An Anisotropic Ocean Surface Emissivity Model Based on a Two-Scale Code Tuned to WindSat Polarimetric Brightness Observations

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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 6-month data set by T. Meissner and F. Wentz [1], and corroborated by this JCSDA 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

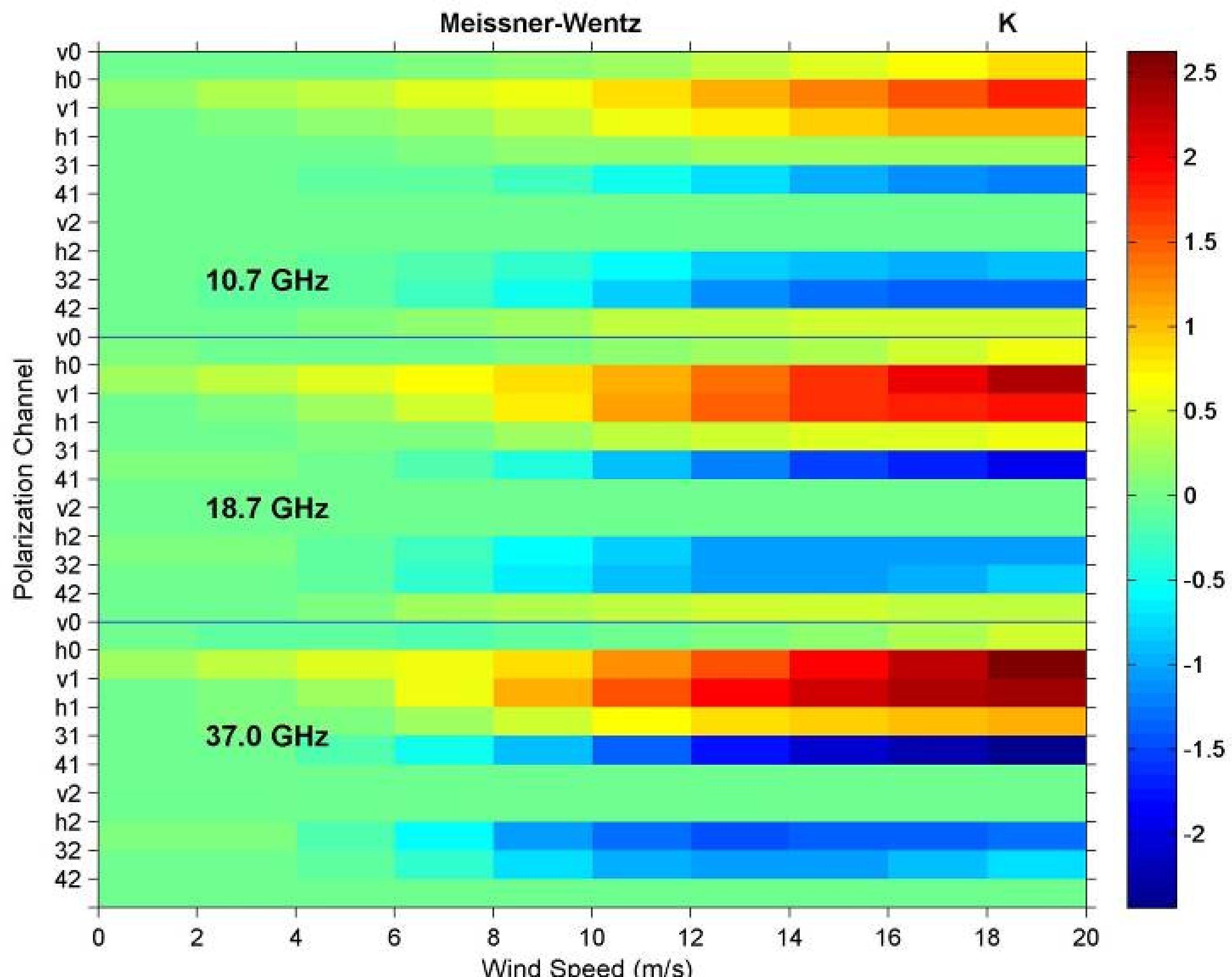
- Foam fraction:
  Monahan and O'Muircheartaigh [8]

- 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)

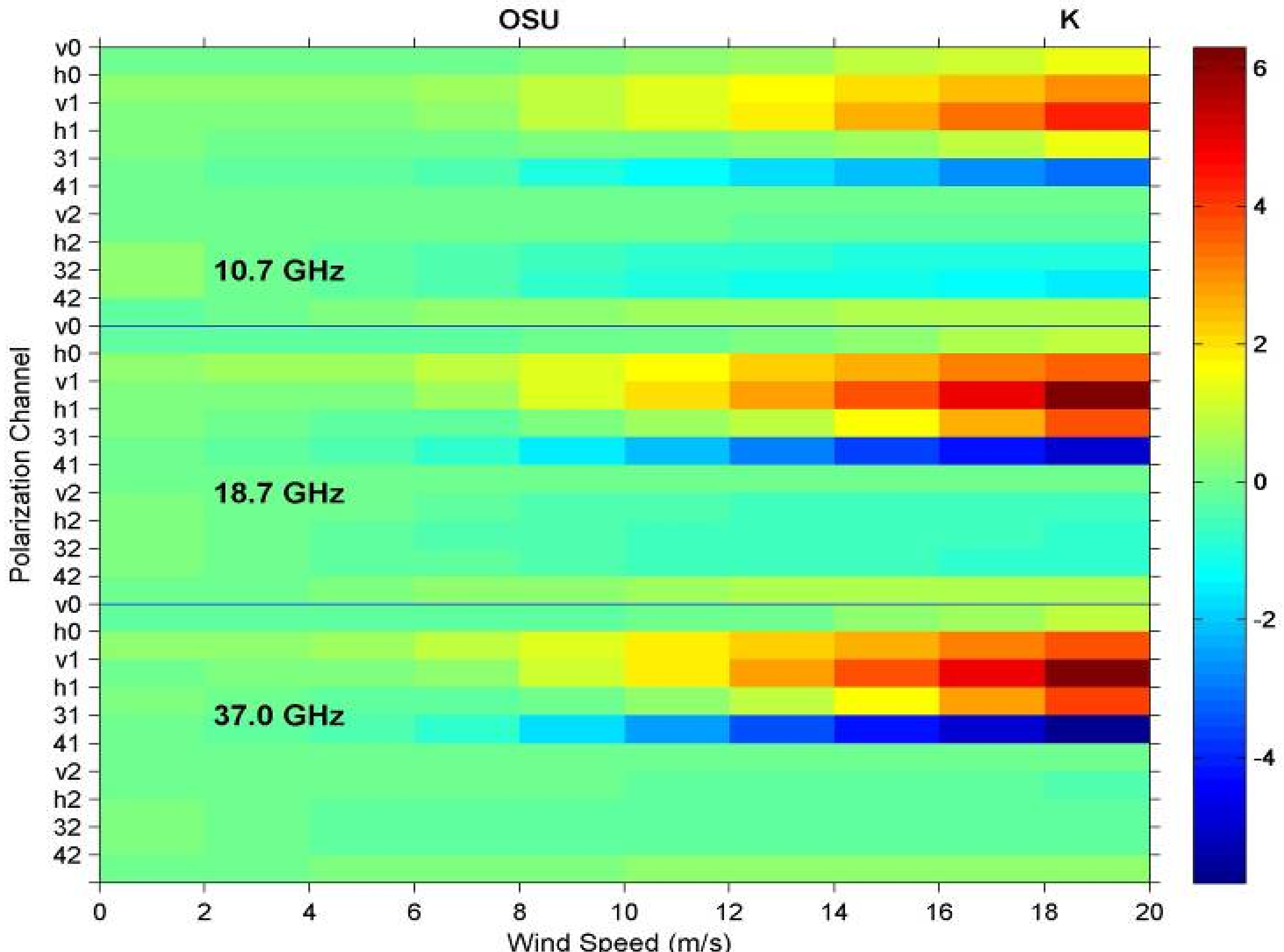
Meissner-Wentz Harmonic Amplitudes

(WindSat, 6-months, two looks)



