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].

Modeling Strategy

- 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
  - ➢ Ω 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 inadvertantly 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:

$$M = [1 - h_a \tanh(\frac{s_x}{s_u} h_b)]$$

Foam, Skewness, and Peakedness

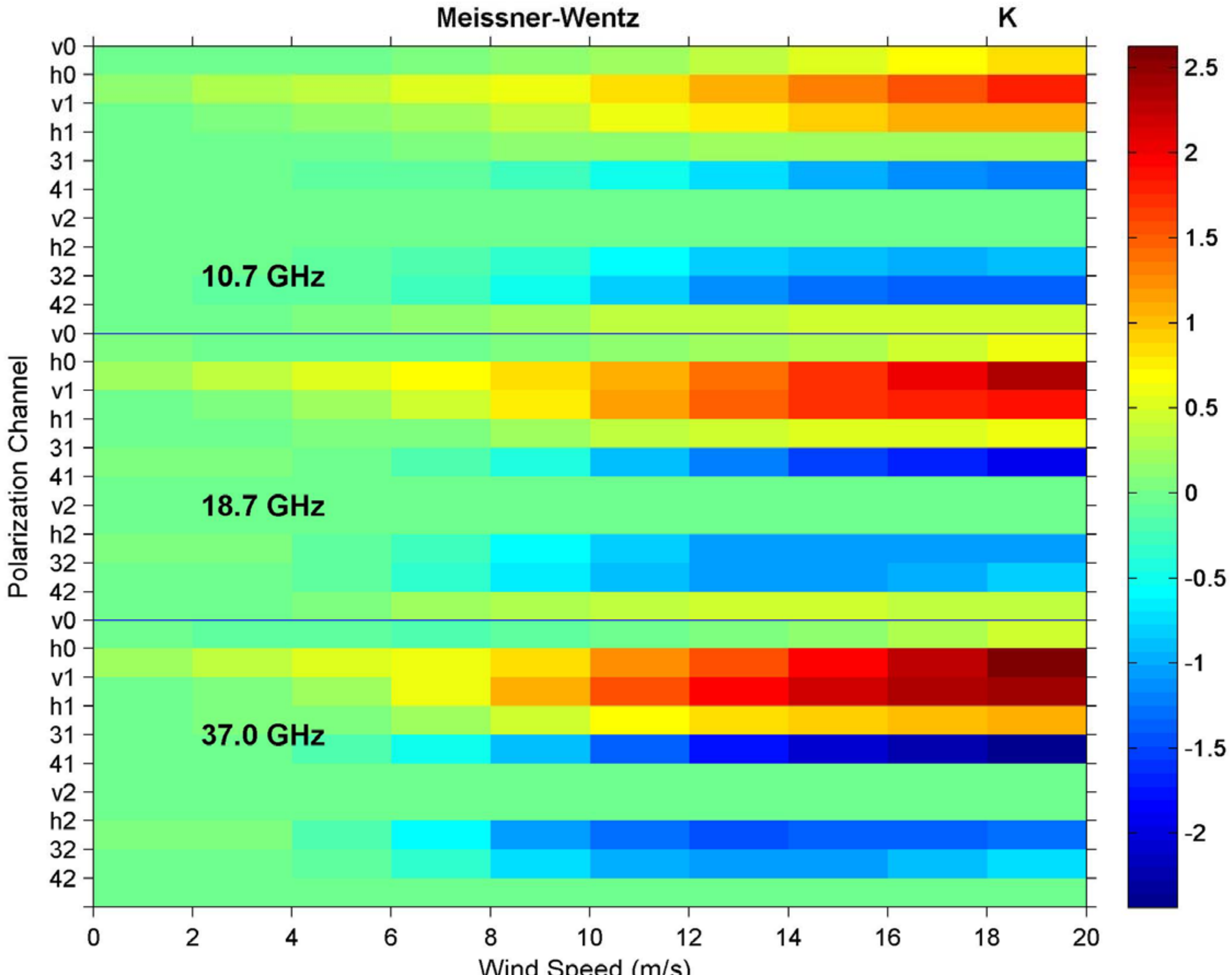
- Foam fraction:
  Monahan and O'Muircheartaigh [8]

- 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)

