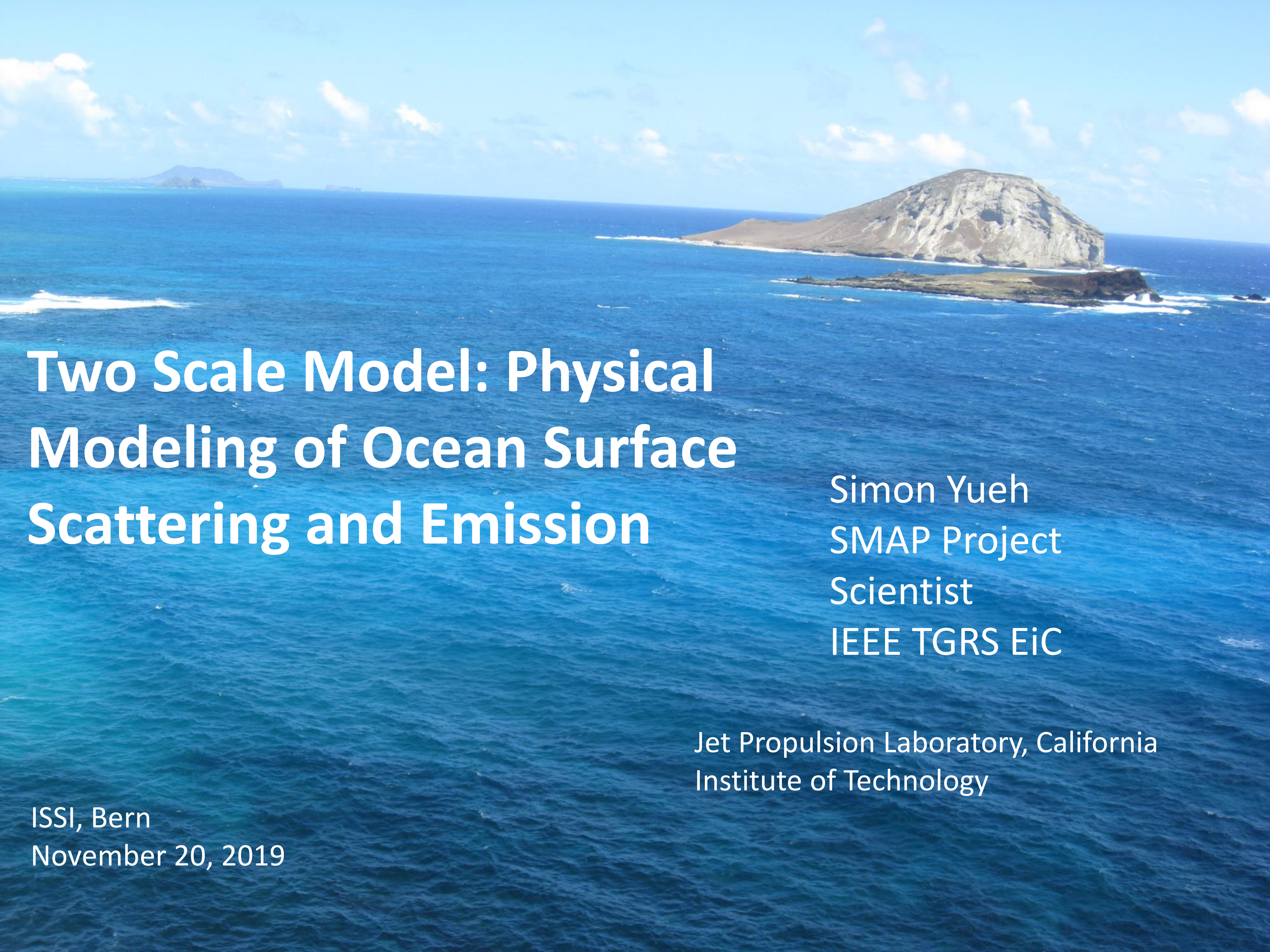

Two Scale Model: Physical Modeling of Ocean Surface Scattering and Emission

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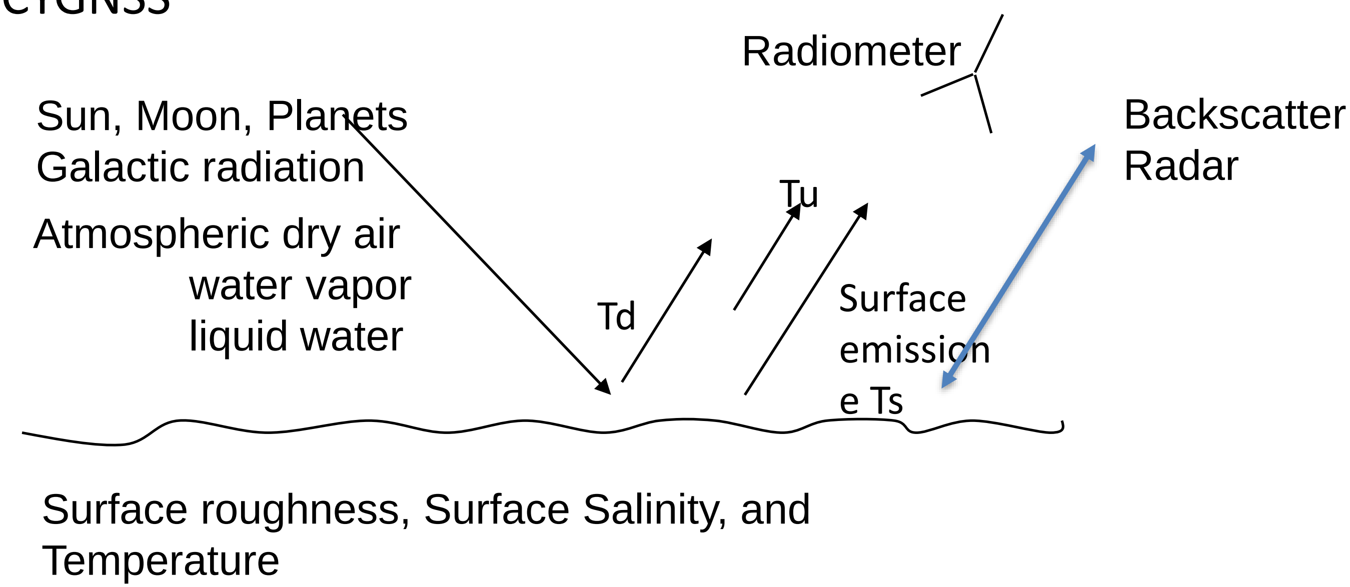
November 20, 2019

Outline

- Two Scale Models
- Recent Advancements
- Hwang's 2-Scale Model
- Some "unique" issues for L-band data
- Summary

Why is Ocean Surface Scattering and Emission Important?

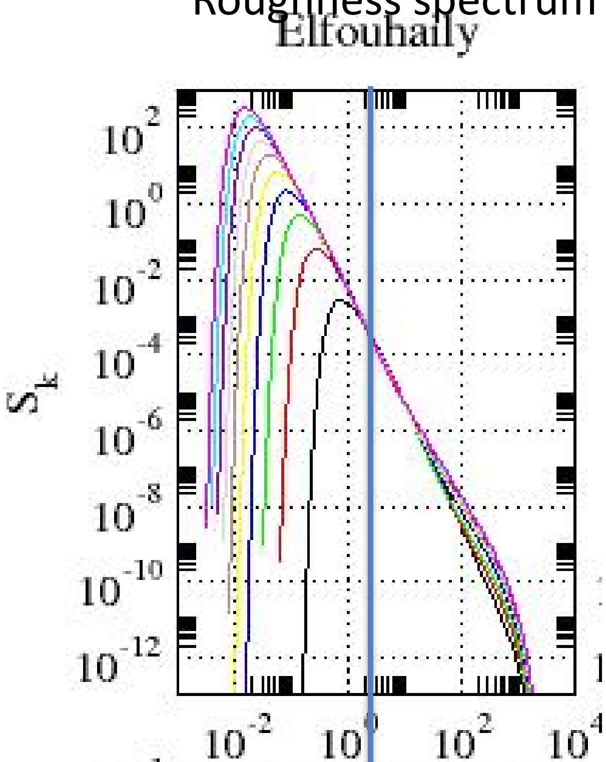
- Ocean surface roughness modulates emissions and scattering by sea surfaces
- Accurate modeling beneficial to many space missions. For examples,
  - Scatterometry: ASCAT, QSCAT
  - Radiometry: SSMI, SSMIS, AMSR, WindSAT, SMOS, Aquarius, and SMAP, CIMR
  - Reflectometry: CYGNSS



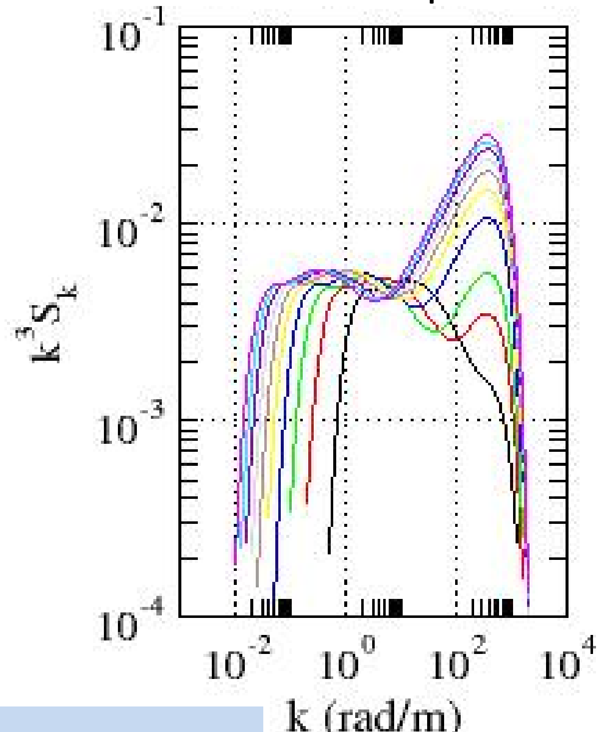
Two Scale Model

- Sea surfaces have a wide range of scales and features: waves and foams
- Two scale models – divided the sea surface roughness into two scales (large and small)
  - Small scattering modelled by Bragg scattering that can be treaded by the Small Perturbation Method)
  - Large scale surfaces introduced a tilting, which can be treated by Geometric Optics)