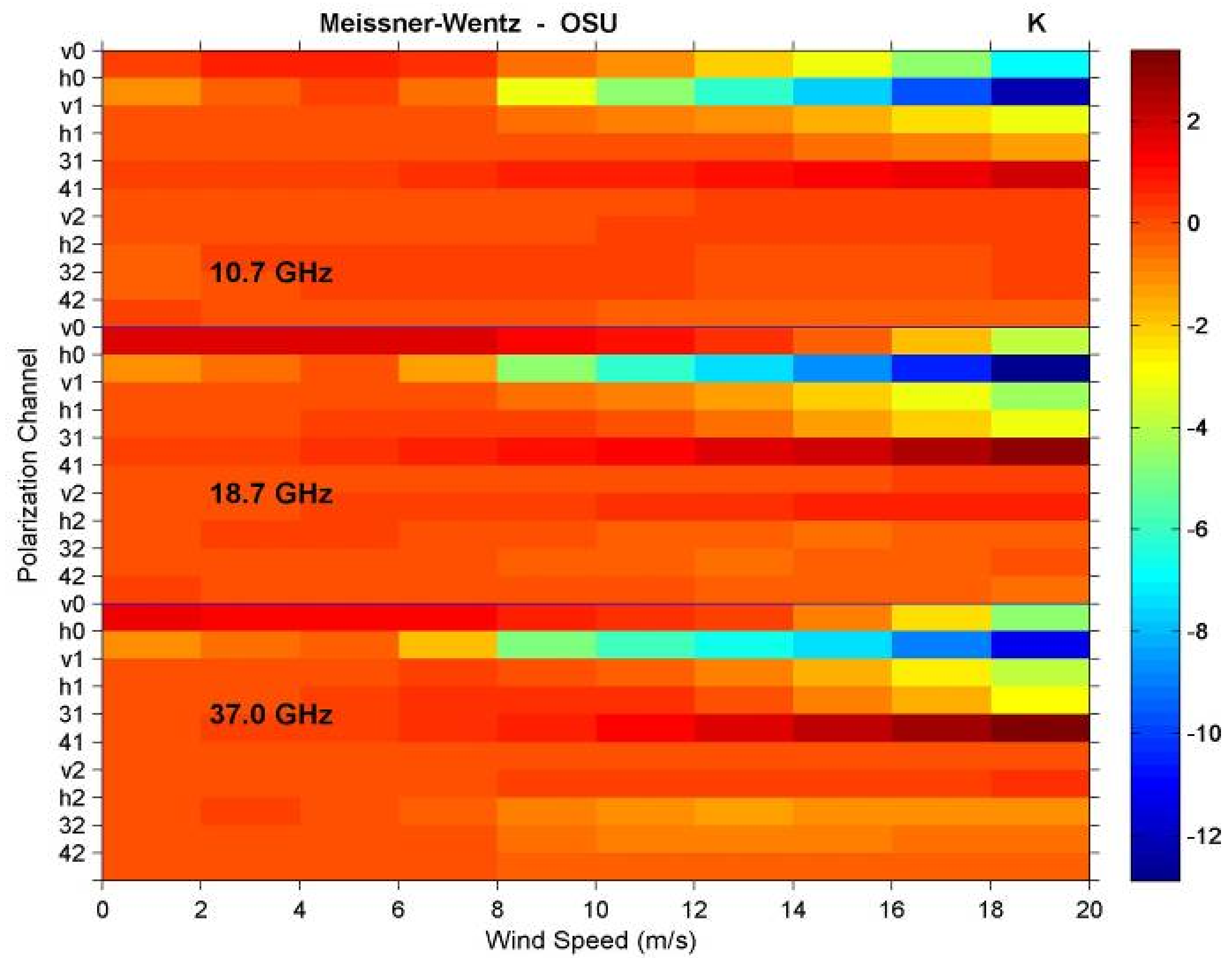
Note: vo and ho are reduced by 10x

Untuned OSU/CET-Modified Harmonic Amplitudes

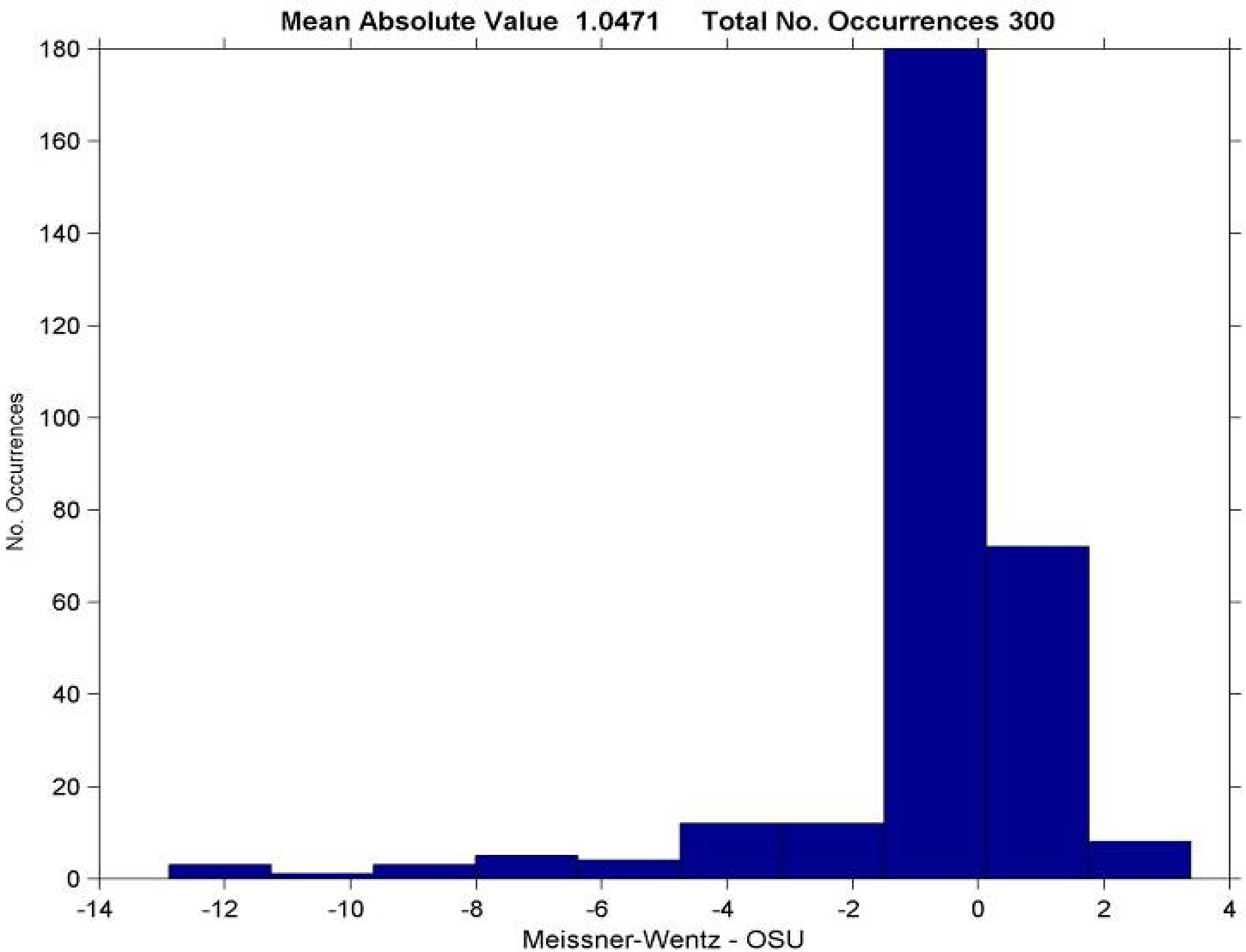


Note: vo and ho are reduced by 10x