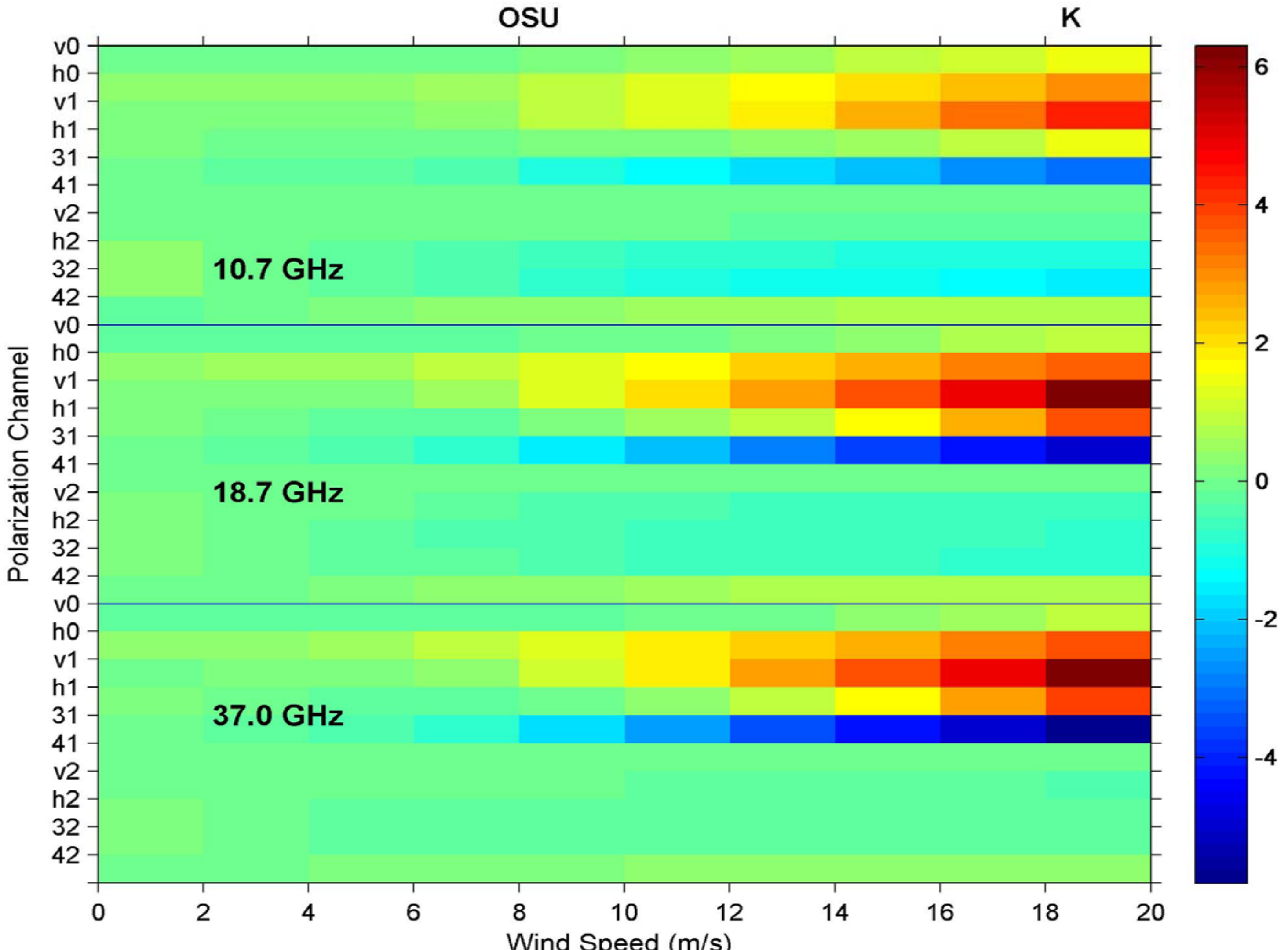
Meissner-Wentz Harmonic Amplitudes

(WindSat, 9-months, two looks)