Roughness spectrum



Curvature spectrum



Kd: cutoff wavenumber

Geometrics Optics | Bragg scattering

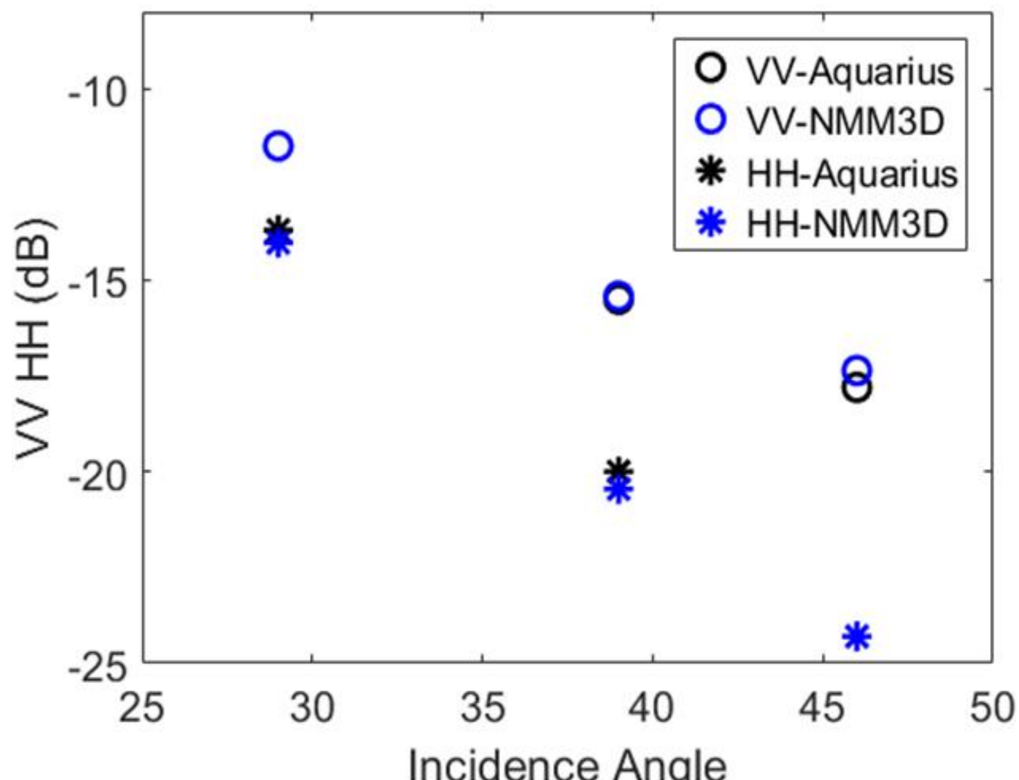
Key Issues for Two Scale Models

- Is the composite scattering model sufficiently accurate?
  - Sample publications on scattering and emission modeling: Semynov, 1966; Wu and Fung, 1972; Wentz, 1975; Durden and Vesecky, 1985; Yueh, 1997
  - Kd is an ad hoc parameter
- Description of sea surface spectrum: Pierson and Stacy, 1973; Fung and Lee, 1982; Donelan and Pierson, 1987; Apel, 1994; Elfouhaily et al., 1997; Wackerman et al., 2002, Kudryavtsev, V et al., 1999, 2003; Hwang et al., 2011, 2012, 2018, 2019
- How to model breaking waves?
  - Wedge scattering, multiple scattering
  - West and Ja, 2002
- How to model foam?

Validation by Numerical Solution of Maxwell's Equations

Qiao, Tsang, Vandemark, Yueh, Liao, Nouguier, Chapron, Sea Surface Radar Scattering at L-Band Based on Numerical Solution of Maxwell's Equations in 3-D (NMM3D) IEEE TGRS, June 2018

- Generate random rough surfaces up to the size of 64 wavelengths based on Durden/Vesecky spectrum
- Solve the surface scattering problem using numerical techniques for ~30 realizations

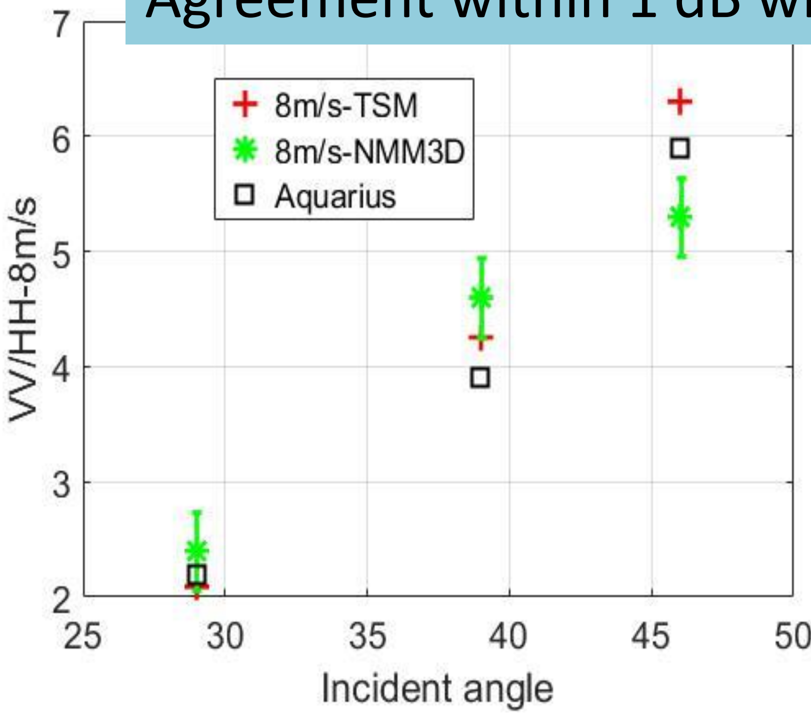


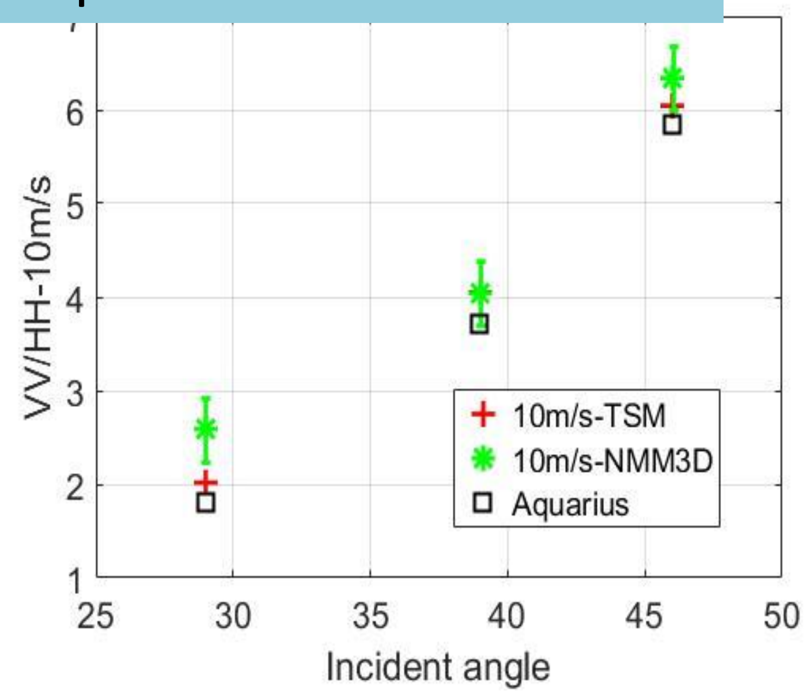
L-band backscatter at a wind speed of 5 m/s for different incidence angles: 29, 39, 46 degrees and isotropic DV spectrum compared with upwind Aquarius data

Validation by Numerical Solution of Maxwell's Equations –VV/HH Ratio

Qiao, Tsang, Vandemark, Yueh, Liao, Nouguier, Chapron, Sea Surface Radar Scattering at L-Band Based on Numerical Solution of Maxwell's Equations in 3-D (NMM3D) IEEE TGRS, June 2018

Agreement within 1 dB with Aquarius Model at L-band





Comparison of NMM3D and two scale model of VV/HH with Aquarius at 29°, 39°, and 46°. NMM3D is using isotropic DV spectrum for 8 m/s and anisotropic DV spectrum for 10 m/s. TSM with kd=k0/2 is derived using the anisotropic DV spectrum for wind = 8 and 10m/s. Each data point is obtained by averaging over all wind directions.