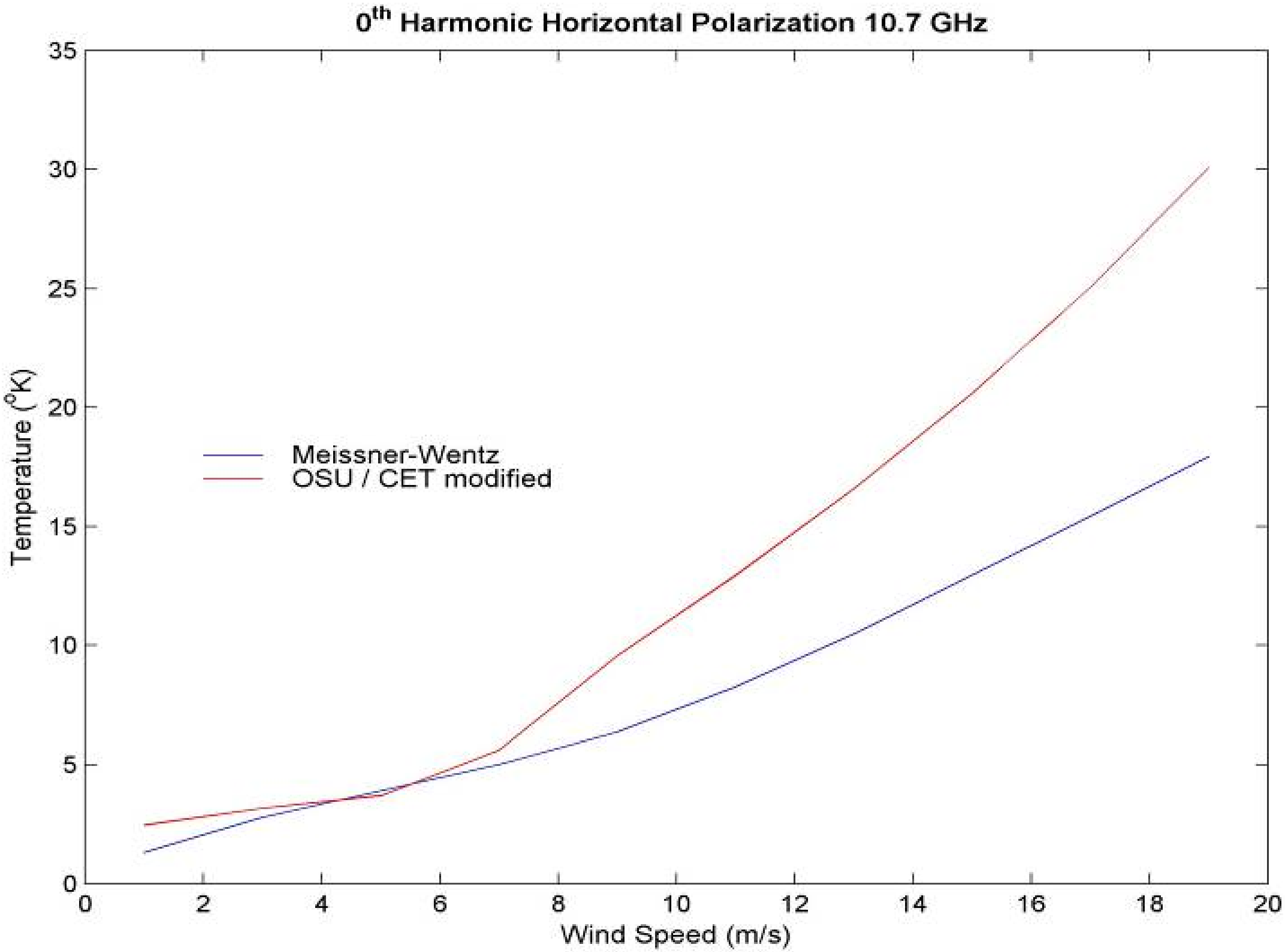
Meissner-Wentz – OSU Amplitudes
(untuned)



Histogram of MW-OSU Differences
(untuned)

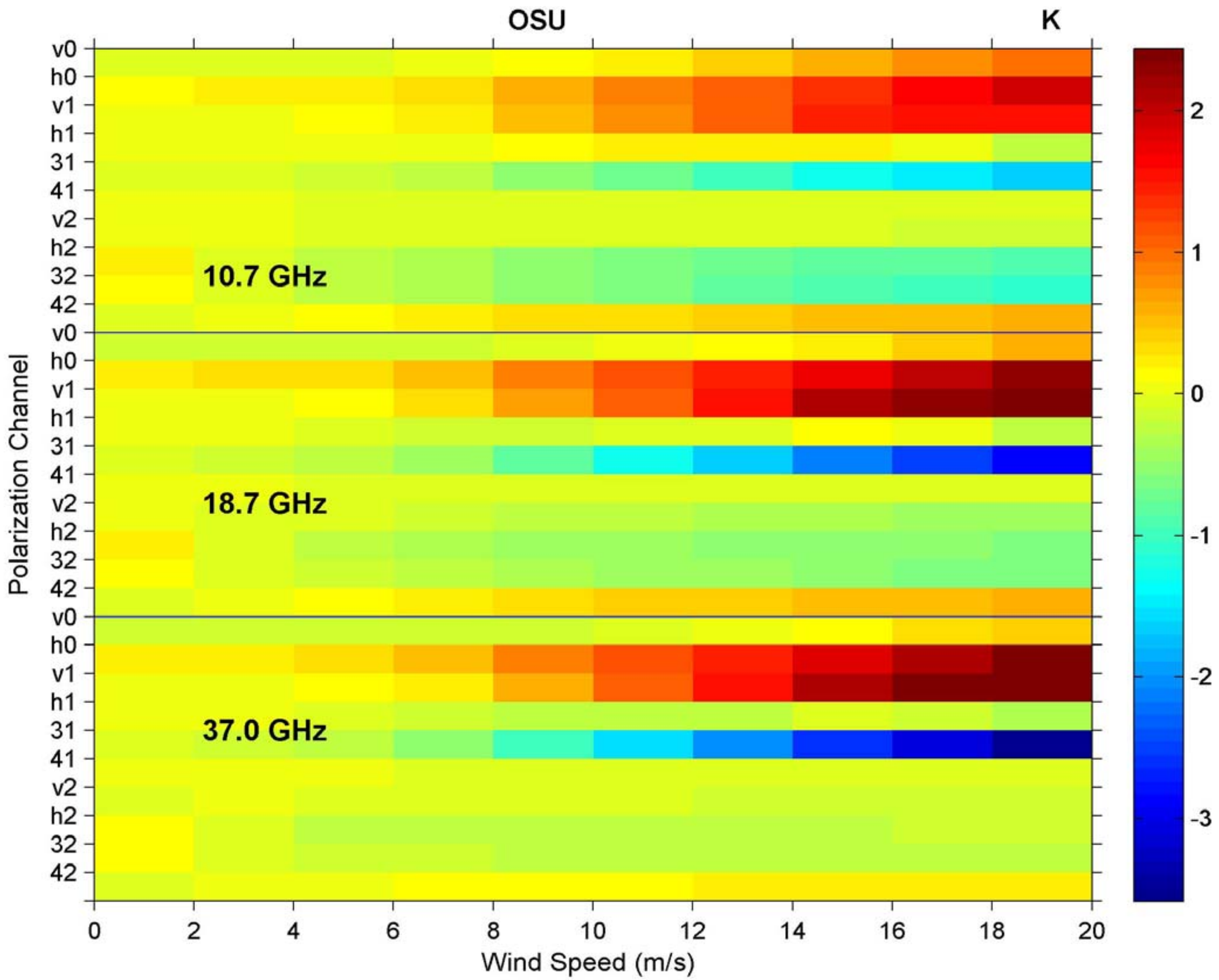


Zeroth Harmonic h-polarization
(untuned)