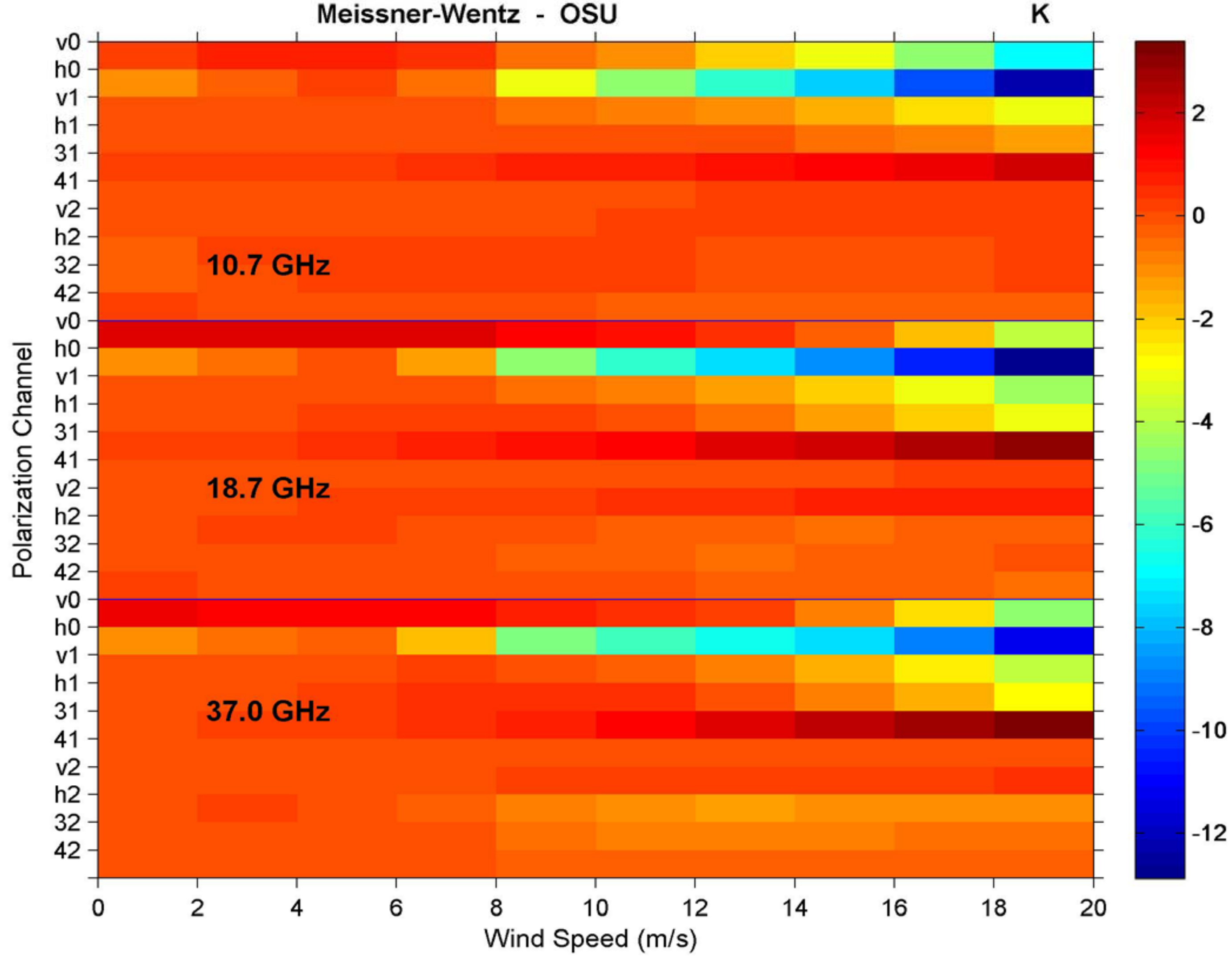
Note: vo and ho are reduced by 10x

Untuned OSU/CET-Modified Harmonic Amplitudes

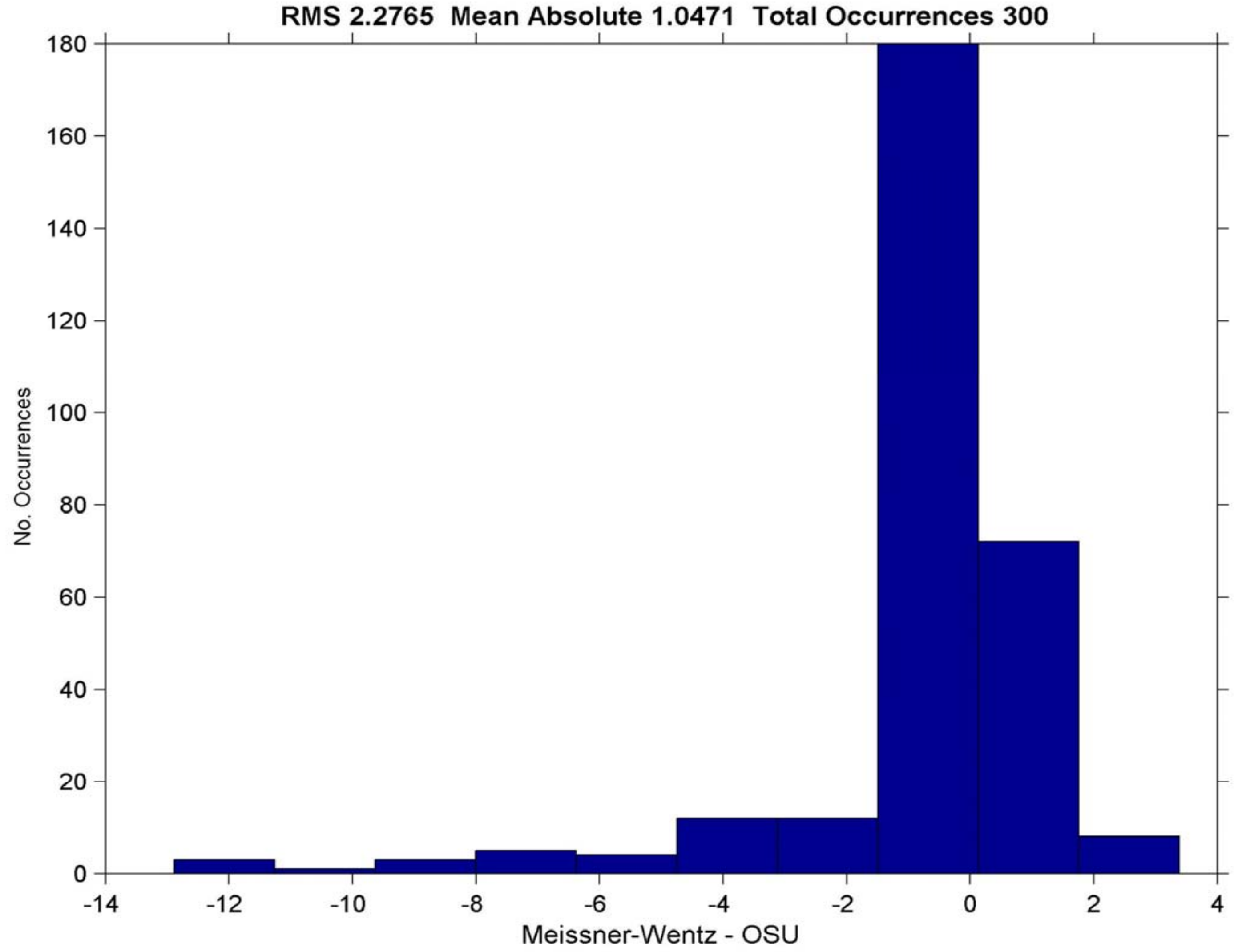