Features of Roughness Spectrum

- Nominally expressed as linear sum of low and high number spectra

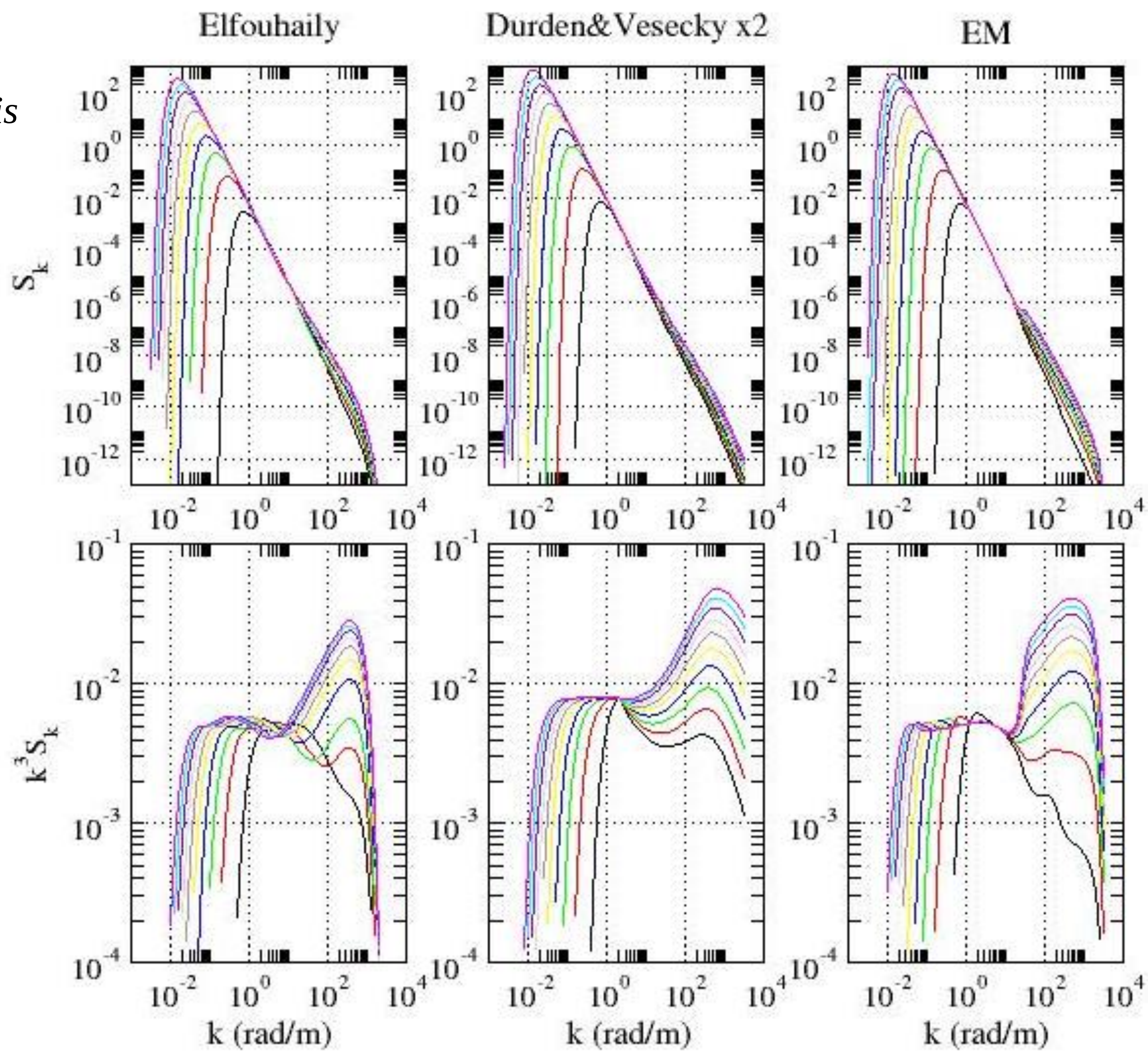
$$S_k = k^{-3}(B_l + B_h)V_{dis}$$

$$B_l = B_{lo} \cdot F_p$$

$$B_{l0} = 0.004$$

$$k_{dis} = 6238$$

$$V_{dis} = \exp[-(k / k_{dis})^2]$$



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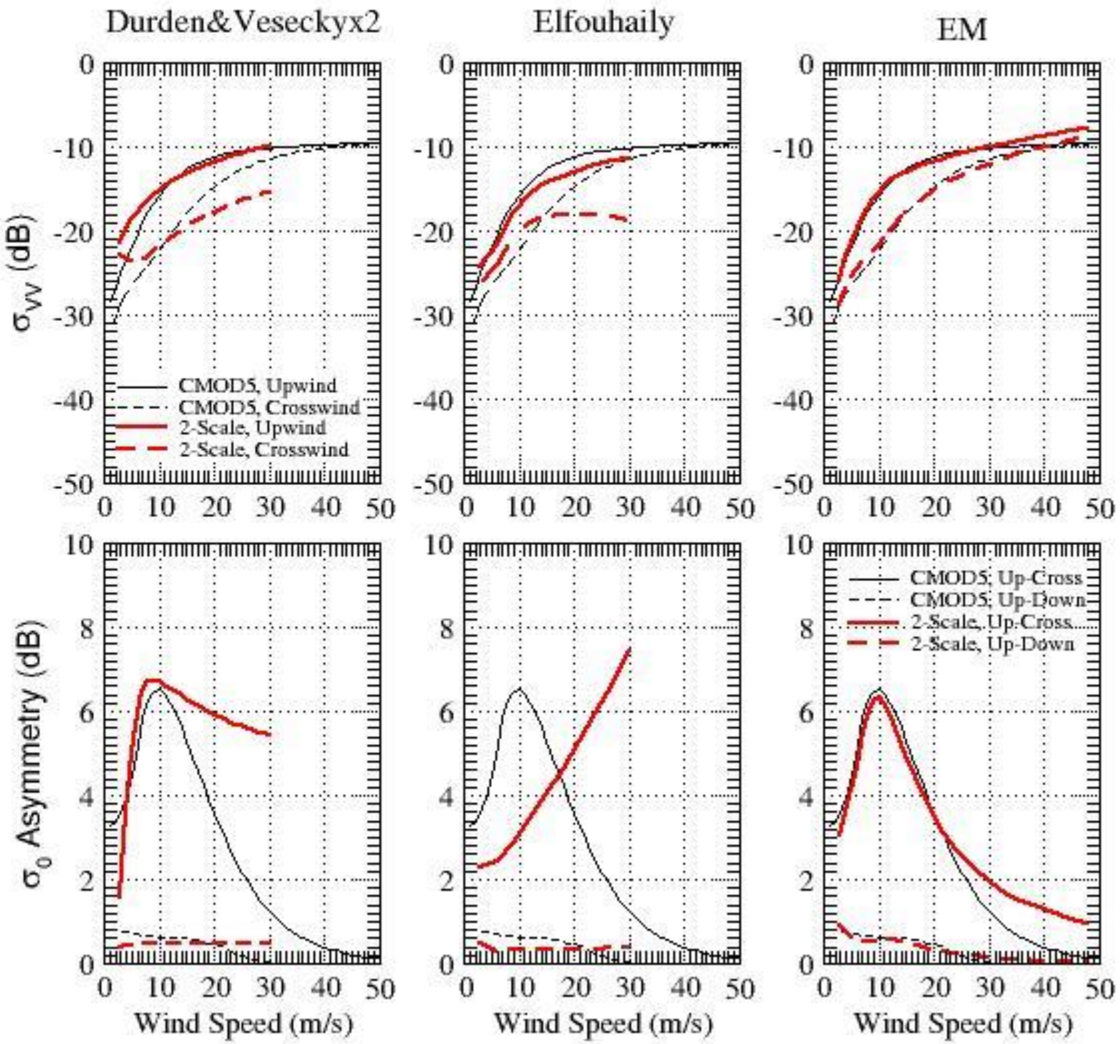
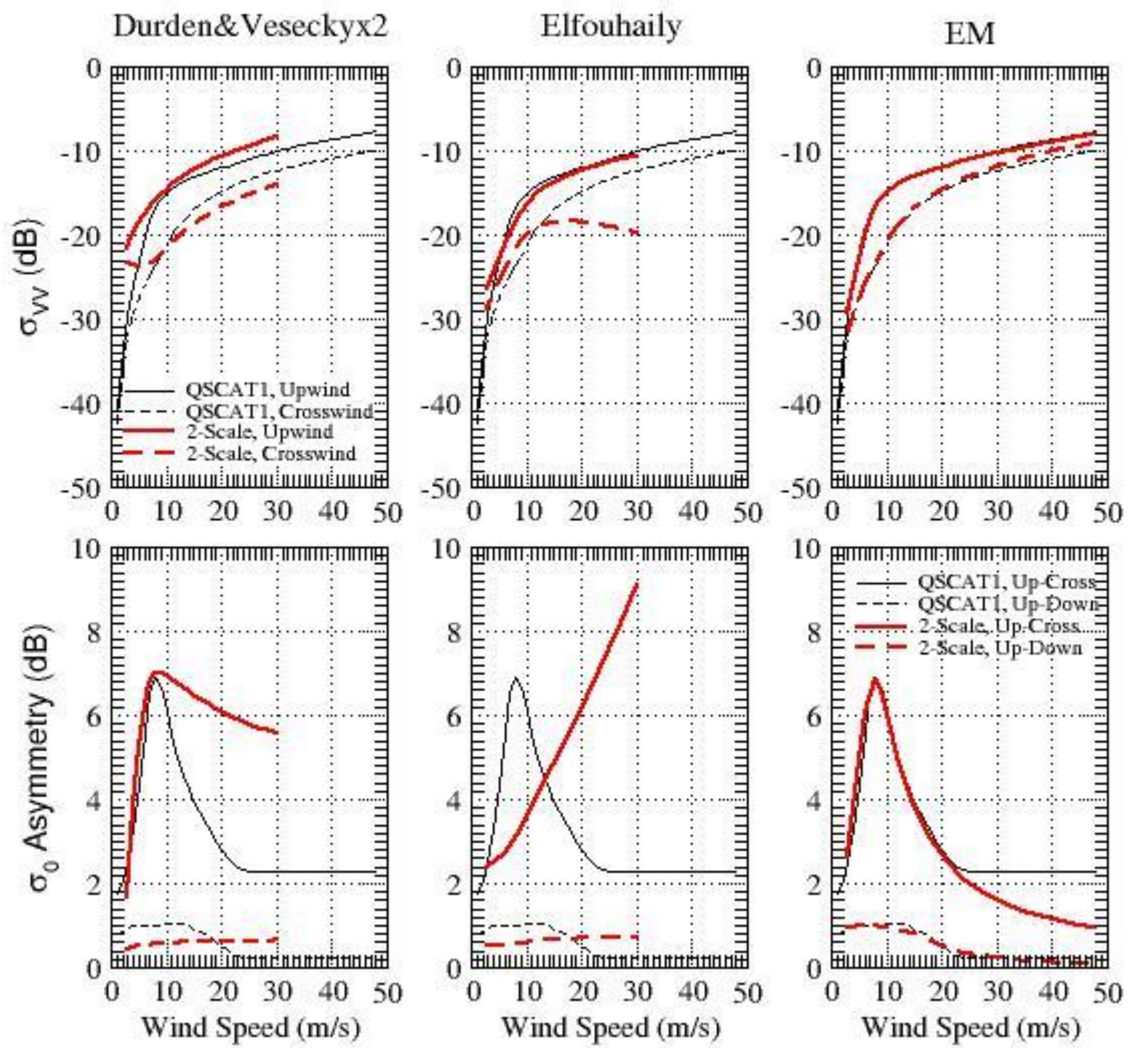
2-Scale Model Comparison with CMOD5