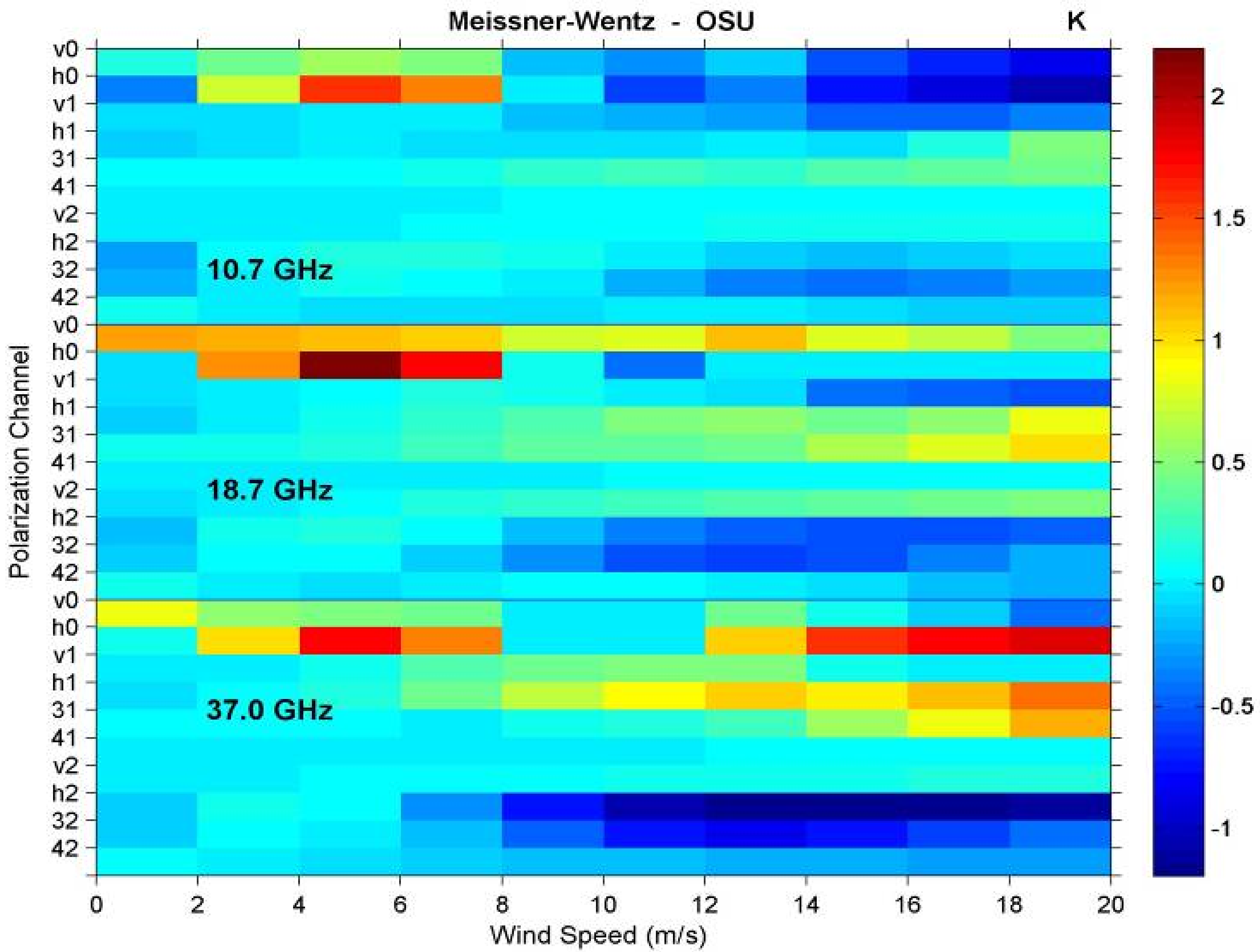
T_B values are offset relative to those for a calm surface

