THEORETICAL MODELING OF DUAL-FREQUENCY SCATTEROMETER RESPONSE: IMPROVING OCEAN WIND AND RAINFALL EFFECTS

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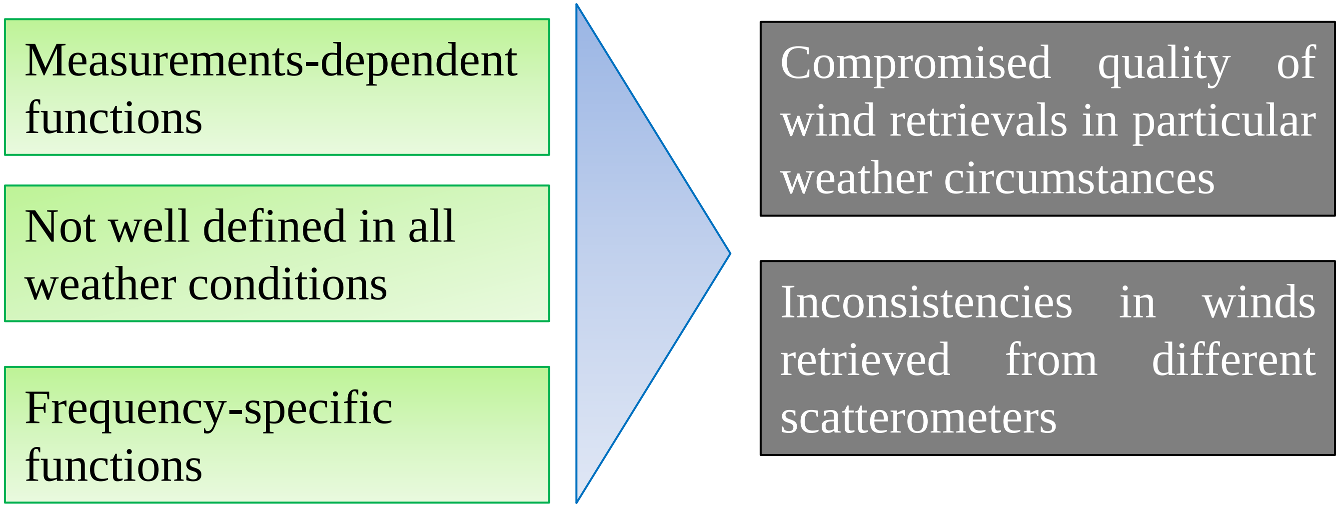
IOVWST Meeting May 2-4, 2017

Outline

- Theoretical Modeling in Presence of Wind
- Theoretical Modeling in Presence of Both Wind and Rain
- Conclusion

Introduction

Good confidence in the use of the **Geophysical Model Functions (GMFs)** to define the relationship between the ocean surface backscattering coefficient (σ^0) and **wind speed (ws)** / **wind direction (φ_R)** and to perform wind retrievals. However:



The GMF are:

- Measurements-dependent functions
- Not well defined in all weather conditions
- Frequency-specific functions

- Compromised quality of wind retrievals in particular weather circumstances
- Inconsistencies in winds retrieved from different scatterometers

Goals: Improving Theoretical Models

The theoretical models have the big potential to:

- describe the **physical-based relation** between the **radar backscattering** and the **ocean surface wind**

- Account for the additional effects compromising the surface backscattering and it turn the wind measurements.

It requires:

- full understanding of the mechanisms regulating the relation between the ocean wind and waves;
- accurate physics-based parameterization of such mechanisms;
- accurate parameterization of the ocean surface itself.

The *objective* is to **improve the theoretical modeling** of the ocean scatterometer backscatter, accounting for the different sources that the current sensor-specific GMFs are not able to characterize, such as **frequency-specific sensor sensitivity to wind**, **rain effects** and different viewing geometries.

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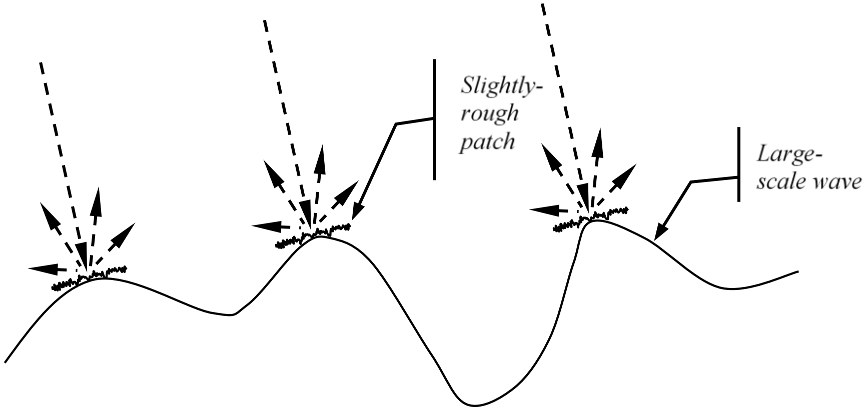
Two Scale Model (TSM)

