A Temperature Dependent Correction to the Model for Microwave Excess Emissivity of the Ocean due to Surface Winds

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ABSTRACT

Coincident measurements of ocean surface windspeed, temperature, and microwave emissivity reveal a clear dependence of the slope of the emissivity versus windspeed on the temperature. Water at higher tempertures has a greater increase in emissivity per unit wind speed. This temperature dependence is a residual result of the dependence of the specular ocean surface emissivity on temperature. As the temperature increases, specular microwave emissivity decreases. Since wind roughening and foam increase the emissivity, the increase with respect to the specular baseline is proportionately larger at higher temperatures.

INTRODUCTION

Surface winds raise the microwave emissivity of the ocean above its specular value by modifying the surface slope distribution and, at higher wind speeds, by generating foam. Semi-empirical models for the excess emissivity due to changes in the surface slope have typically relied on a geometric optics analysis of a tilted facet specular surface. The models are semi-empirical by virtue of the manor in which the slope distribution is estimated. Similarly, models for the excess emissivity due to foam typically rely on semi-empirical relations between wind speed and fractional foam coverage . One example of such a model at nadir incidence angle is given by [Wilheit, 1979]

$$\varepsilon_{tot} = \varepsilon_{spec} + 0.0005 \times W \quad \text{@W} \leq 7 \text{ m/s} \qquad (1)$$
$$= \left(\varepsilon_{spec} + 0.0035\right)\left(1 - f_s\right) + f_s \quad \text{@W} > 7 \text{m/s}$$

where ε_{tot} is total emissivity, ε_{spec} is specular emissivity, W is wind speed in m/s and f_s, the effective fractional foam coverage, is given by

$$f_s = a\left(1 - e^{-f/f_0}\right)\left(W - 7\right) \quad \text{@ W} \geq 7 \text{ m/s} \qquad (2)$$
$$f_s = 0 \quad \text{@ W} < 7 \text{ m/s}$$

where a=0.006 s/m, f is the frequency in GHz, f_0=7.5 GHz and W is the wind speed in m/s. Our intent is to independently test the model for excess emissivity by assembling coincident estimates of emissivity and wind speed from radiometer observations.

ASSEMBLY OF COINCIDENT DATA BASE

Data for use in estimating the sea surface emissivity were obtained from the TOPEX satellite. Brightness temperature (TB) at 18, 21, and 37 GHz was directly available from the TOPEX Microwave Radiometer (TMR) and wind speed could be estimated using cross-section data from the radar altimeter.

The data used covers a period from 1 January 1997 to 31 December 1997. The amount of data from this period that remained after filtering was on the order of 50,000 measurements. Data from this time interval was then further filtered to remove conditions that impeded the retrieval of an accurate measure of sea surface emissivity. The first data filtering criteria is based upon quality flags found in the TOPEX Geophysical Data Records. If any of the quality flags were set, the associated instrument measurements were discarded. These flags are set if the TOPEX operational algorithms indicate non-optimal performance. Sea surface temperature was restricted to be greater than 275 Kelvins. This was done to prevent contamination from ice on the surface of the water. The surface temperature, T_s, was estimated from monthly mean ocean temperature data generated from the AVHRR (Advanced Very High Resolution Radiometer) instruments aboard a number of meteorological satellites. The reported wet path delay was chosen be 8 cm or less. Higher path delays lead to greater errors in the estimation of opacity and the correction for atmospheric conditions. Finally, the radar derived wind speed must be less than 30 m/s and the amount of liquid water, as calculated by the TOPEX path delay algorithm, must be zero. One additional constraint was placed on the selected data points. No two consecutive otherwise valid points were allowed to be closer than 400 km along the ground track. This was done to increase the independence of consecutive samples.

In order to derive emissivity from TB, it is necessary to measure or estimate a number of physical parameters. Specifically, we need to know the upwelling brightness, T_u, downwelling brightness, T_d, surface temperature, T_s, and opacity. T_u and T_d are estimated from the surface temperature. Assuming that the surface air temperature is approximately equal to the sea surface temperature, it is possible to use a regression model developed by Wentz [1983]. Opacity was estimated from the TOPEX retrieved wet path delay. For atmospheric conditions that do not have liquid water and have low vapor content it is possible to estimate the atmospheric opacity accurately as a simple quadratic function of path delay. In a similar fashion, surface wind speed was retrieved from the altimeter radar cross section using a polynomial fit to the modified Chelton-Wentz wind speed algorithm [*Witter and Chelton*, 1991].

The relationship between emissivity and TB is given by a simplified version of the equation of radiative transfer

$$T_b = T_u + \varepsilon T_s e^{-\tau} + T_d(1-\varepsilon)e^{-\tau} \qquad (3)$$

Equation (3) can be solved for ε. An example of the resulting coincident data base of ocean surface emissivities and wind speeds in shown in Figure 1. Note the significant shift in the slope of emissivity vs. windspeed with the onset of foaming near 7 m/s.