- Spectrum can be tuned to fit the C-band scatterometer data



2-Scale Model Comparison with QSCAT1

- Spectrum can be tuned to fit the C-band scatterometer data



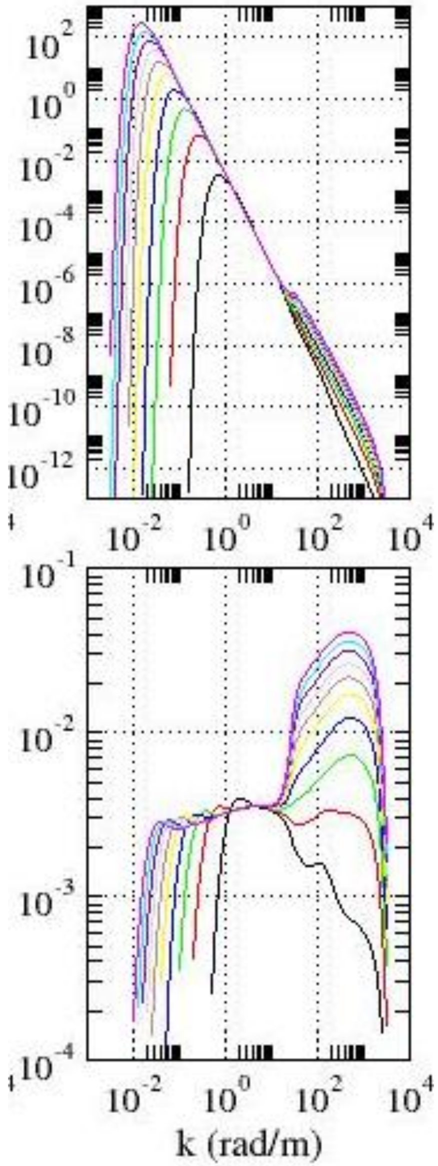
Sensitivity to Long Wave

$$S_k = k^{-3}(B_l + B_h)V_{dis}$$

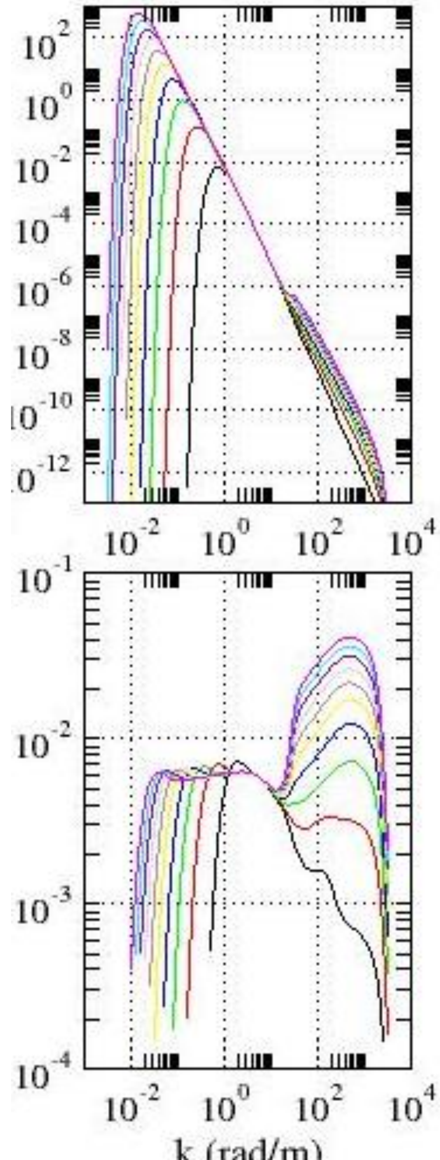
$$B_l = B_{lo} \cdot F_p$$

$$B_{l0} = 0.004$$

- Bl=0.002



- Bl=0.005



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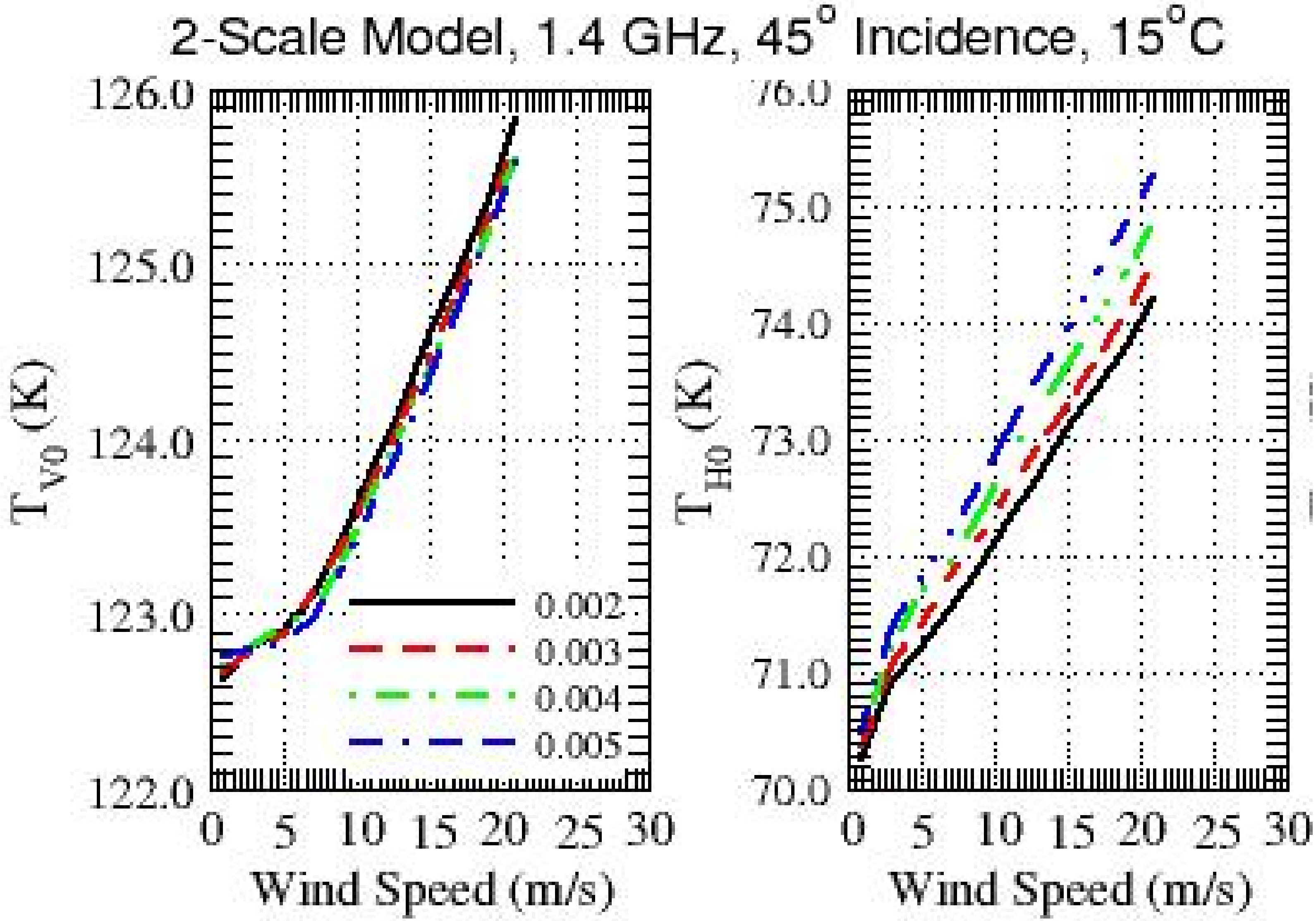
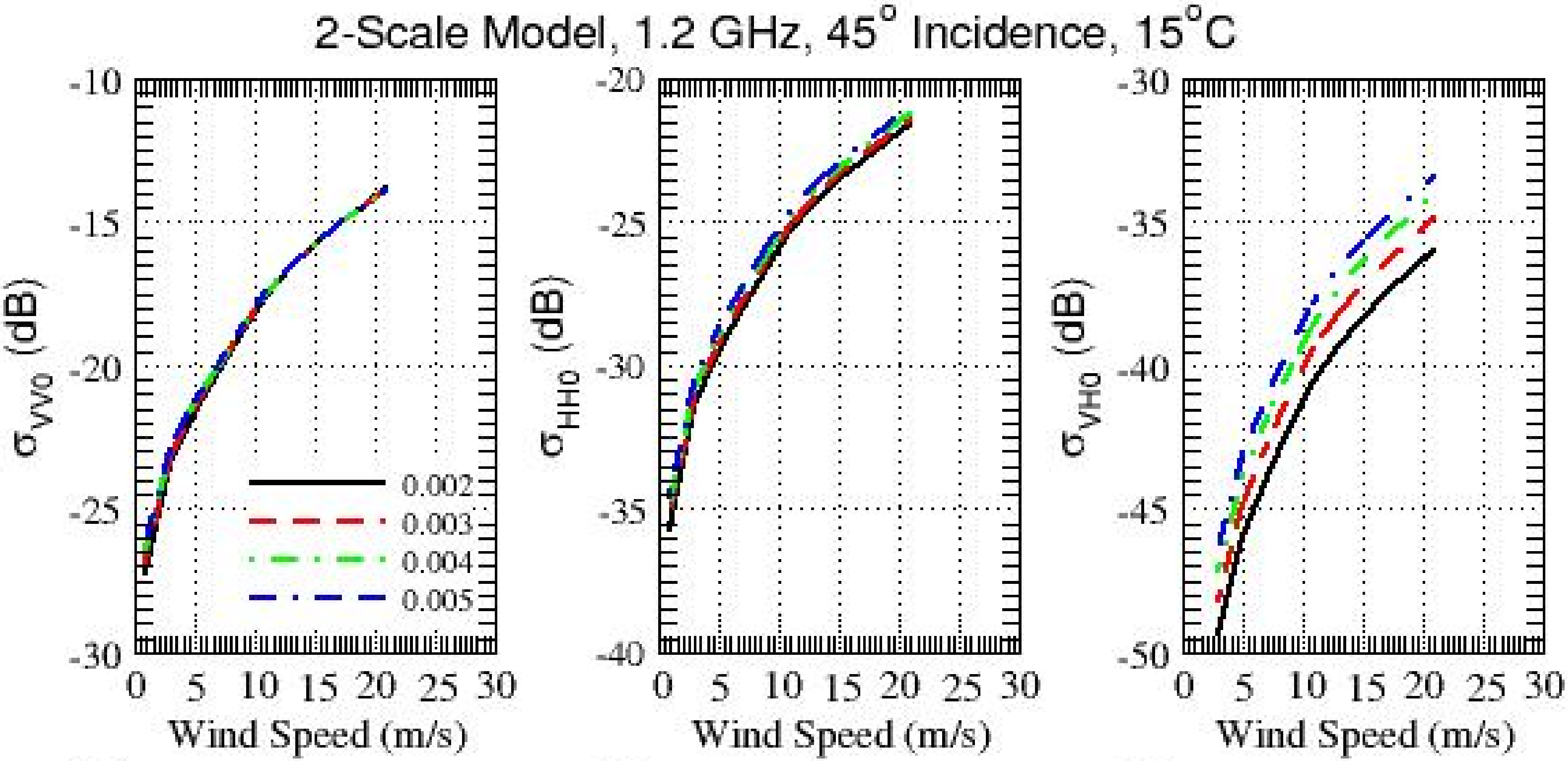
2-Scale TB Model Sensitivity to Large Scale Wave