- The ocean surface is assumed as composed by small-scale **wind-driven capillary waves** (slightly-rough patches) superimposed to large-scale **gravity waves**;



- The backscattering coefficient σ^0 is defined as the sum of **quasi-specular backscattering coefficient σ$^{0(0)}$** from the large-scale waves and the contribution of the **small-scale roughness component σ$^{0(1)}$**:

$$\sigma_{pq}^{0}(\theta,\varphi) = \sigma_{pq}^{0(0)}(\theta,\varphi) + \boxed{\sigma_{pq}^{0(1)}(\theta,\varphi)}$$

integral of the radiation from the single slightly-rough patch, weighted by the probability density function of the long waves slopes P(S_x, S_y)

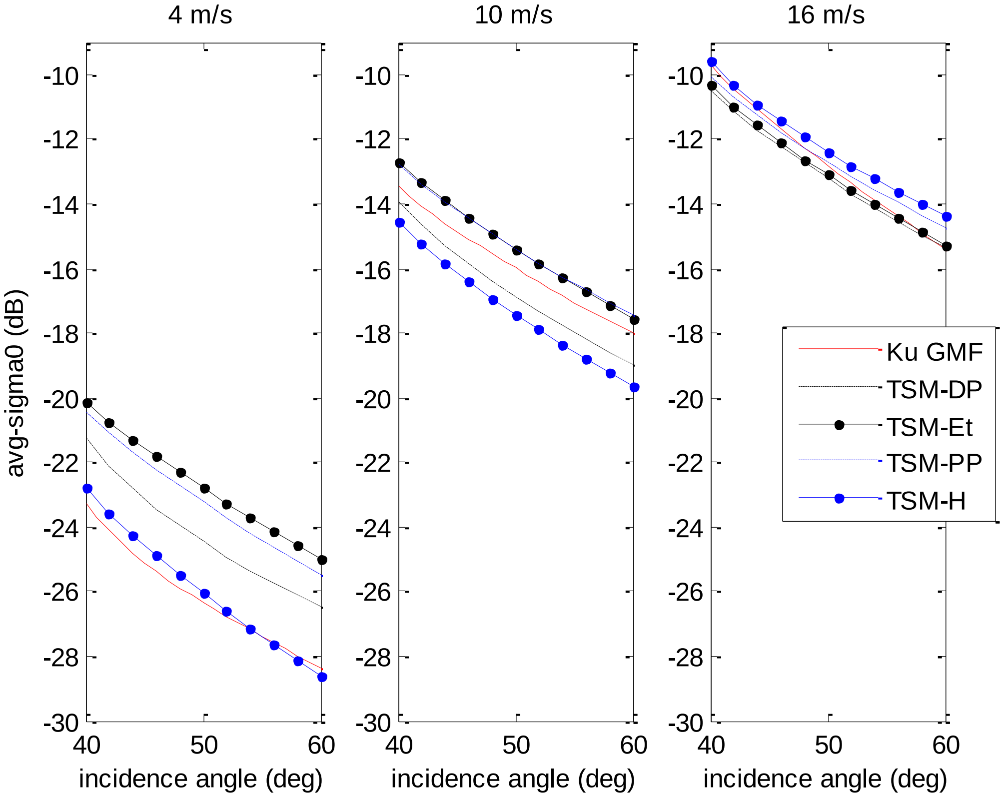
An accurate representation of the ocean surface roughness is crucial

Ocean Wave Spectrum Models (1/2)

The wave spectrum comes from the equation describing the ocean waves evolution, regulated by the **equilibrium** amongst surface **wind input**, **non-linear wave-wave interactions**, and **wave energy dissipation** [Thomson *et al*., 2013]

Analized spectrum models:

- Donelan and Pierson, (1987)
- Elfouhaily et al., (1997);
- Pierdicca and Pulvirenti, (2008)
- Hwang et al., (2011)