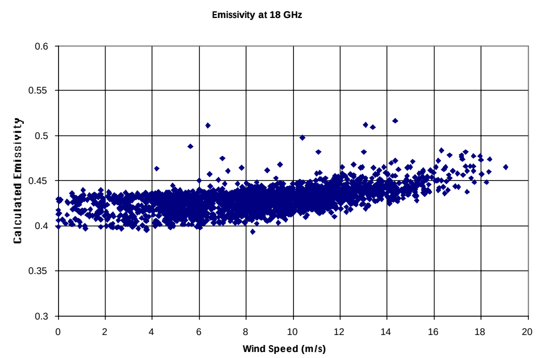

Figure 1. 2500 representative emissivity estimates at 18 GHz as a function of wind speed.

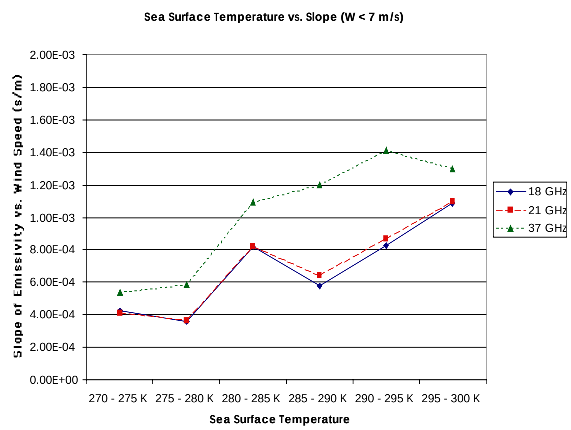

Figure 2. Slope of emissivity vs. wind speed as a function of sea surface temperature for speeds less than 7 m/s.

ANALYSIS OF RESULTS

The slope of emissivity versus windspeed can be estimated from the data base shown in Fig 1. The slope is partitioned into separate regions above and below 7 m/s due to foaming. If the slope is additionally partitioned with respect to the sea surface temperature, the results shown in Figure 2 are produced for W<7m/s. Note that there is a clear dependence of the slope on temperature. This is not predicted by the model given in (1). A similar temperature dependence also occurs for the W>7m/s partition.

The slope's behavior results from the temperature dependence of the ocean's specular emissivity. For the temperature ranges and frequencies considered, the specular emissivity of the ocean drops with increasing temperature. This implies that, for warm water, the enhanced emissivity due to surface roughening will have a larger effect on the overall emissivity than it does for cooler water.

Low Wind Speeds (< 7 m/s)
To account for this temperature dependant change in emissivity in the model, the following form was selected for windspeeds below 7 m/s

$$\varepsilon_{total} = \left[\varepsilon' - \varepsilon_{spec}(T_s)\right]\frac{W}{W'} + \varepsilon_{spec}(T_s) \qquad (4)$$

where ε_{total} is the total emissivity estimate, ε' is defined below, ε_{spec} is specular emissivity at temperature T_s, T_s is sea surface temperature, W is surface wind speed and W′ is defined below.
This form assumes that there is a hypothetical point (W′, ε′) at which the specular emissivity contribution to total emissivity becomes insignificant compared to the roughness component. To determine W′ and ε′ for each frequency, an optimization method was used to find values that would minimize the squared error between the model function and TOPEX measurements. Table 1 shows the resulting values.

High Wind Speeds (> 7 m/s)
For wind speeds greater than 7 m/s, foaming becomes an important factor in determining the sea surface emissivity. At the frequencies considered here, foam can be treated as an ideal blackbody radiator. The new model, for winds greater than 7 m/s, is similarly a temperature dependent modification to (1), given by

$$\varepsilon_{total} = \left\{\left[\varepsilon' - \varepsilon_{spec}(T_s)\right]\frac{7}{W'} + \varepsilon_{spec}(T_s)\right\}(1 - f_s) + f_s \qquad (5)$$

where f is given by (2). Using the values of W′ and ε′ for W<7m/s, it is possible to solve for ‘a’ in (2) at the three frequencies. The results are shown in Table 2.

In both the W<7m/s and the W>7m/s cases, the modified, temperature dependent, model explains and corrects for the dependence of the slope of emissivity vs. windspeed on temperature.

REFERENCES

Wentz, F.J. (1983), “Model function for ocean microwave brightness temperatures, J. Geophys. Res., 88, 1892-1908.

Wilheit, T.T. (1979), “A model for the microwave emissivity of the ocean’s surface as a function of wind speed,” IEEE Trans. Geosc. Remote Sens., 17, 244-249.

Witter, D.L., and D.B. Chelton (1991), “A GEOSAT altimeter wind speed algorithm and a model for altimeter wind speed algorithm development,” J. Geophys. Res., 96, 8853-8860.

Table 4.3. Coefficients for the new model. Wind speeds less than 7 m/s.

Freq (GHz)	W′ (m/s)	ε′	RMS Error
18	21.42	0.4420	0.0061
21	31.70	0.4560	0.0055
37	25.00	0.5147	0.0068

Table 2. Coefficients for the new model. Wind speeds greater than 7 m/s.

Freq (GHz)	A (s/m)	RMS Error
18	5.688×10^{-3}	0.0067
21	5.648x10-^{3}	0.0061
37	6.692×10^{-3}	0.0070