Note: vo and ho are reduced by 10x

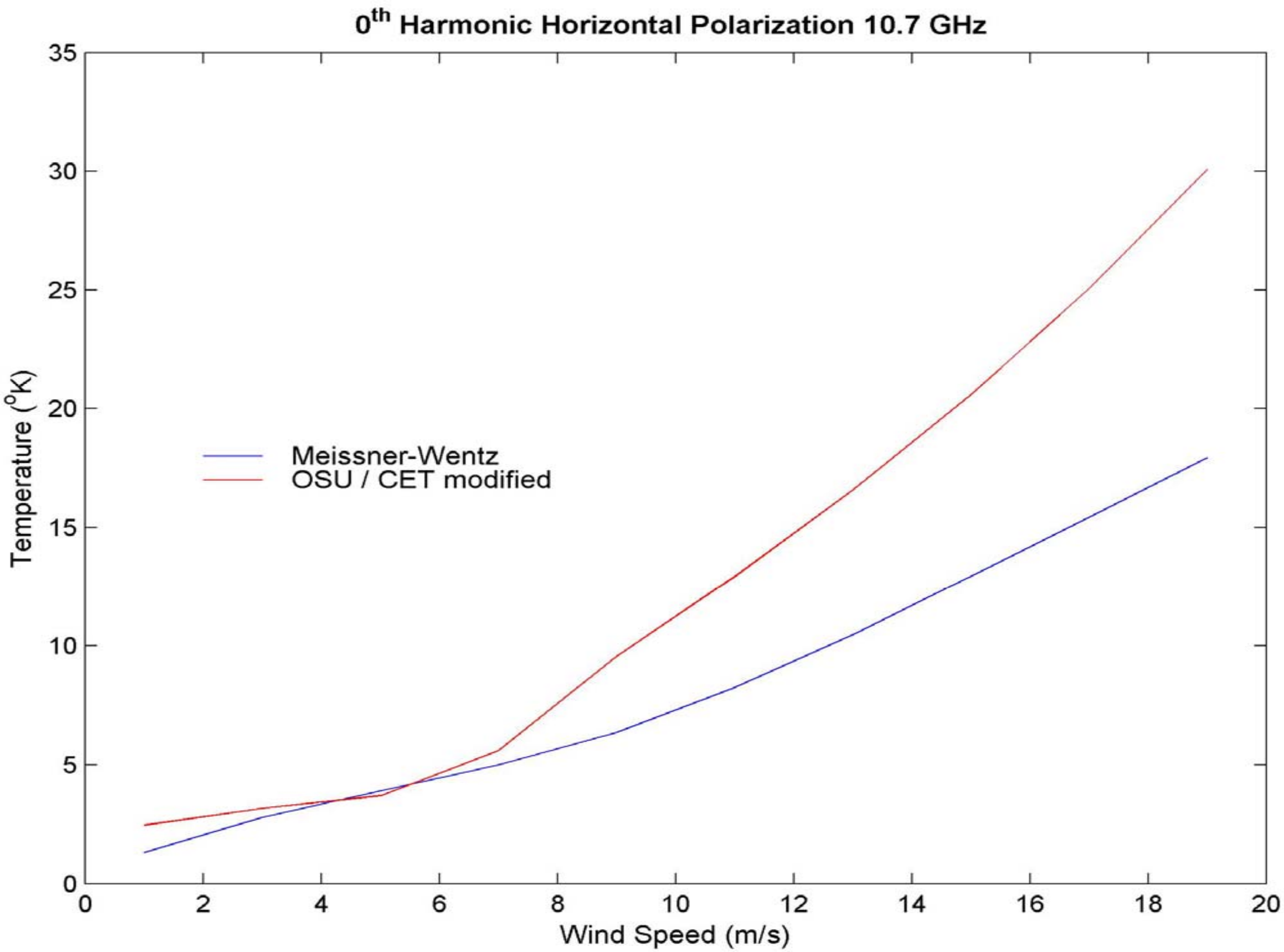
Meissner-Wentz – OSU Amplitudes
(untuned differences)