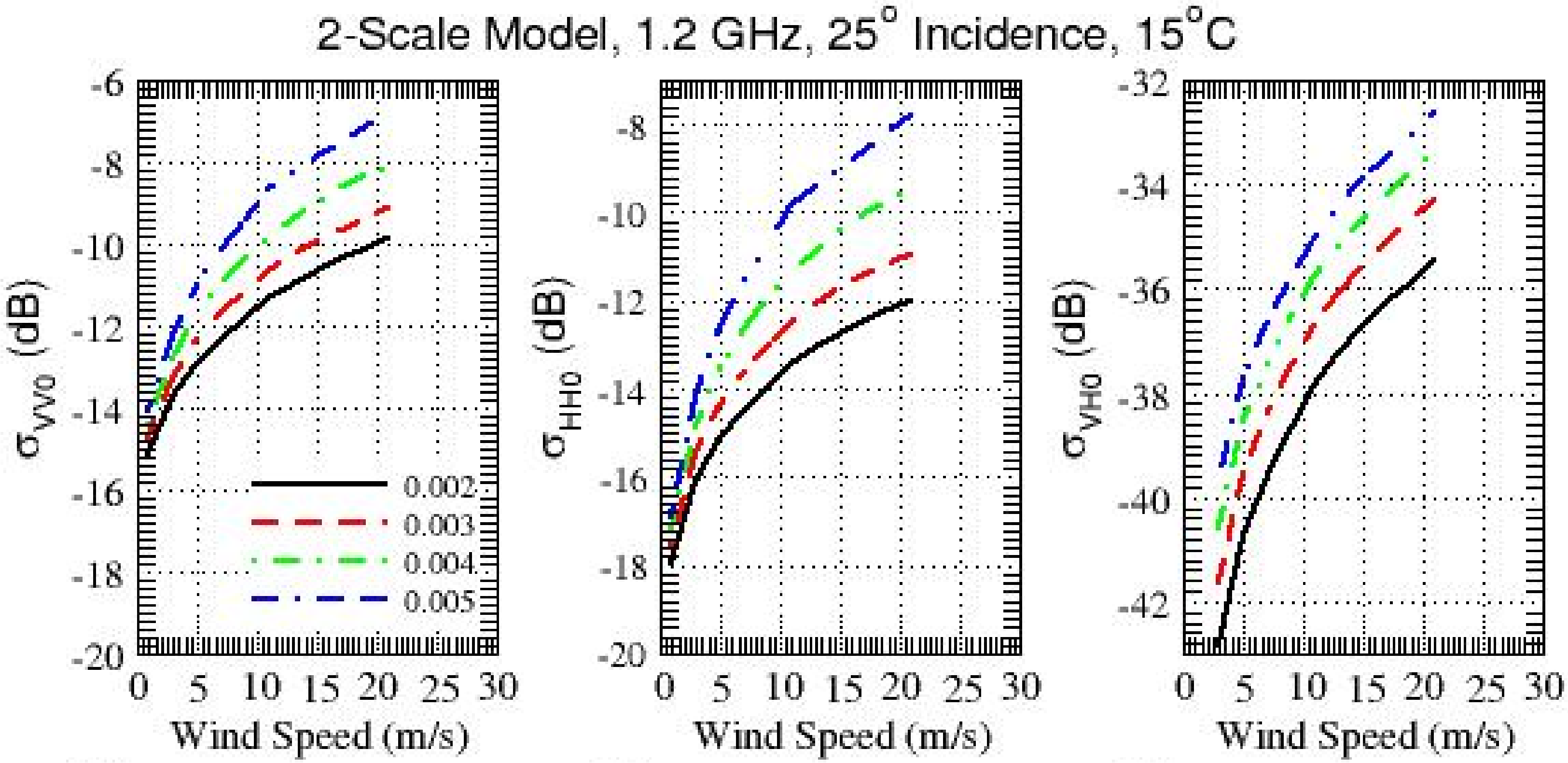


2-Scale Radar Model Sensitivity to Large Scale Wave



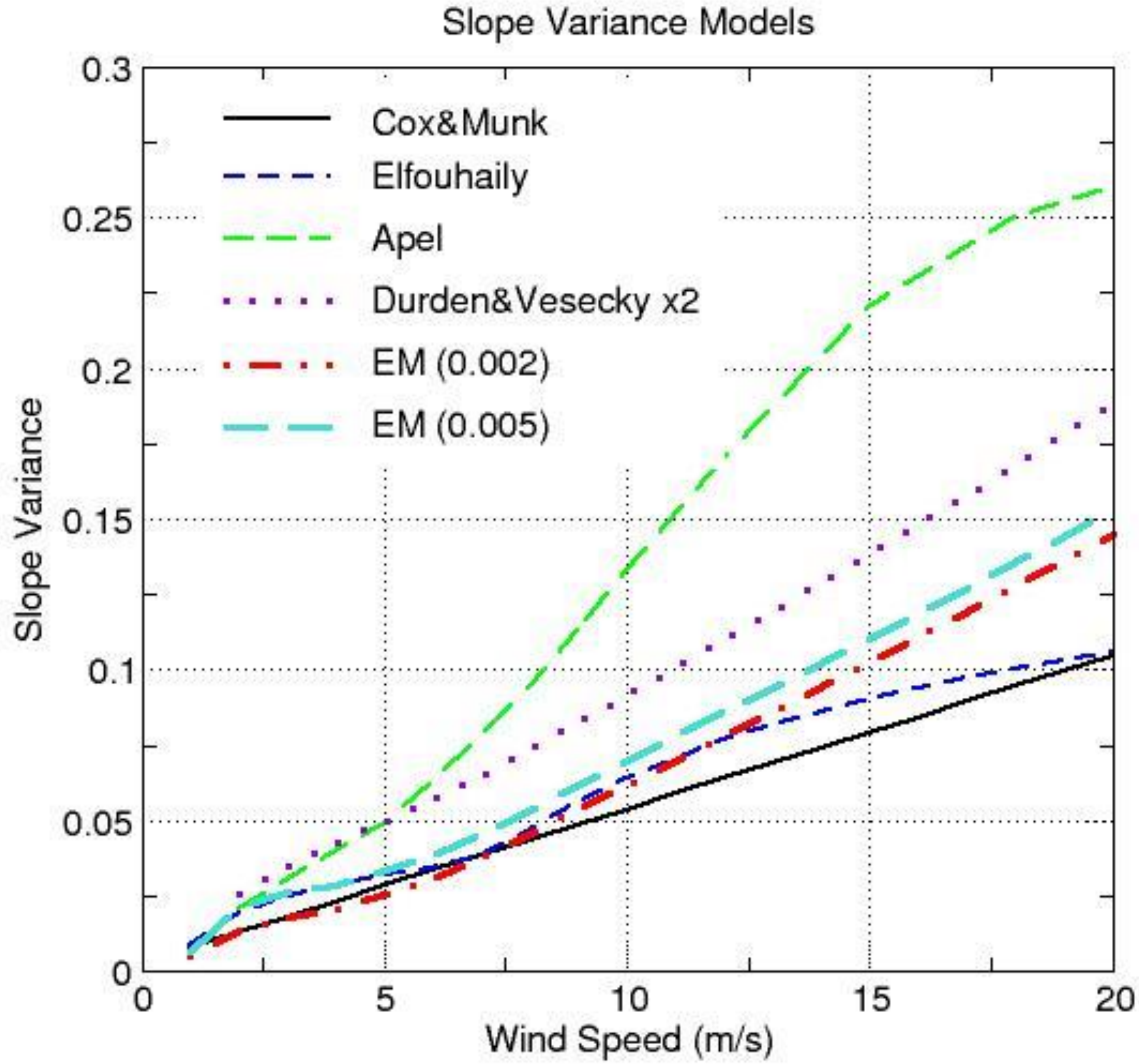
2-Scale Radar Model Sensitivity to Large Scale Wave

Large Impact at Low Incidence Angles



Total Wave Slope

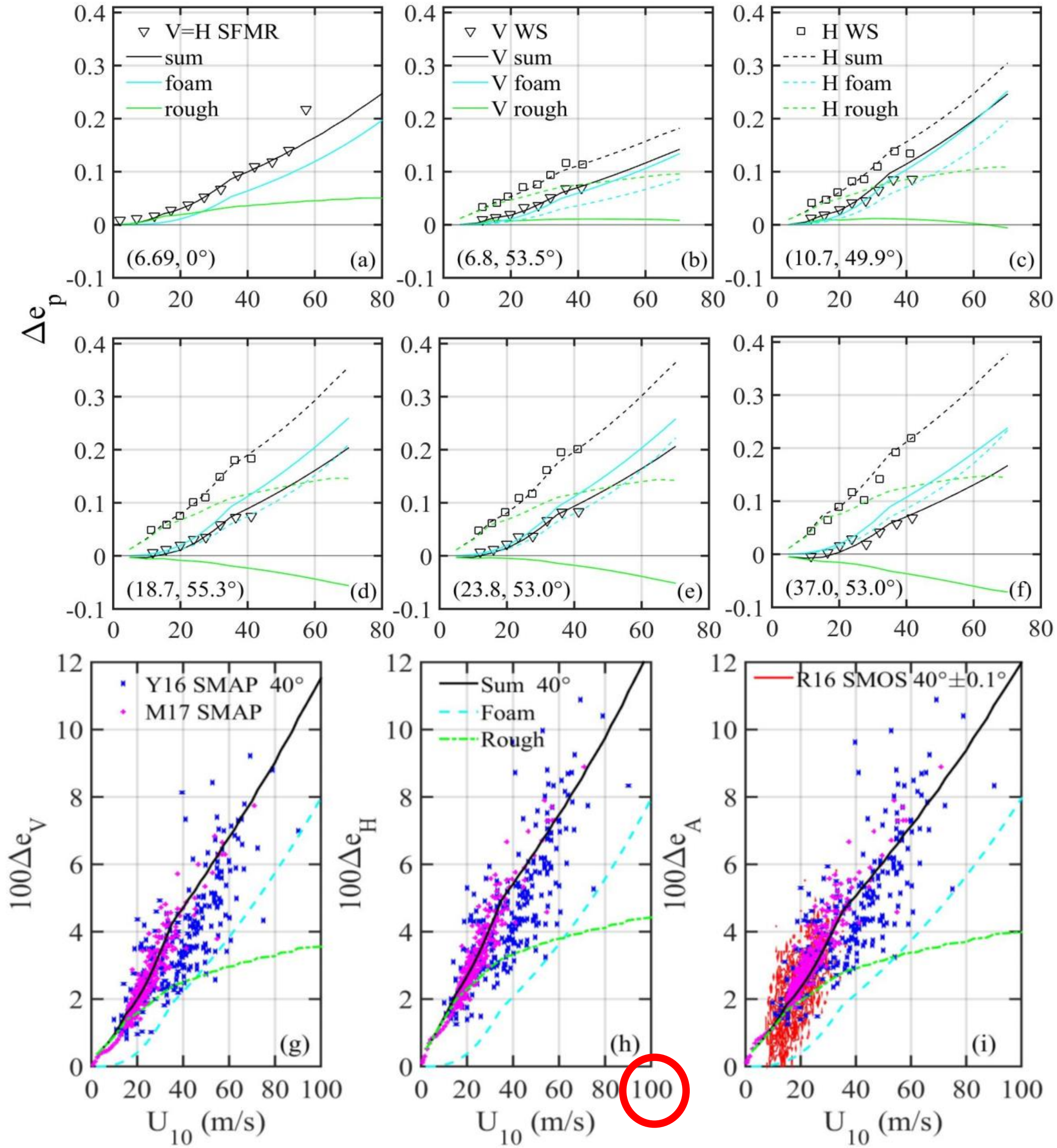
Cox&Munk has the smallest rms slope.