Tuned OSU/CET-Modified Results

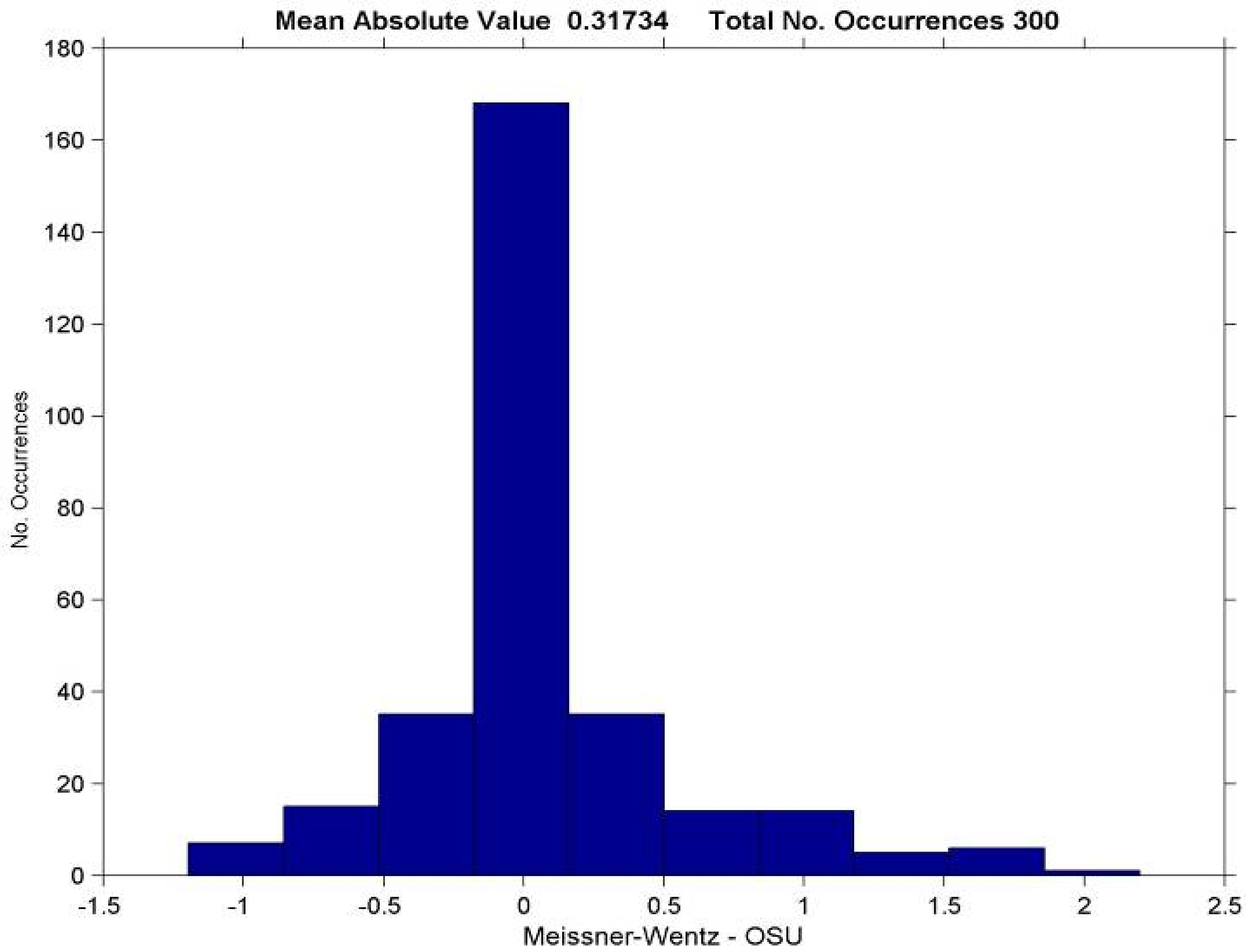


Note: vo and ho are reduced by 10x

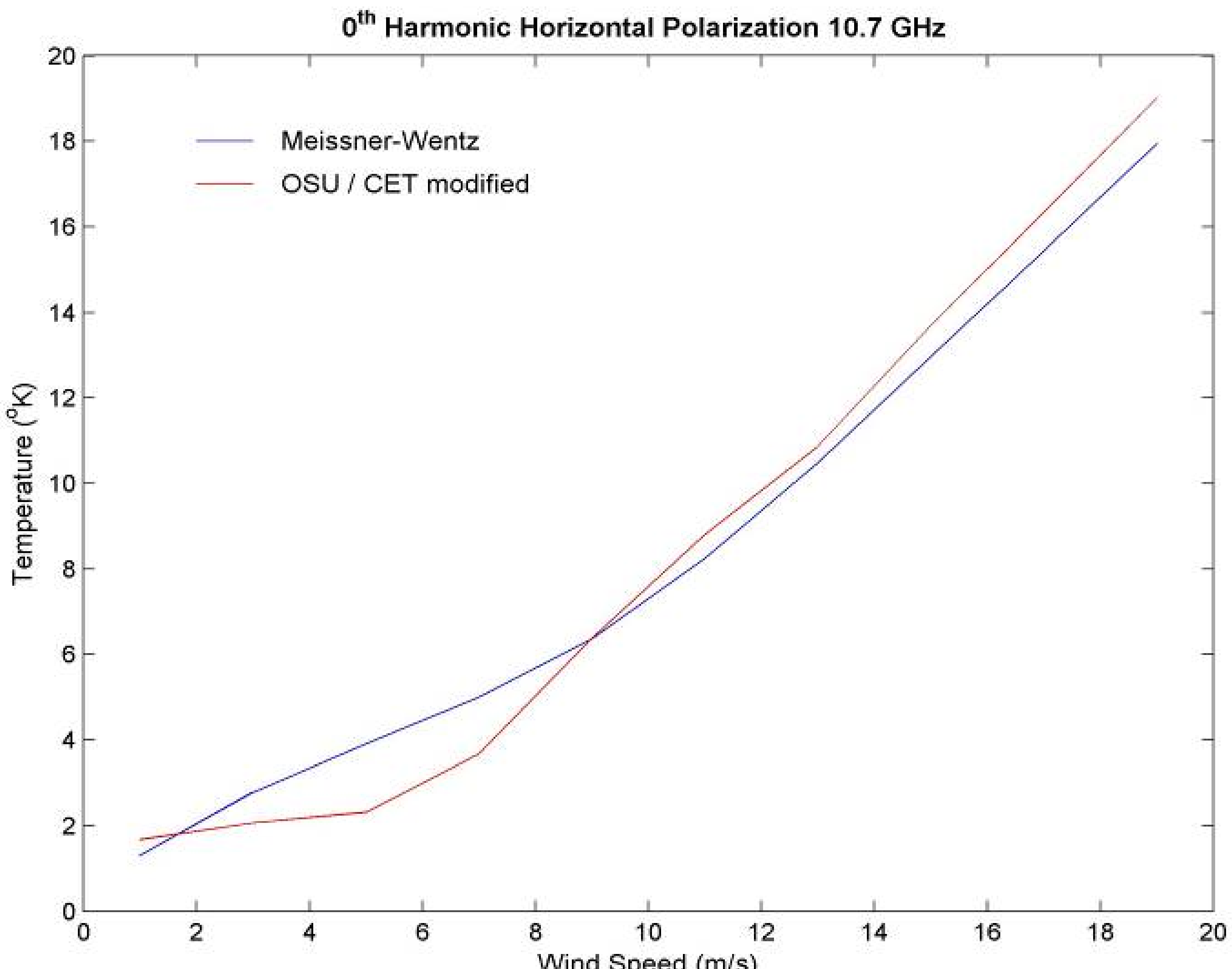
Meissner-Wentz – OSU Results (tuned)



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. 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
- These biases are subsequently subtracted from all OSU code radiances upon spectral interpolation

Next Steps

- Retune using RMS error (vs absolute error difference)
- Develop tabularized tuned OSU model including Jacobian for use in CRTM.
  - Ten emissivity parameters and Ω factor
  - 1-degree and1 GHz tabulation for 1-100 GHz
    => ~10^5 numbers
- 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 AMSU-A and HSB data sets from May 2002 to February 2003 (when the HSB ceased to function) using the AMSR-E retrievals for wind speeds, and column water vapor and liquid water values to model the downwelling and upwelling atmospheric brightnesses. This validation 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.

- Since AMSU-A and HSB are cross track scanners, they will provide data for the full range of incidence angles as well as a wide range of frequencies.

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 0.3K mean absolute 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.

References

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

[2] Yueh, S.H., “Modeling of Wind Direction Signals in Polarimetric Sea Surface Brightness Temperatures”, *IEEE Trans. Geosci. Remote Sens.*, vol. 35, pp. 1400-1418, 1997.

[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.*

[5] Durden, S.L., and J.F. Vesecky, “A Physical Radar Cross-Section Model for a Wind Driven Sea with Swell, *IEEE Trans. Geosci. Remote Sens.*, vol. OE-10, pp.445-451, 1985.

[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.

[8] Monahan, E.C., and I.G. O’Muircheartaigh, “Whitecaps and the Passive Remote Sensing of the Ocean Surface”, *Int. J. Remote Sens*., vol. 7, 627-642, 1986.

[9] Stogryn, A. “The Emissivity of Sea Foam at Microwave Frequencies”, *J. Geophys. Res*., vol. 77, 1658-1666.

[10] Cox, C., and W. Munk, “Measurement of the Roughness of the Sea Surface from Photographs of the Sun’s Glitter”, *J. Opt. Soc. America*, vol. 44, 838-850, 1954.

Radiative Transfer Modeling in Support of All-Weather Radiance Assimilation

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Goal

Develop a standardized fast full-Stokes ocean multi-stream model for use at arbitrary frequencies (microwave to IR) with Jacobian to support all-weather radiance assimilation.