Histogram of MW-OSU Differences
(untuned)

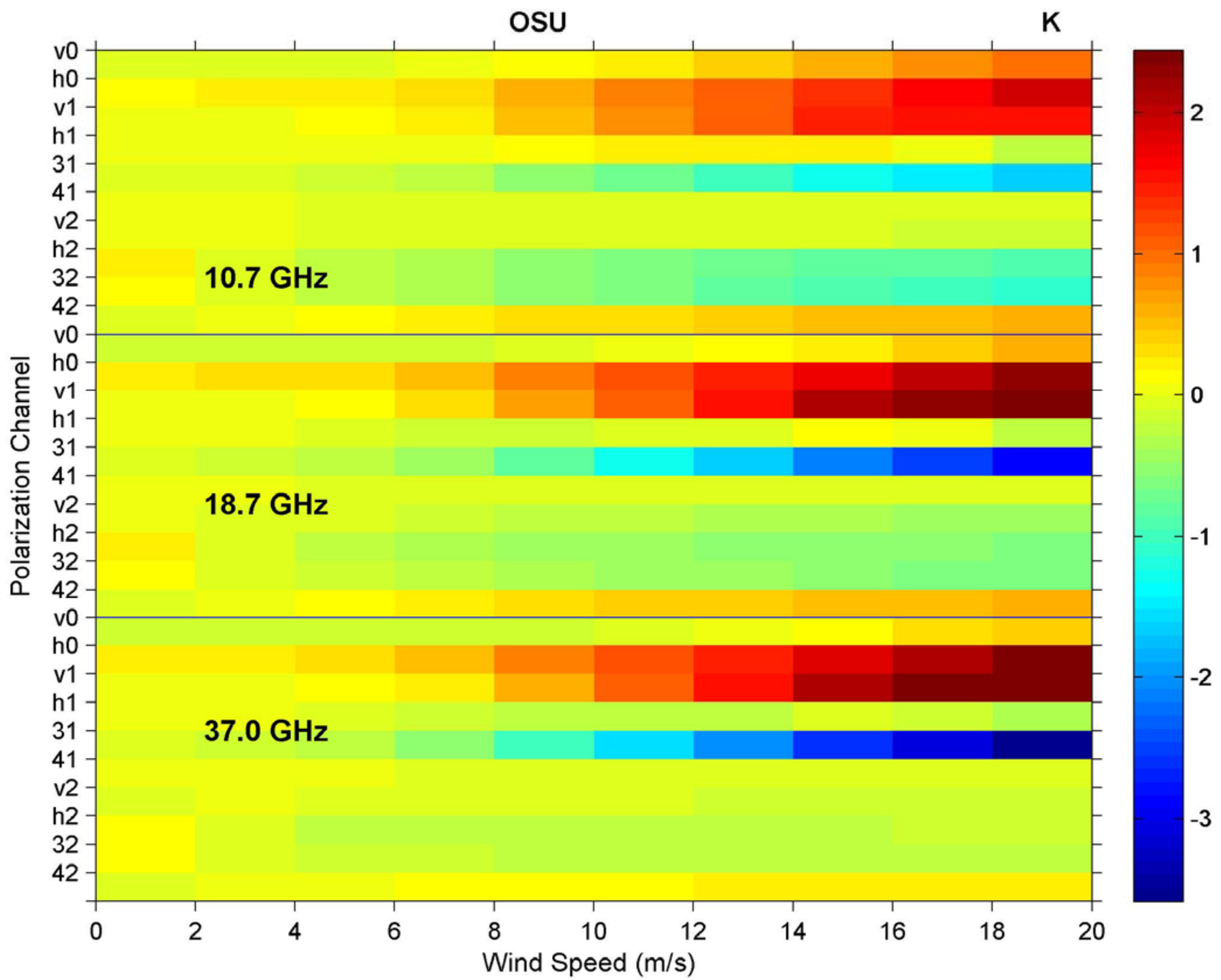


Zeroth Harmonic h-polarization
(untuned)