H-Spectrum and 2-Scale Model

Hwang et al., 2011, 2012, 2018, and 2019

Hwang et al. 2019



- Revised drag coefficient, wave spectrum, and foam models.

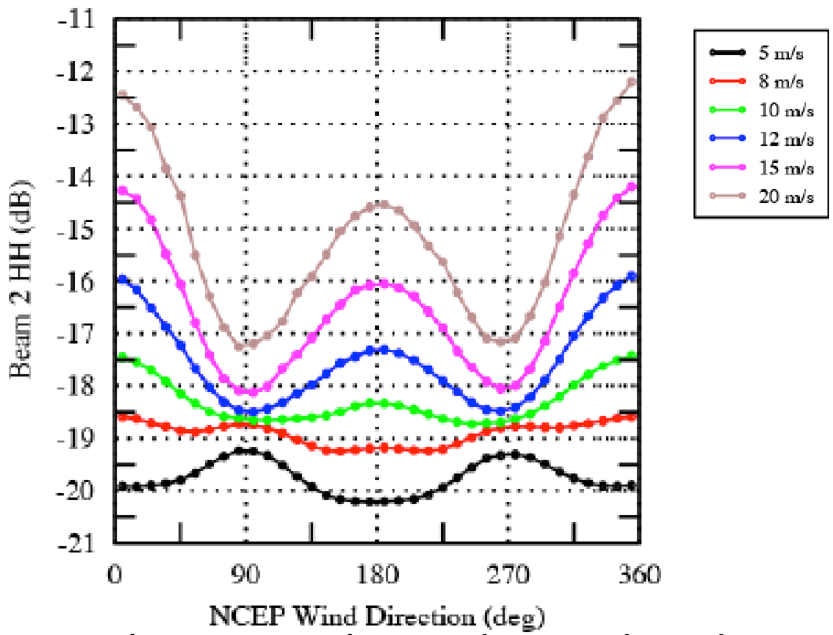
Calculated Δe_V and Δe_H at various microwave frequencies, and comparison with field data.

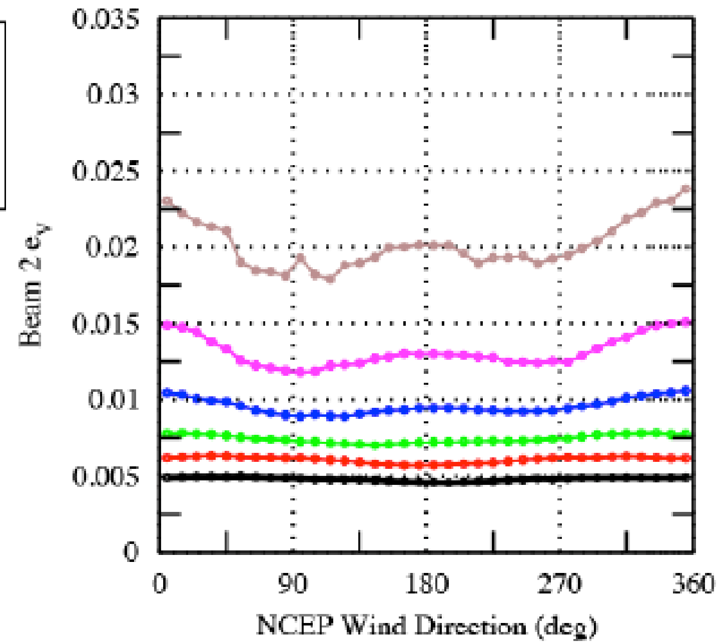
Top two rows: SFMR and WindSat (4.7 to 37 GHz)
Bottom row (L band 1.41 GHz): SMAP and SMOS

Sum, foam and roughness contributions are given by black, cyan and green curves, solid and dashed lines show vertical and horizontal polarizations, respectively. Numbers in parentheses are frequency (in GHz) and EIA.

Wind Direction Signatures in L-band Radar and Radiometer Signals

- The matchup of Aquarius data with NCEP wind direction, SSMIS wind speed indicates impact of ocean wind on radar and radiometer signals.
  - The charts below indicate the signal sensitivity for the data from Aquarius beam# 2 (~39 deg incidence angle)





- Radar signals vary with wind speed and wind direction
  - Cosine signal changes sign at about 8 m/s
- Radio emissivity (TB/Ts) varies with wind speed and wind direction

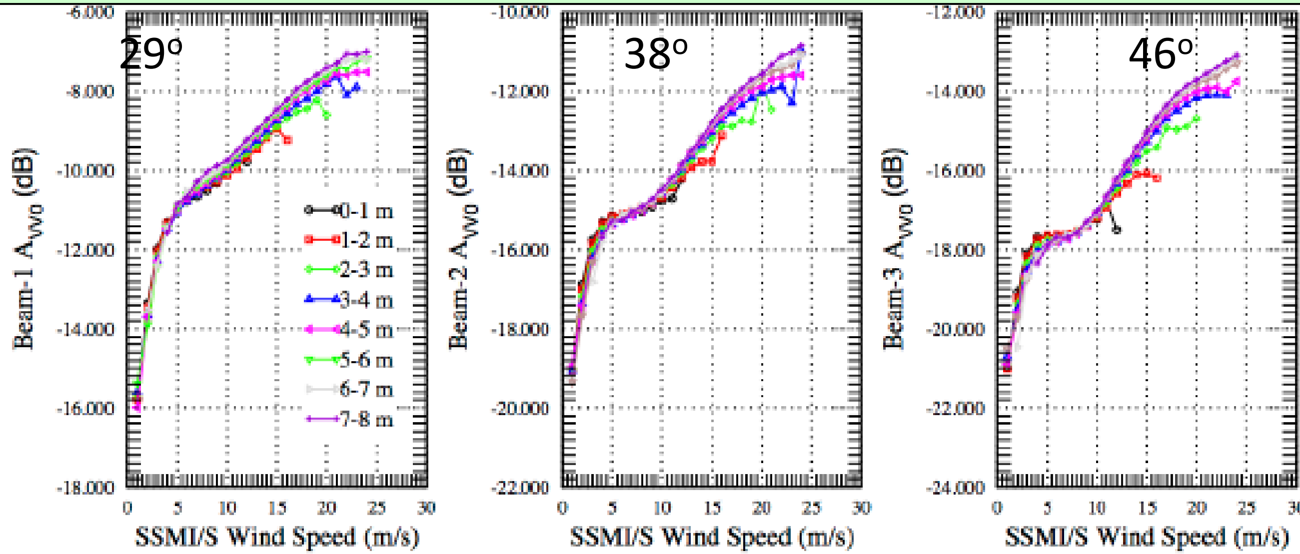
Present sea surface spectrum models do not have this directional reversal features.

Impact of Wave Height on Radar Data

Yueh et al., IEEE JSTARS, 2015

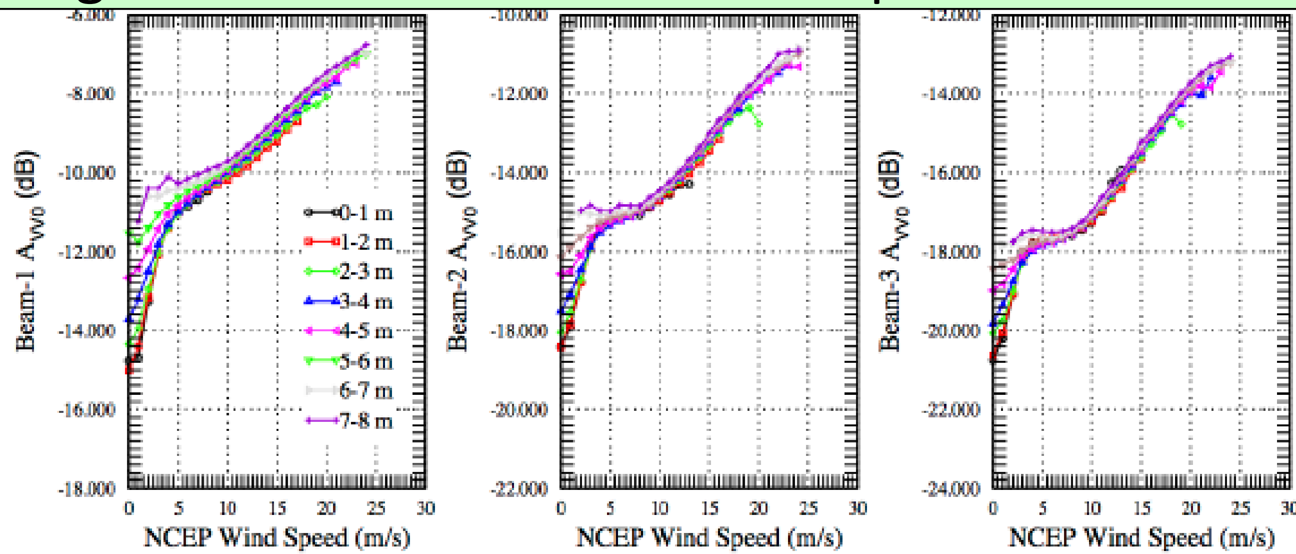
- SWH has strong influence at high SSMIS wind speeds.

Aquarius
SSMIS Wind
NCEP WW3 SWH



- SWH has strong influence at low NCEP wind speeds.