- Model must seemlessly accommodate scattering
- Model must be compatible with CRTM framework
- Model must be compatible with NCEP operational constraints (size, speed)

DOTLRT* Model Development

Attribute DOTLRT version >	v1.0	v1.0c	v2.0	v2.1
Atmospheric radiation and geophysical Jacobians; Mie spherical scatterer model	☑	☑	☑	☑
Five hydrometeor phases / exponential size distribution	☑	☑	☑	☑
Henyey Greenstein phase function	☑	☑		
Fast Mie lookup library		☑		☑
Full Mie scattering phase function			☑	☑
Interface with CRTM	☑	☑		☑

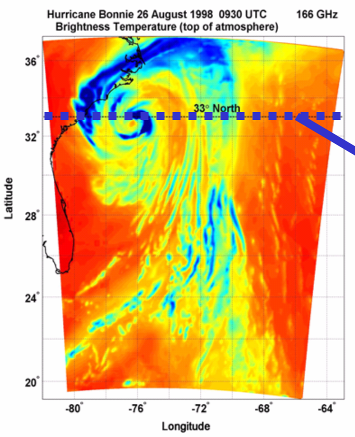
* Discrete Ordinate Tangent Linear Radiative Transfer Model

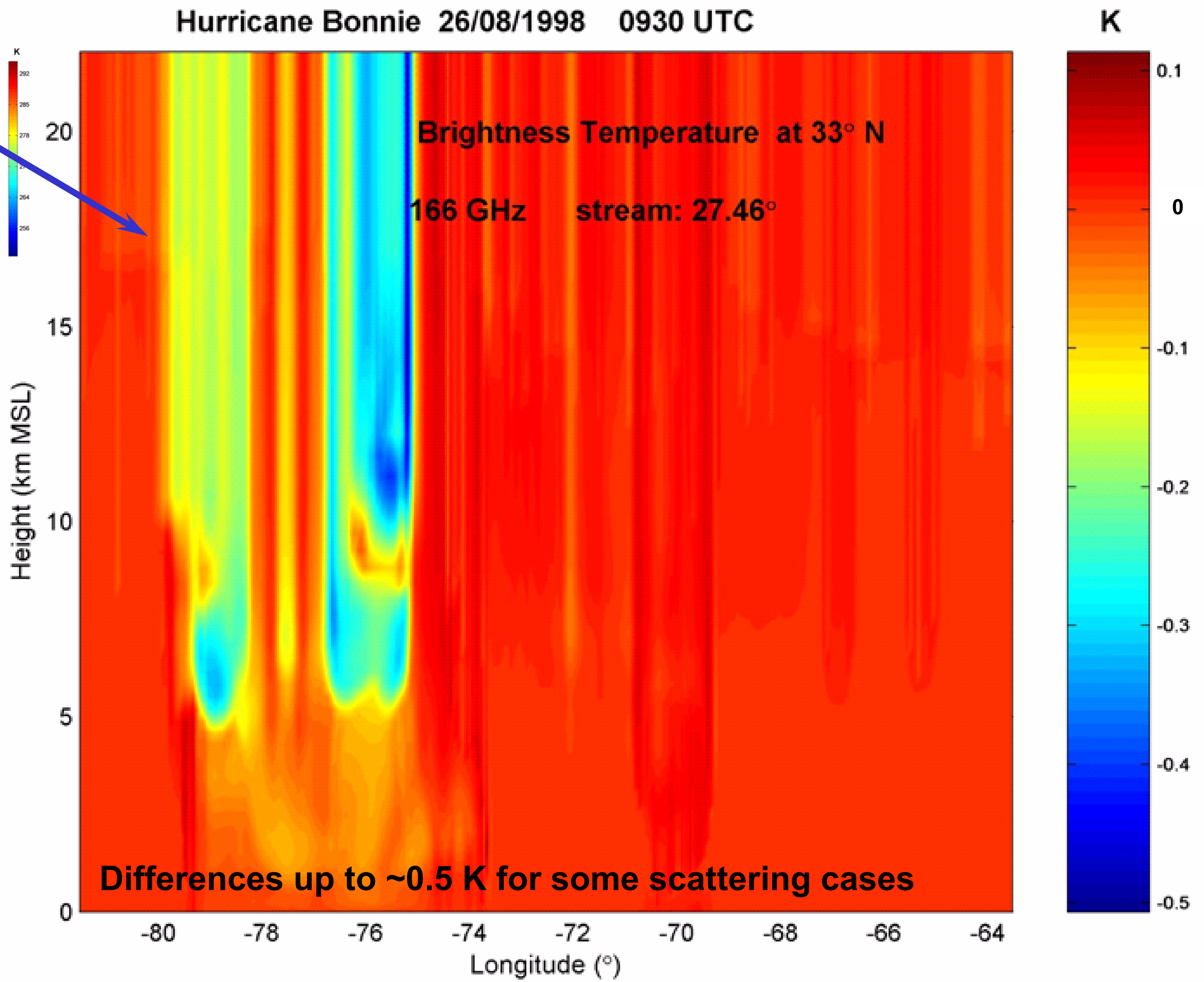
DOTLRT* v2.0 Full Mie Table

- Full Mie scattering phase matrix calculated (no phase matrix approximation)
- ~0.5K precision using 50 MB library space
- Library space required to achieve ~0.05K consistency with full Mie calculation: ~2.5 GB

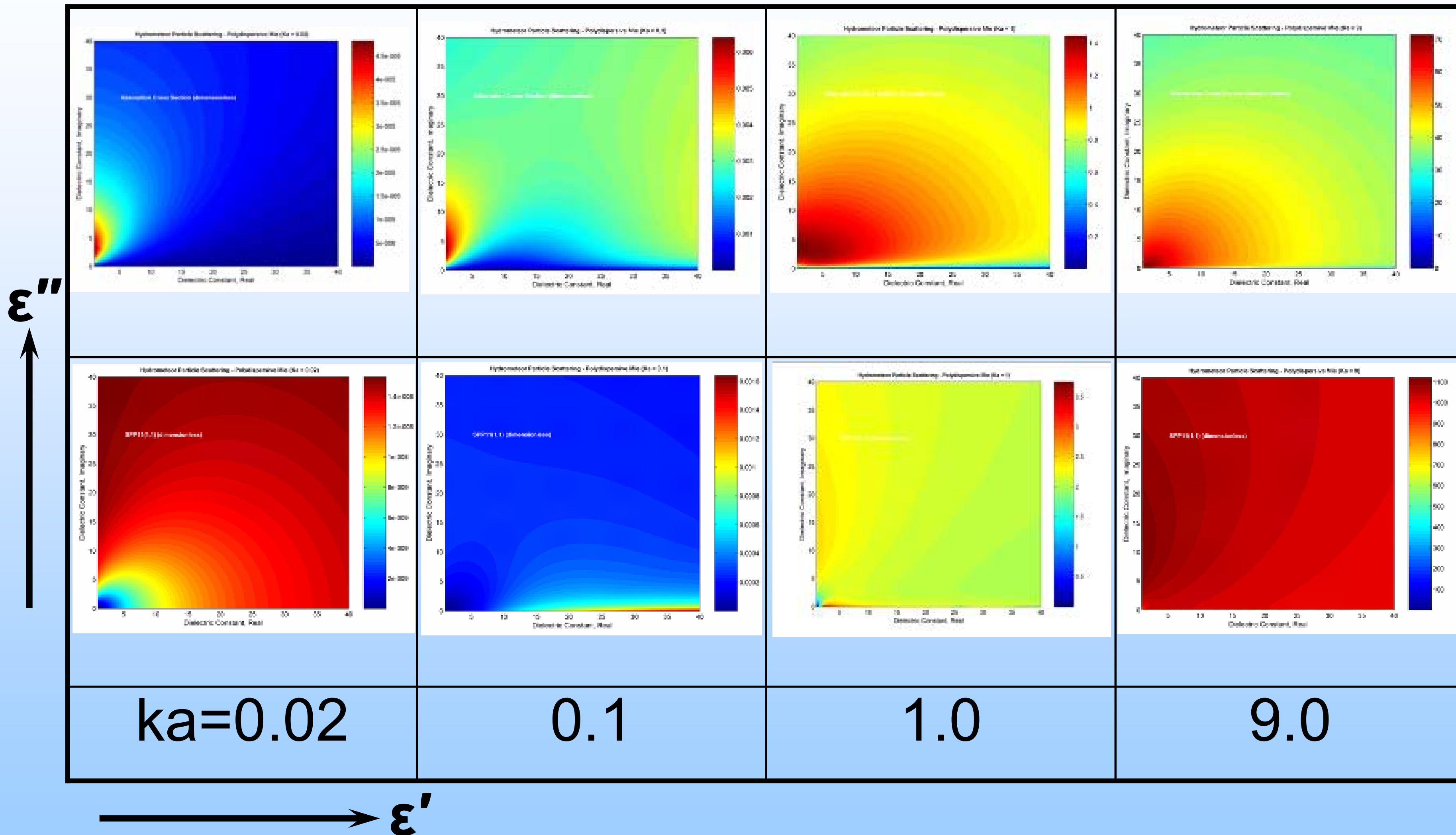
* Discrete Ordinate Tangent Linear Radiative Transfer Model