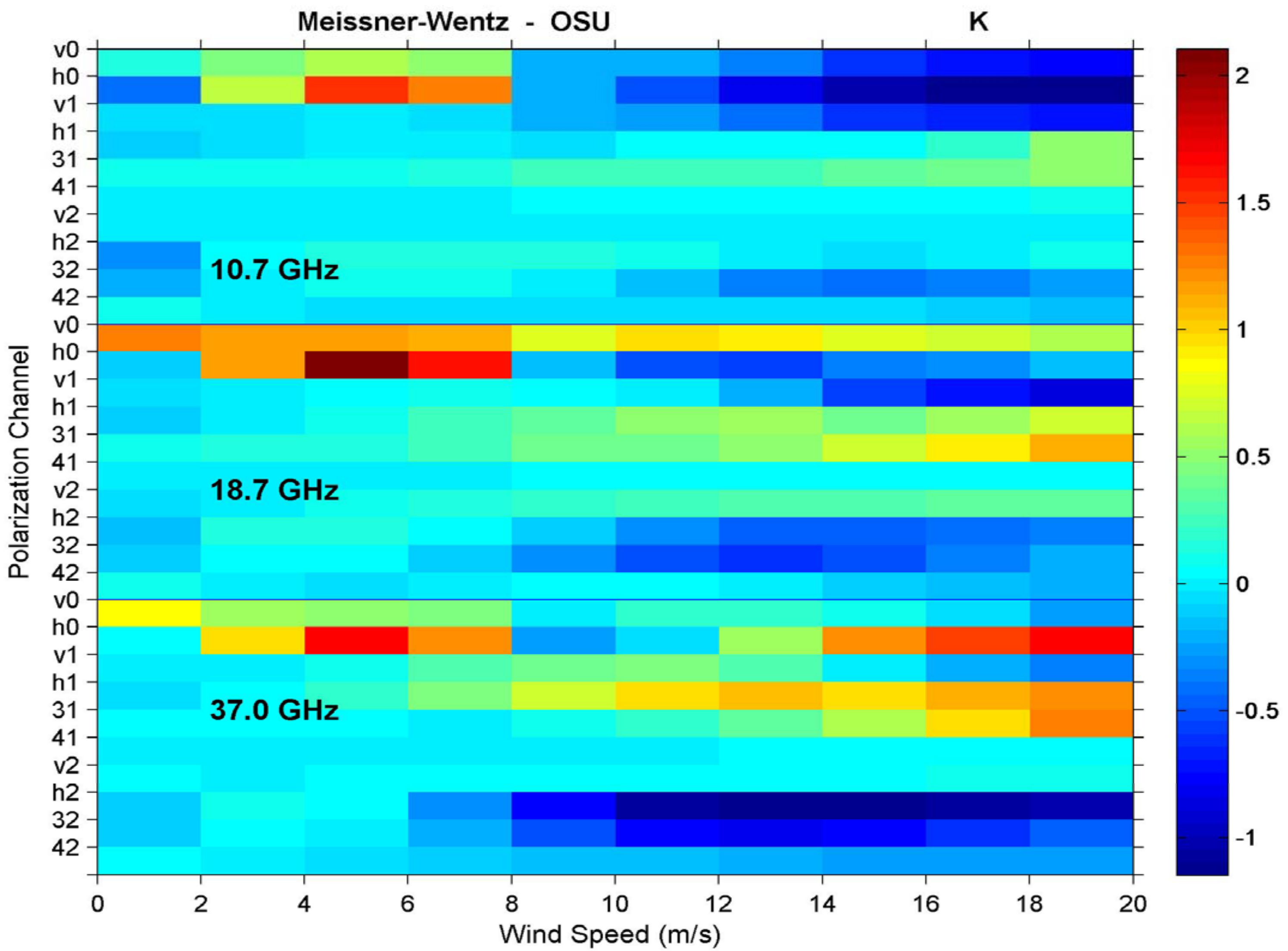
T_B values are offset relative to those for a calm surface