Aquarius
NCEP Wind
NCEP WW3 SWH



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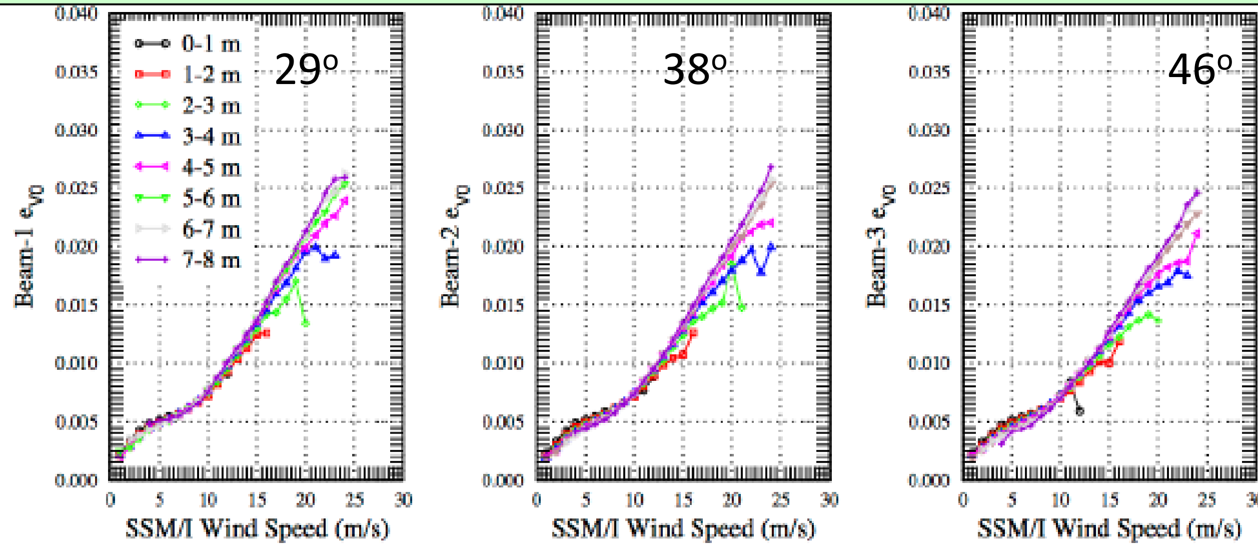
Impact of Wave Height on Radiometer TB

Yueh et al., IEEE JSTARS, 2015

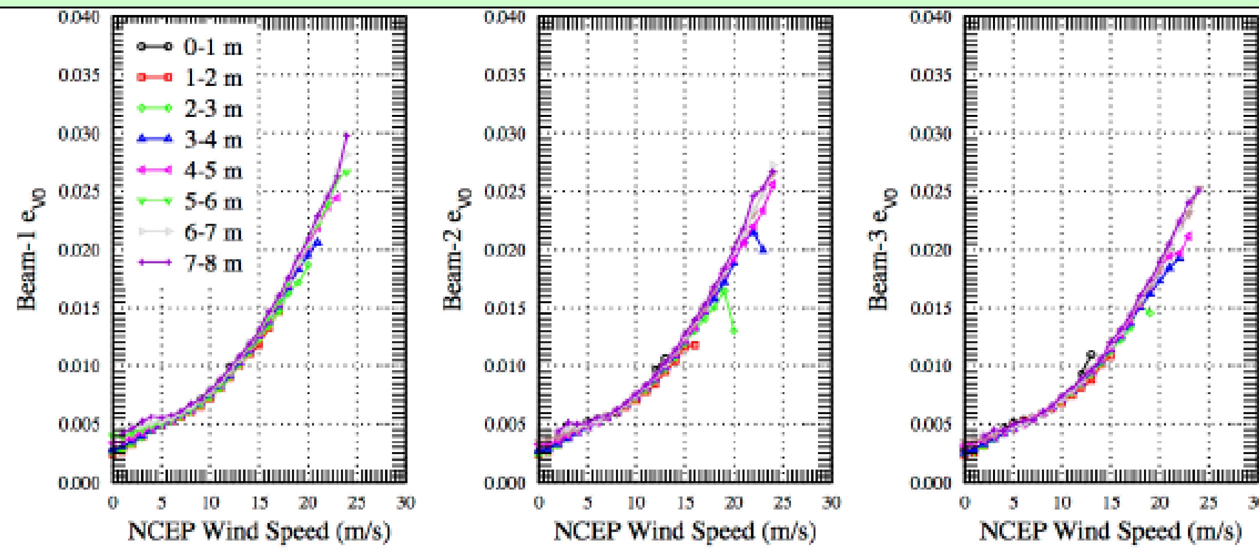
- WW3 SWH has strong influence at high SSMIS wind speeds.

Aquarius
SSMIS Wind
WW3 SWH



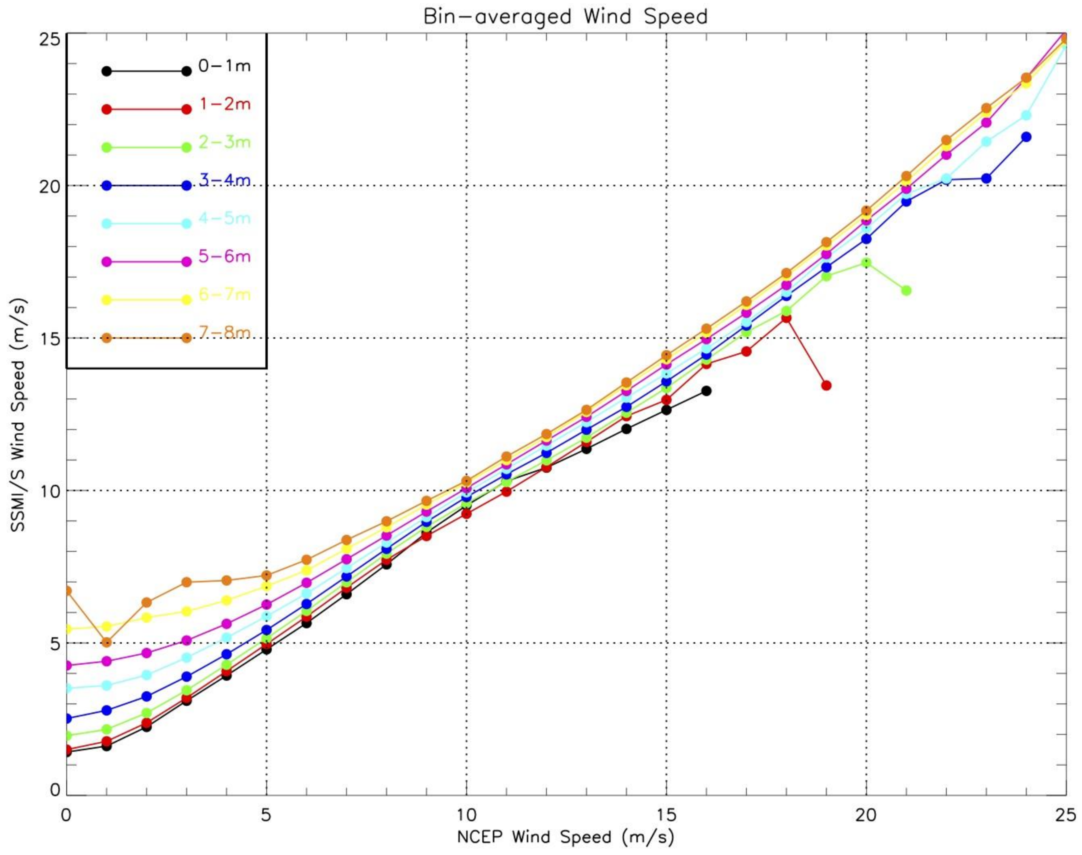
- WW3 SWH has strong influence at low NCEP wind speeds.

Aquarius
NCEP Wind
WW3 SWH

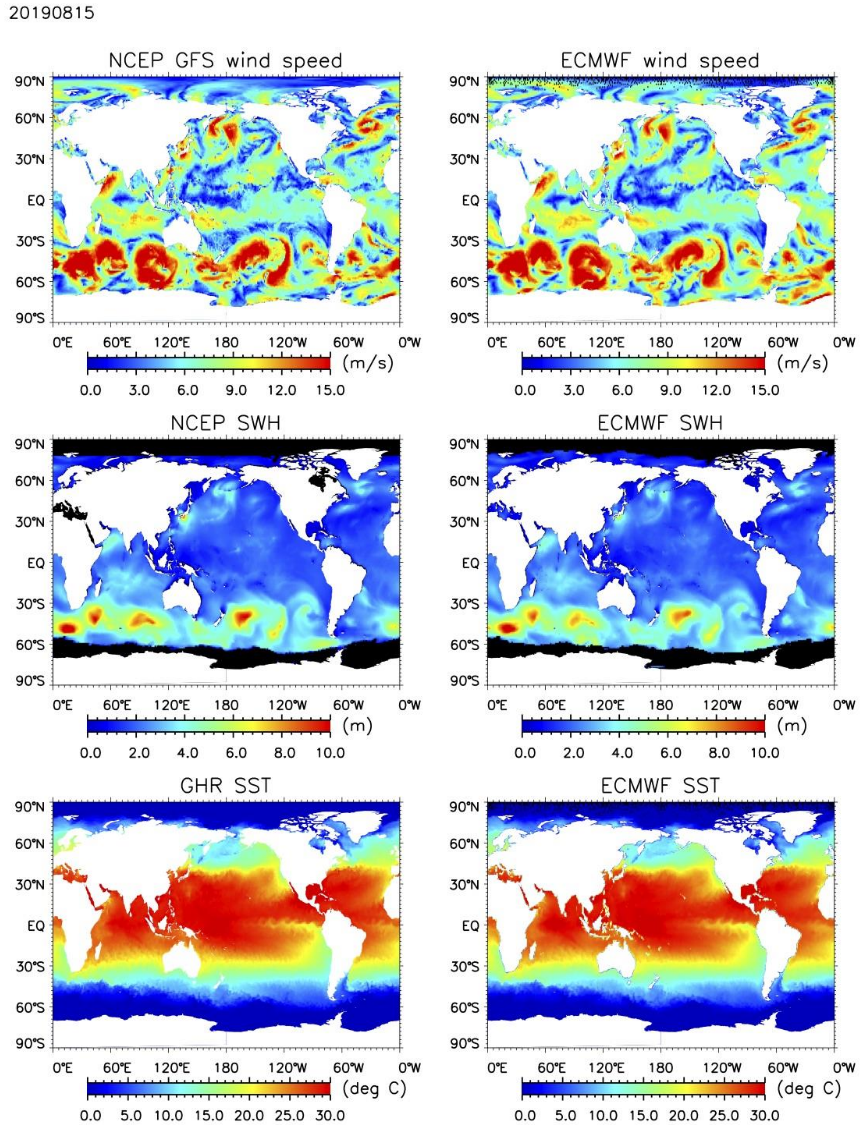


NCEP and SSMIS winds Based on Matchup Before 2015

- The difference has a systematic dependence on WW3 SWH
- NCEP wind is a data assimilation and numerical weather product

