission: Sea Surface L-band Brightness Temperature Observations and their applications to Sea Surface Salinity Retrieval," IEEE Trans. Geosci. Remote Sens., 2004.

[11] T. Meissner and F. Wentz, "An updated analysis of the ocean surface wind direction signal in passive microwave brightness temperatures," IEEE Trans. Geosci. Remote Sens., Vol. 40, No. 6, pp. 1230-1240, 2002.