DOTLRT v2.1 - v2.0 Differences
(50 MB library relative to full Mie series calculation)





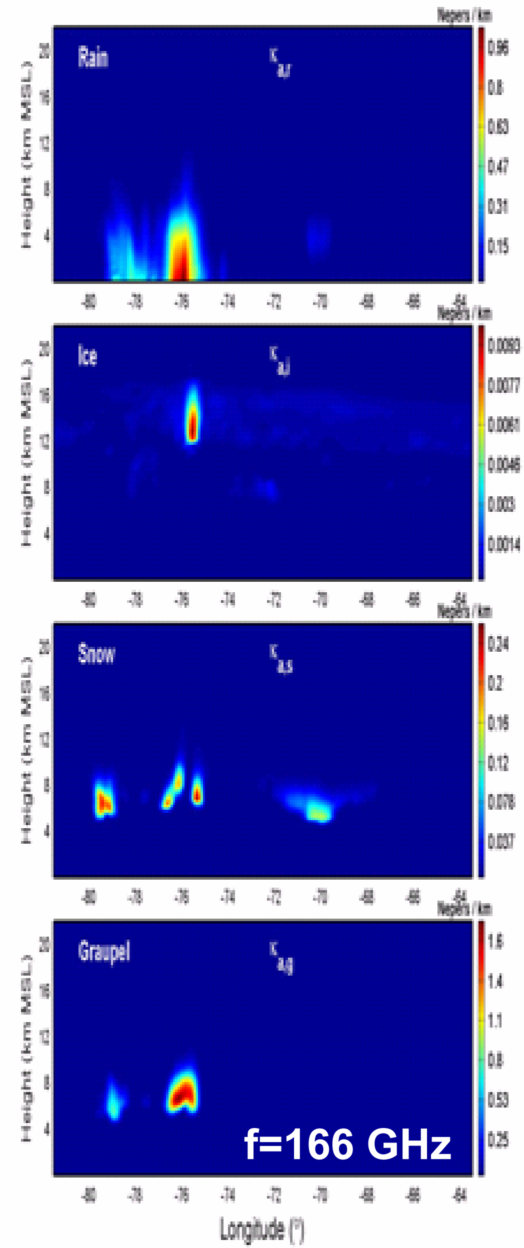
DOTLRT v2.1 Mie Products

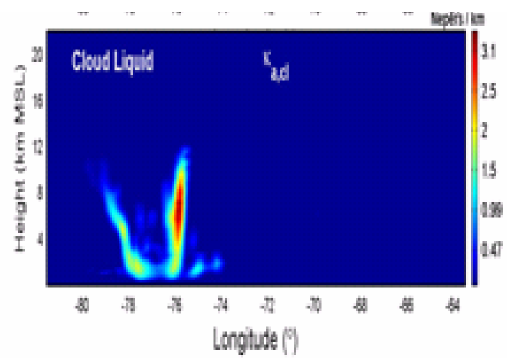


Top: Absorption cross section, **Bottom:** SPP11(1,1) one of 72

DOTLRT v1.0c: HGPM Mie Table

- Henyey-Greenstein Mie table for $<\kappa_a>$, $<\kappa_s>$, $<g>$ and temperature derivatives for each of five phases versus ka, ε',ε", and dε'/dT, dε"/dT
- Library size ~50 MB, fully CRTM compliant
- Major speed improvement relative to DOTLRT v1.0b
- Delivered to JCSDA: Dec 2006*





*** Weber, et al., "The Discrete Ordinate Tangent Linear Radiative Transfer (DOTLRT) v1.0c Model: Interface to JCSDA Community Radiative Transfer Model (CRTM), December 2006"**

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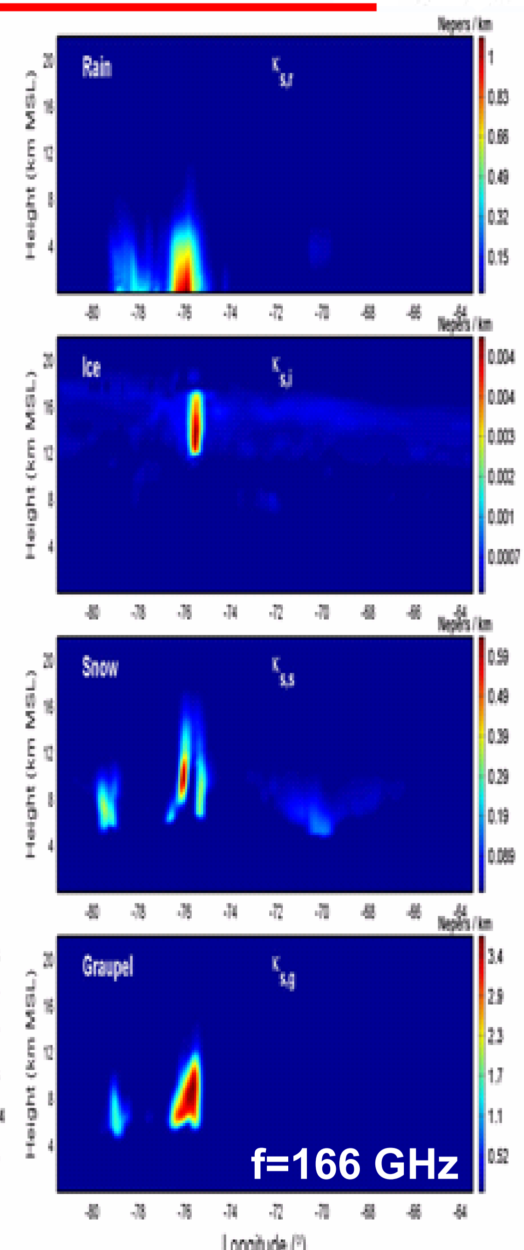