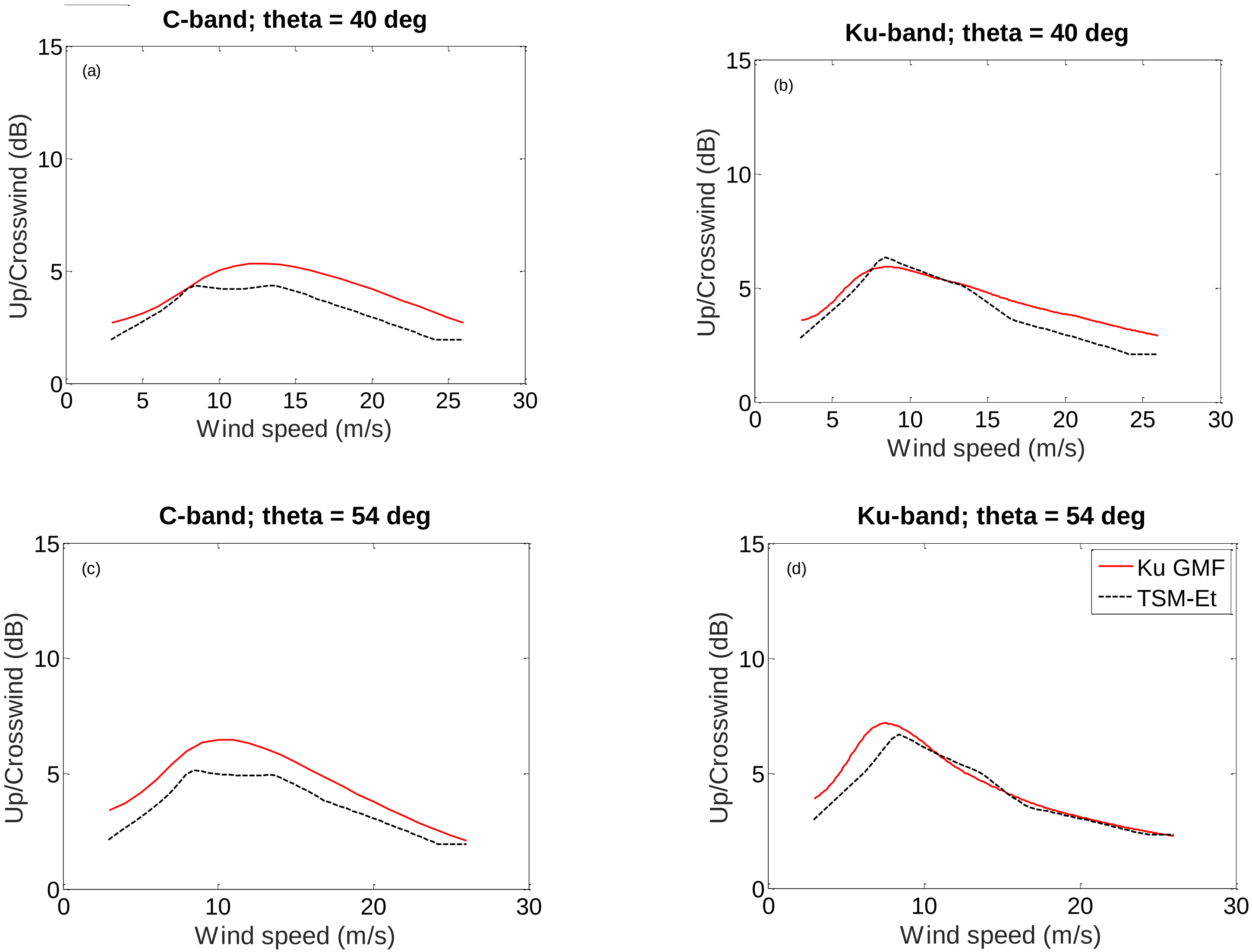


<u>We have decided to use the Elfouhaily spectrum model</u>

With a tuned spreading function, according to Pierdicca and Pulvirenti (2008).

Ocean Wave Spectrum Models (2/2)

The Et spectrum is ingested in the TSM (TSM-Et). **Disagreement** seen at **both C- and Ku-band** between **TSM-Et** and the corresponding **GMF**