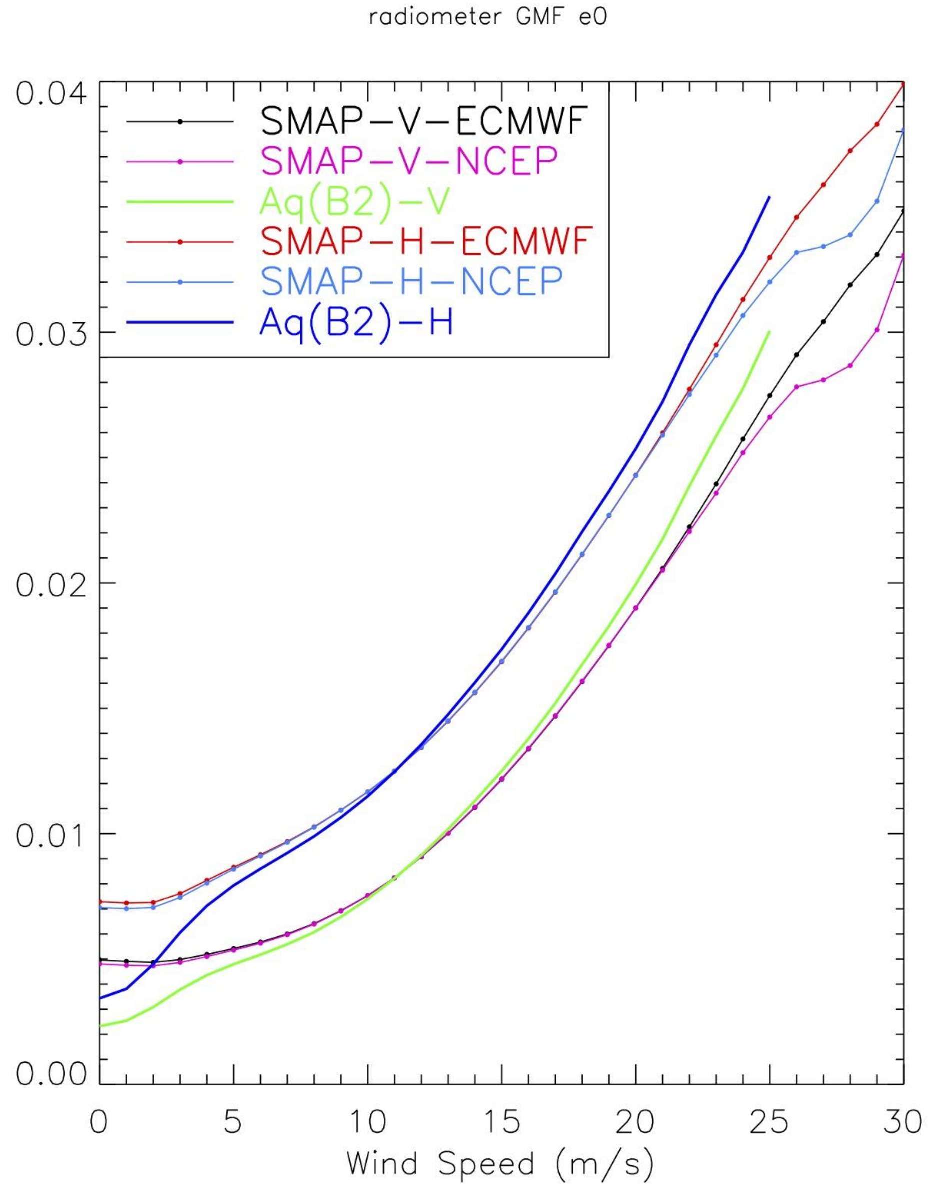


NCEP and ECMWF Are Similar Based on Recent Matchup with SMAP



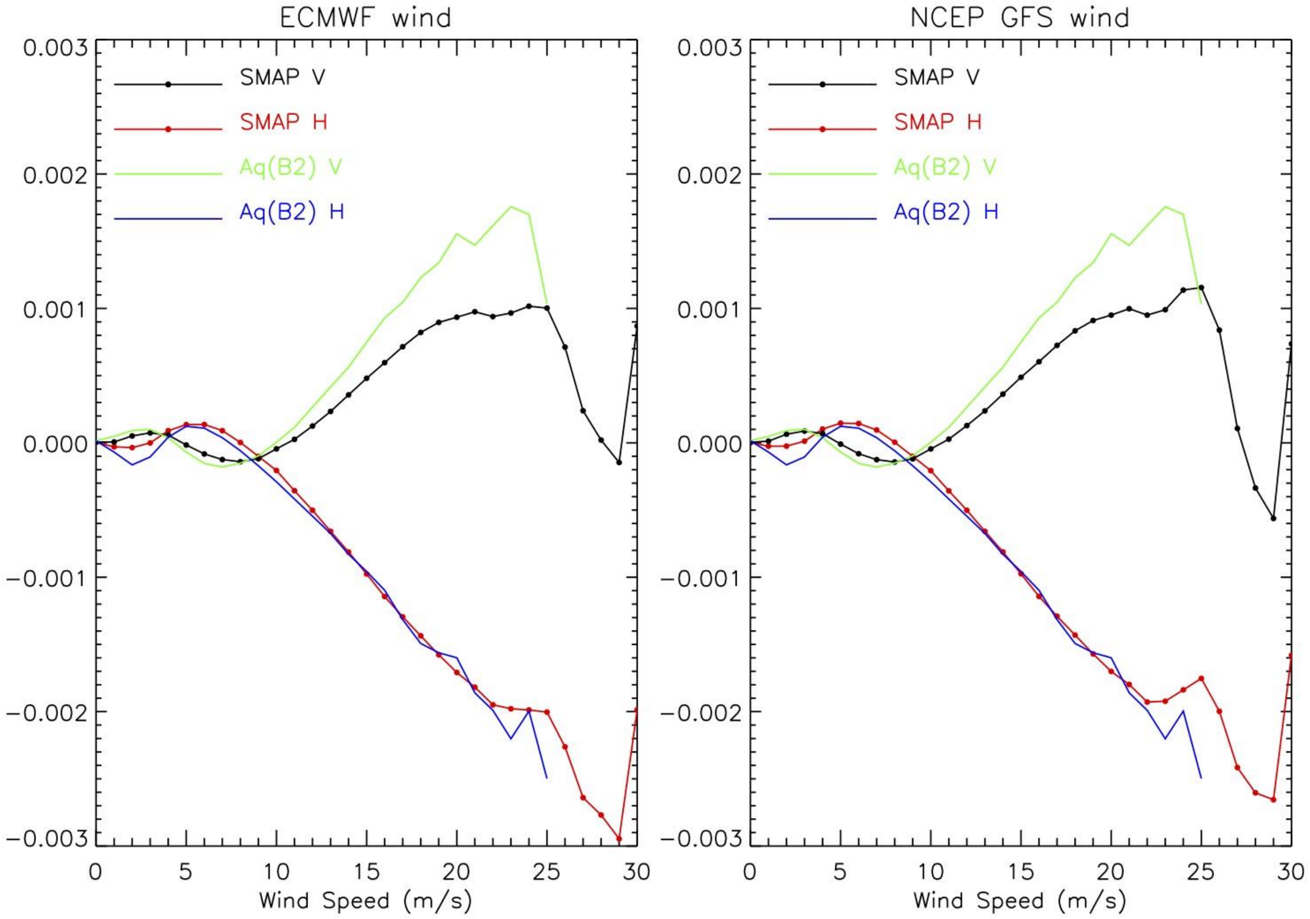
Excessive emissivity

- Similar excessive SMAP emissivity from NCEP and ECMWF
- Aquarius model based on SSMIS/WindSAT matchup is slightly different

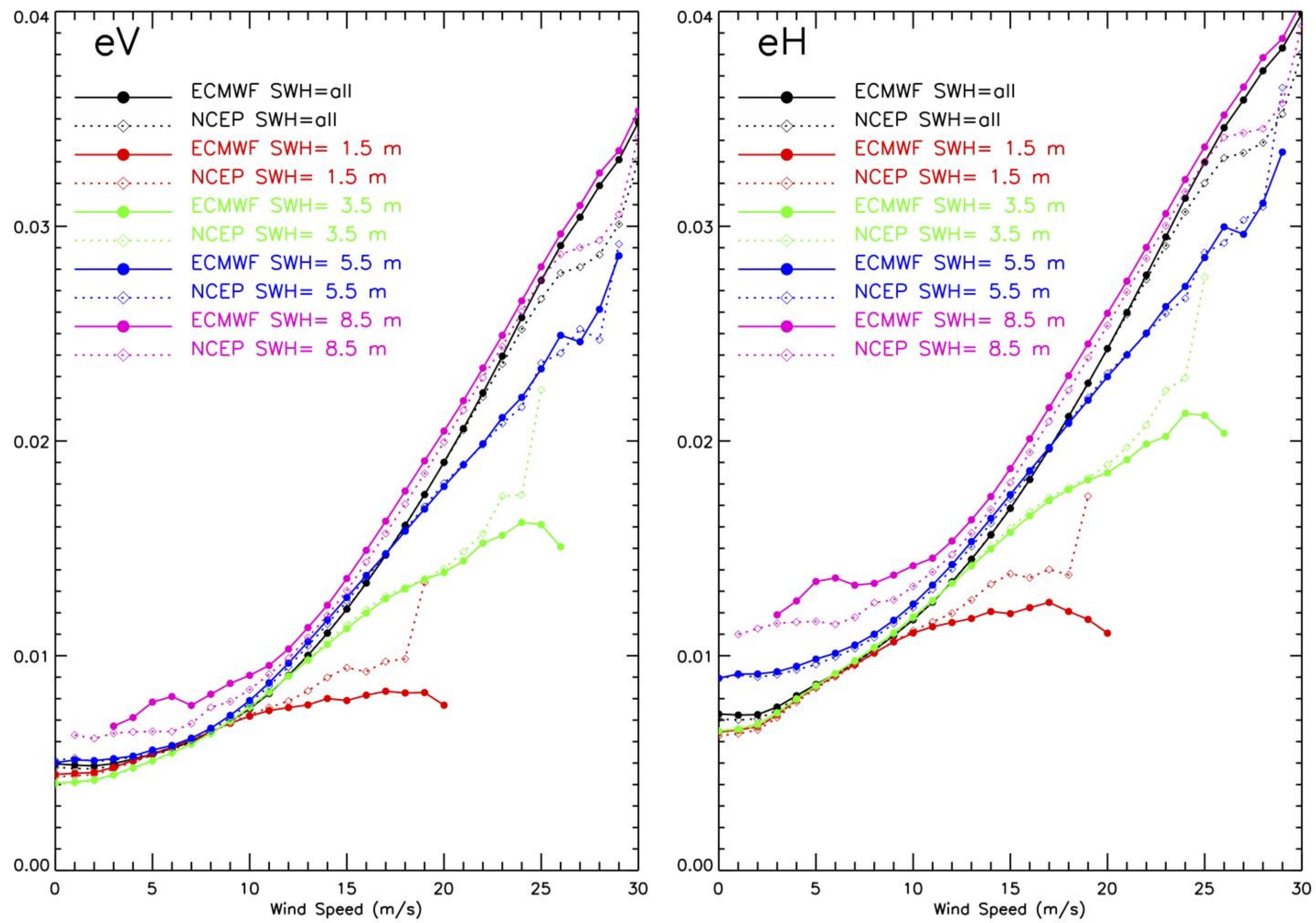


Excessive emissivity – 2nd Harmonics Dependence on Wind Direction

Similar excessive emissivity from NCEP and ECMWF matchups



Excessive emissivity
Dependence on Reference Wind and SWH



Summary

- The electromagnetic scattering part of 2-scale model appears to be quite accurate
- Semi-empirical wave spectrum and foam parameterization has been significantly improved to match experimental data from L- to Ka-band
- A few remaining issues
  - Directional wave spectrum for L-band frequencies
  - Wave impact
  - What should be the reference wind – NCEP/ECMWF or microwave?