An Anisotropic Ocean Surface Emissivity Model Based on a Two-Scale Code Tuned to WindSat Polarimetric Brightness Observations (JOEM – Joint Ocean Emissivity Model)

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Goal

Develop a standardized fast full-Stokes ocean surface emissivity model for a wind-driven ocean surface applicable at arbitrary microwave frequencies and incidence angles, and thus relevant to all existing and planned conically and cross-track scanned sensors (WindSat, AMSR-E, TMI, SSMI, SSMIS, and CMIS as well as AMSU-A, NPP ATMS, and NPOESS ATMS, and GPM).
Strategy

- Analyze a sufficiently long sequence of WindSat data to derive the wind induced isotropic and anisotropic emissivity variations for all four Stokes parameters.

- Above was done for 9-month data set by T. Meissner and F. Wentz [1], and corroborated by this study.

- Extend the WindSat results to other frequencies and incidence and angles using the two-scale model [e.g., S. Yueh, 2].
The two-scale model has recently been cast into a computationally efficient form by J. Johnson [3] who has provided CET a copy of this code. Code features are:

- Resonant thermal emission from short-wave portion of wind-driven wave spectrum
- Modified geometrical optics emission from facets tilted by long-wave portion of spectrum
- Upwind/downwind modulation of wind-driven wave spectrum
- $\Omega$ factor [4] to describe the modification of the downwelling reflected radiation beyond that of simple specular reflection due to tilted surface facets (related to Maetzler’s and Rosenkranz’ “Lambertivity”)
- Applicable to full Stokes emission for satellite data modeling.
Modeling Strategy (cont’d)

• The OSU code originally used the Durden-Vesecky model for the sea surface spectrum [5] which can be improved for radiometric purposes. This spectrum does, however, incorporate an adequate angular spreading function.

• Thus, the isotropic component of the Durden-Vesecky spectrum [5] was replaced by the Elfouhaily spectrum [6], but with the Durden-Vesecky angular spreading function retained.

• The Meissner-Wentz dielectric permittivity model [7] replaces the original (Klein-Swift) permittivity model because it is more accurate.
Tuning Strategy

• The model sea spectrum and emissivity code were tuned in five parameters to reproduce the WindSat zeroth, first, and second harmonic v, h results and the first and second harmonic U and V results.

  ➢ Three spectral tuning parameters are independent of wind speed:
    - spectral strength factor
    - hydrodynamic modulation function
    - shortwave/longwave spectral ratio

  ➢ The foam fraction of Monahan and O’Muircheartaigh [8] is tuned according to wind speed.

  ➢ The foam fraction is also modulated by adding foam on the leeward side. This parameter is tuned according to wind speed.
Other Modifications

• The high-frequency portion of the Elfouhaily spectrum was multiplied by the Pierson-Moskowitz shape factor since this modulating was inadvertently omitted in the original work [6].

• The generalized Phillips-Kitaigorodskii equilibrium range parameter for short waves was modeled as a continuous function of the friction velocity at the water surface to eliminate a discontinuous jump in the [6] formulation.

• The hydrodynamic modulation function was modeled as a continuous function of facet slope:

\[
M = \left[ 1 - h_a \tanh\left( \frac{S_x}{S_u} h_b \right) \right]
\]
Foam, Skewness, and Peakedness

- Foam fraction:
  Monahan and O’Muircheartaigh [8]

- Foam emissivity:
  Strogryn [9] (anisotropy data from Reising et al. was considered)

- Slope probability distribution function:
  - Cox and Munk [10]
  - Includes coefficients for:
    - up/downwind skewness
    - peakedness (deviation from Gaussian)
Meissner-Wentz Harmonic Amplitudes
(WindSat, 9-months, two looks)

Note: \( v_0 \) and \( h_0 \) are reduced by 10x
Untuned OSU/CET-Modified Harmonic Amplitudes

Note: $v_0$ and $h_0$ are reduced by 10x
Meissner-Wentz – OSU Amplitudes
(untuned differences)

Polarization Channel

- 10.7 GHz
- 18.7 GHz
- 37.0 GHz

Wind Speed (m/s)
Histogram of MW-OSU Differences (untuned)

RMS 2.2765  Mean Absolute 1.0471  Total Occurrences 300
Zeroth Harmonic H-polarization (untuned)

$T_B$ values are offset relative to those for a calm surface
The graph illustrates the Tuned OSU/CET-Modified Harmonic Amplitudes for different frequencies: 10.7 GHz, 18.7 GHz, and 37.0 GHz. Each frequency is represented across various polarization channels (v0, h0, v1, h1, v2, h2, v3, h3) and wind speeds (0 to 20 m/s). The color scale indicates the magnitude of the amplitudes, with reds representing higher values and blues representing lower values. The note clarifies that v0 and h0 amplitudes are reduced by 10x for clarity.
Meissner-Wentz – OSU Harmonic Amplitudes
(tuned differences)
Histogram of MW-OSU Differences (tuned)

RMS 0.50468  Mean Absolute 0.32513  Total Occurrences 300
Zeroth Harmonic h-polarization (tuned)

$T_B$ values are offset relative to those for a calm surface
Residual Bias Modeling

- The MW-OSU residuals were used as input to construct a bias table usable for all incidence angles $\theta$ and frequencies. The brightnesses near $\theta=0$ are known to satisfy:
  - $v_0$ and $h_0$ tend to the same value at $\theta=0$
  - $v_1, h_1, 31, 41, \text{ and } 42$ tend to zero at $\theta=0$
  - $32 = 2h_2 = -2v_2$ at $\theta=0$

- The biases for all harmonics are presumed to be quadratic in $\theta$
- The biases for all harmonics as a function of frequency are modeled by a piecewise linear fit with a bias of 0 from 0-6 GHz, from 6 GHz to the value at 10.7 GHz, from this value to the value at
Residual Bias Modeling (cont.)

- 18.7 GHz, from this value to the value at 37.0 GHz, from this value to 0 at 89.0 GHz, and 0 for frequencies above 89.0 GHz. There is a separate bias curve as a function of frequency for each Stokes parameter, harmonic, and wind bin.
- These biases are subsequently subtracted from all OSU code radiances.
Next Steps

• Develop tabularized tuned OSU model including Jacobian.
  - Ten emissivity parameters and Ω factors
  - 1-degree and 1 GHz tabulation for 1-100 GHz
    => ~10^5 numbers (archive size)

• Incorporate into DOTLRT v1.0c

• Study AMSU-A/HSB transparent channel data for wind direction biases.
Next Steps (cont’d)

• The refined OSU model is presently being cross-validated against the Aqua AMSR-E data using buoy data (National Buoy Data Center) for sea surface temperature, and wind speed and direction.

  ➢ NCEP reanalysed atmospheres are being used for column water vapor and liquid water values to model the downwelling and upwelling atmospheric brightnesses. \( \sim 10^4 \) matchups are being sought so as to provide \( \sim 50\text{mK} \) accuracy.

  ➢ May lead to some small further model adjustments pursuant to the goal of a standardized fast full-Stokes ocean surface emissivity model applicable at arbitrary microwave frequencies and incidence angles.
Summary (Ocean Emission)

- The OSU two-scale code has been modified with several physically-based improvements and incorporating five key tuning parameters.
- The OSU/CET-Modified code has been tuned against WindSat data developed by Meissner and Wentz.
- Tuned model agreement is within ~0.5K RMS difference over 10 parameters, 10 wind bins and 3 frequency bands.
- A model bias function was developed to extend use of the tuned model to arbitrary incidence angles and frequencies.
- Independent satellite verification using AMSR-E is in progress.
References