Tuned OSU/CET-Modified Harmonic Amplitudes

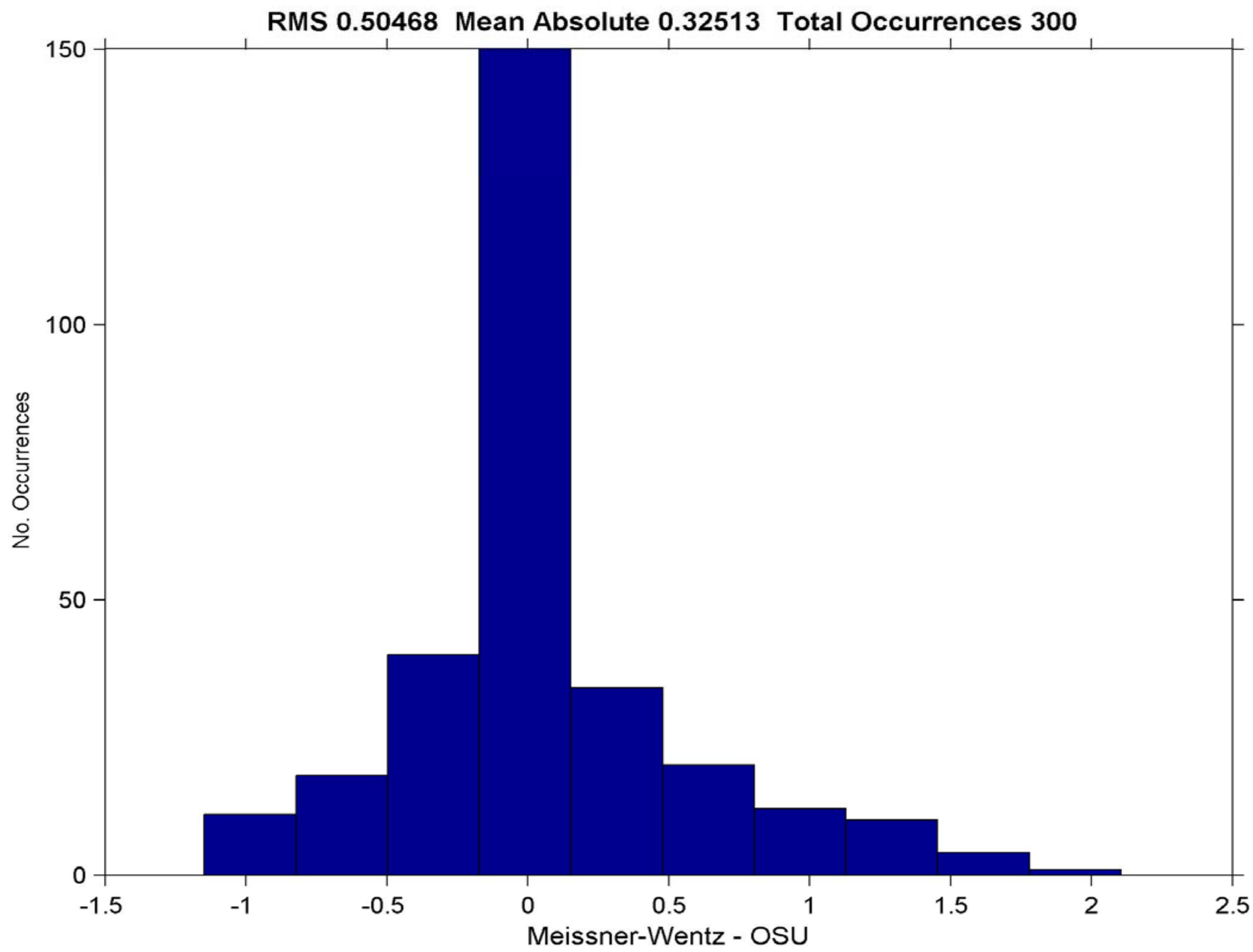


Note: v0 and h0 are reduced by 10x for clarity

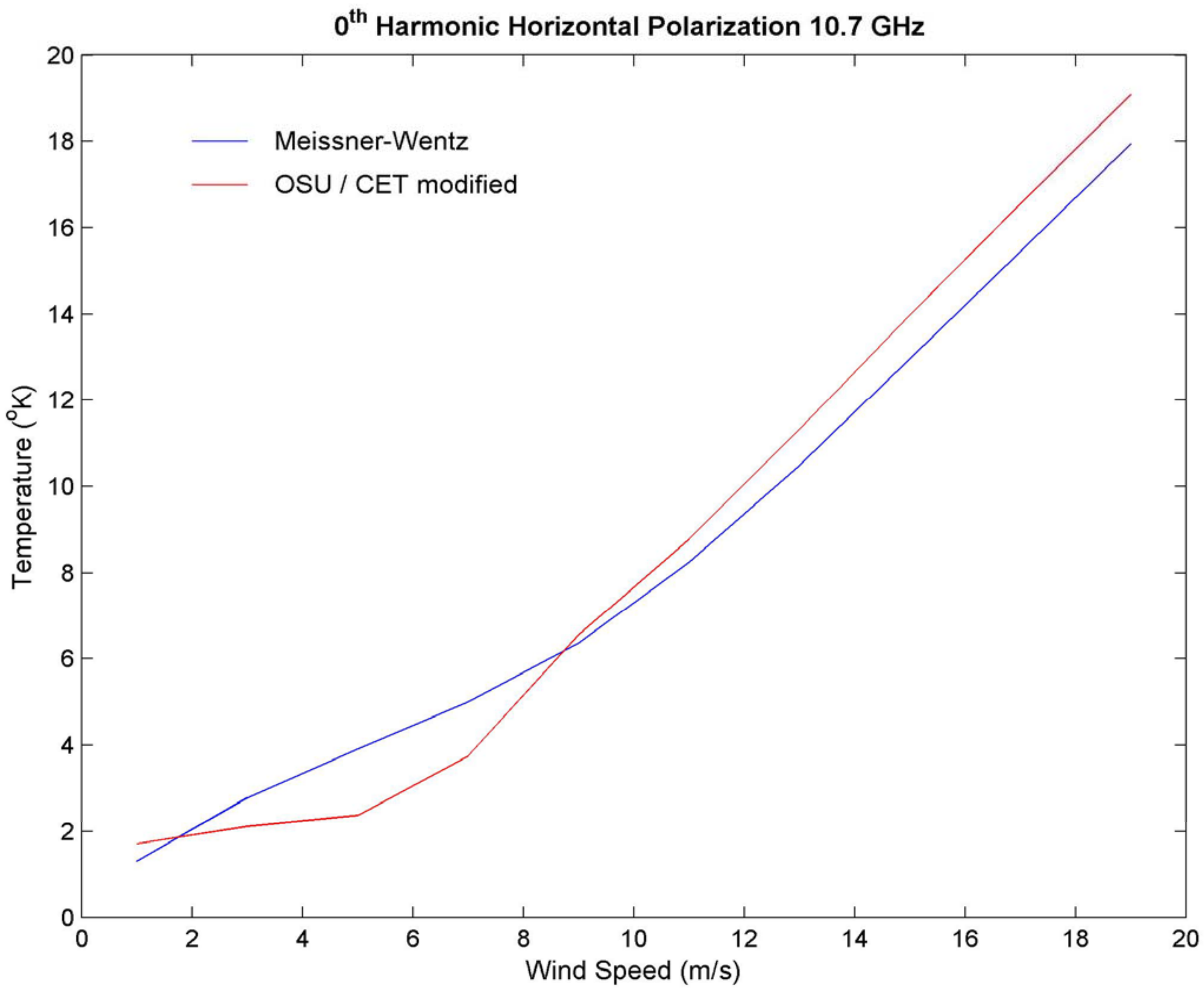
Meissner-Wentz – OSU Harmonic Amplitudes (tuned differences)



Histogram of MW-OSU Differences
(tuned)



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 θ and frequencies. The brightnesses near θ=0 are known to satisfy:
    - v0 and h0 tend to the same value at θ=0
    - v1,h1,31,41, and 42 tend to zero at θ=0
    - 32 = 2h2 = - 2v2 at θ=0
- The biases for all harmonics are presumed to be quadratic in θ
- 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. ~10^4 matchups are being sought so as to provide ~50mK 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-Modifed 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

[1] Meissner, T., and F. Wentz, “Physical Ocean Retrievals for WindSat”, Proc. MicroRad ’06, in press.

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[3] Johnson, J.T., “An Efficient Two-scale Model for the Computation of Thermal Emission and Atmospheric Reflection From the Sea surface”, *IEEE Trans. Geosci. Remote Sens.*, vol. 44, pp. 560-568, 2006.

[4] Wentz, F.J., and T. Meissner, “Algorithm Theoretical Basis Document: AMSR Ocean Algorithm, version 2, report from Remote Sensing Systems, available at *www.remss.com.*

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[6] Elfouhaily, T., B. Charon, K. Katsaros, and D. Vandemark, “A Unified Directional Spectrum for Long and Short Wind-driven Waves”, *J. Geophys. Res.*, vol. 102, C7, pp. 15781-15796, 1997.

[7] Meissner, T., and F. Wentz, “The Dielectric Constant of Pure and Sea Water from Microwave Satellite Observations”, *IEEE Trans. Geosci. Remote Sens.*, vol. 42, pp.1836-1849, 2004.

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