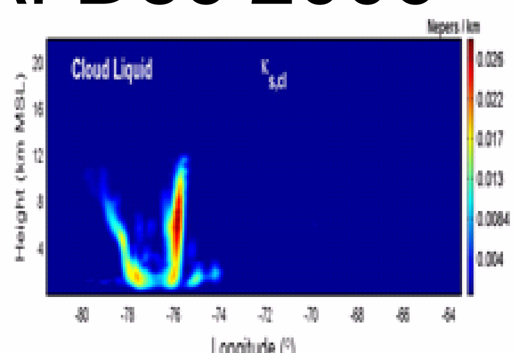

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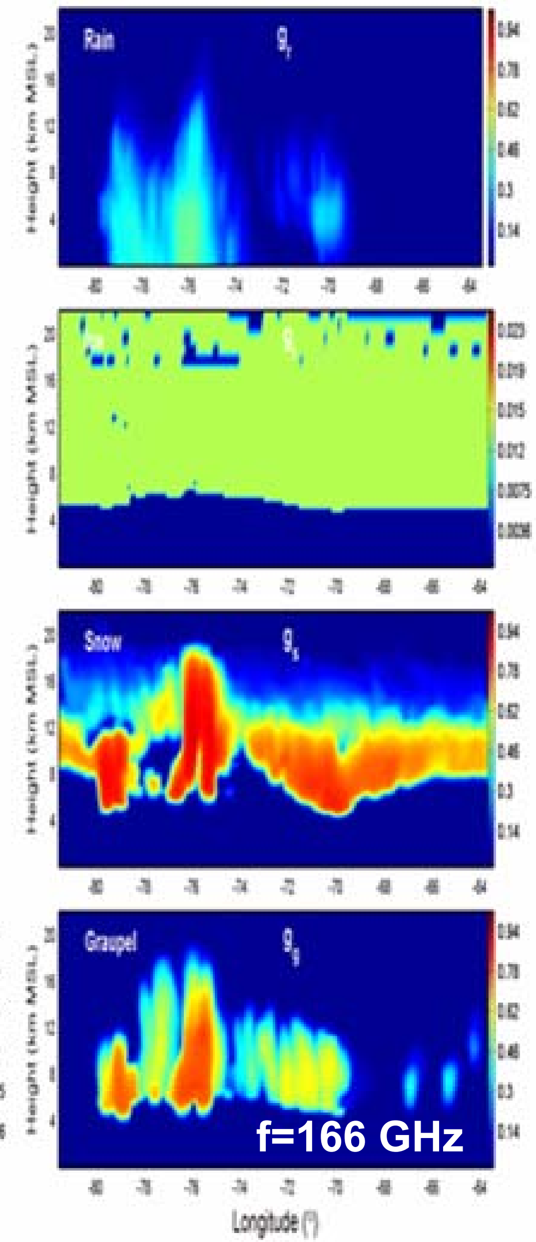

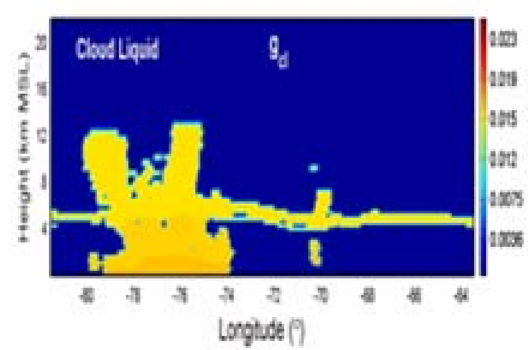

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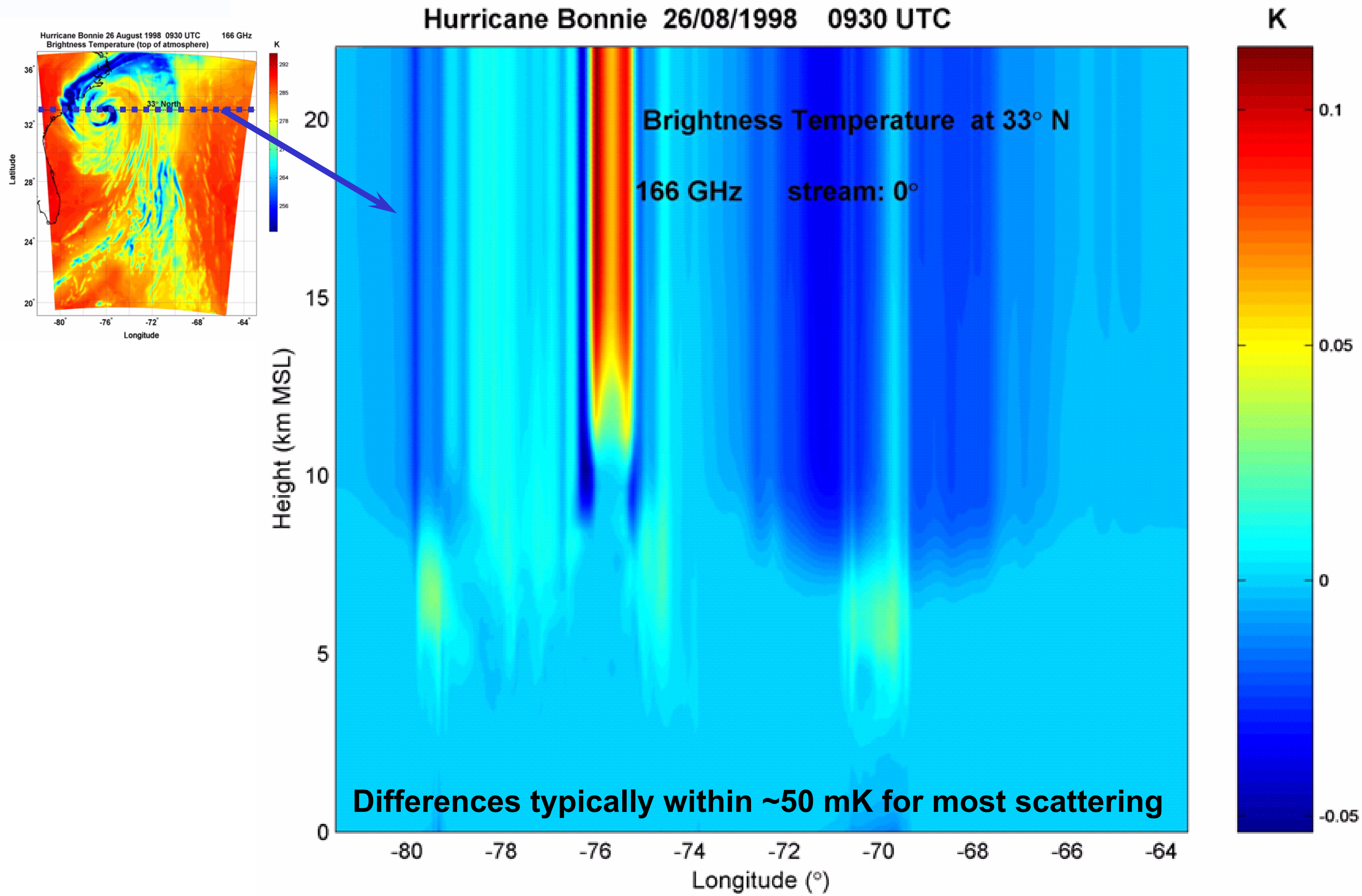
DOTLRT v1.0c Differences
(relative to v1.0b)



Summary (RT Modeling)

- A full Mie phase matrix version of DOTLRT compatible with CRTM has been developed (DOTLRT v2.0)
- A fast version of above with Mie lookup library was developed (DOTLRT v2.1), but required ~2.5 GB to achieve ~0.05K precision
- A fast CRTM-compatible version of DOTLRT using the Henyey Greenstein phase matrix and HGPM Mie lookup library was developed and distributed. This code is both fast and compact.
- Further comparisons and full Stokes enhancement are underway.