C-band; theta = 40 deg

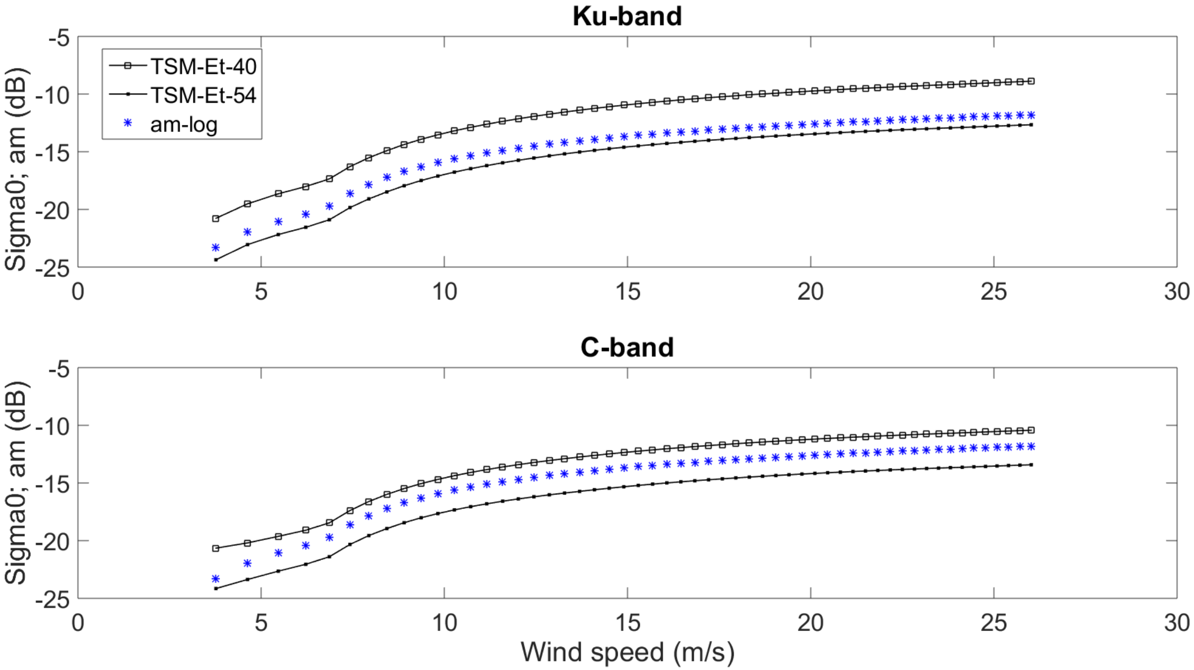
Ku-band; theta = 40 deg

C-band; theta = 54 deg

Ku-band; theta = 54 deg

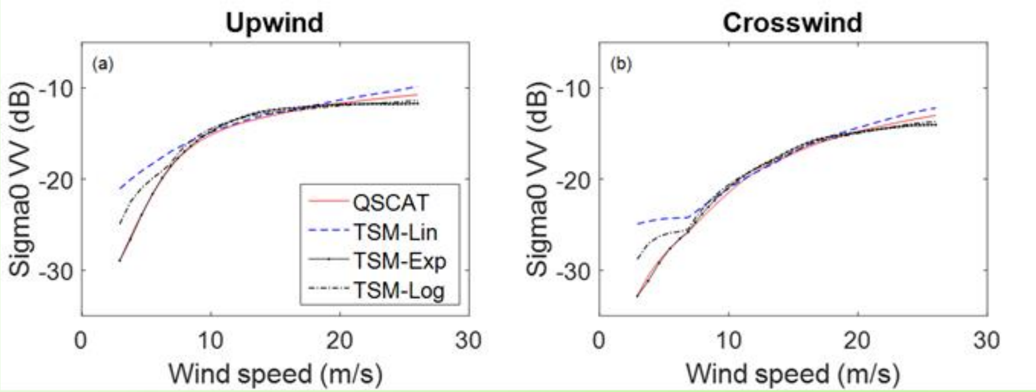
Our Modified Ocean Wave Spectrum (1/3)

We have recognized the **equilibrium range parameter α_m** of the short wave spectrum as the principal contribution in the ocean response to surface wind speed

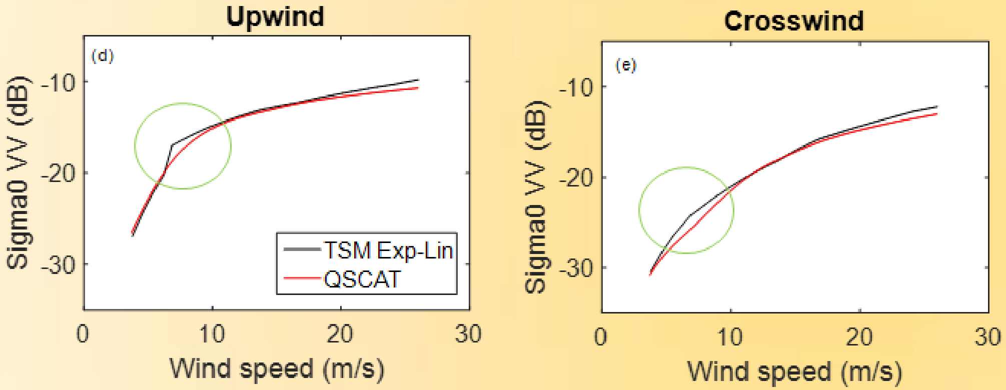


It is a parameterization of the equilibrium condition among non-linear wave-wave interactions, wind forcing and water viscosity.

Our Modified Ocean Wave Spectrum (2/3)



Analysis of the TSM when different α_m expressions (available in the literature) are included.



TSM-Lin → high winds;
TSM-Exp → low winds

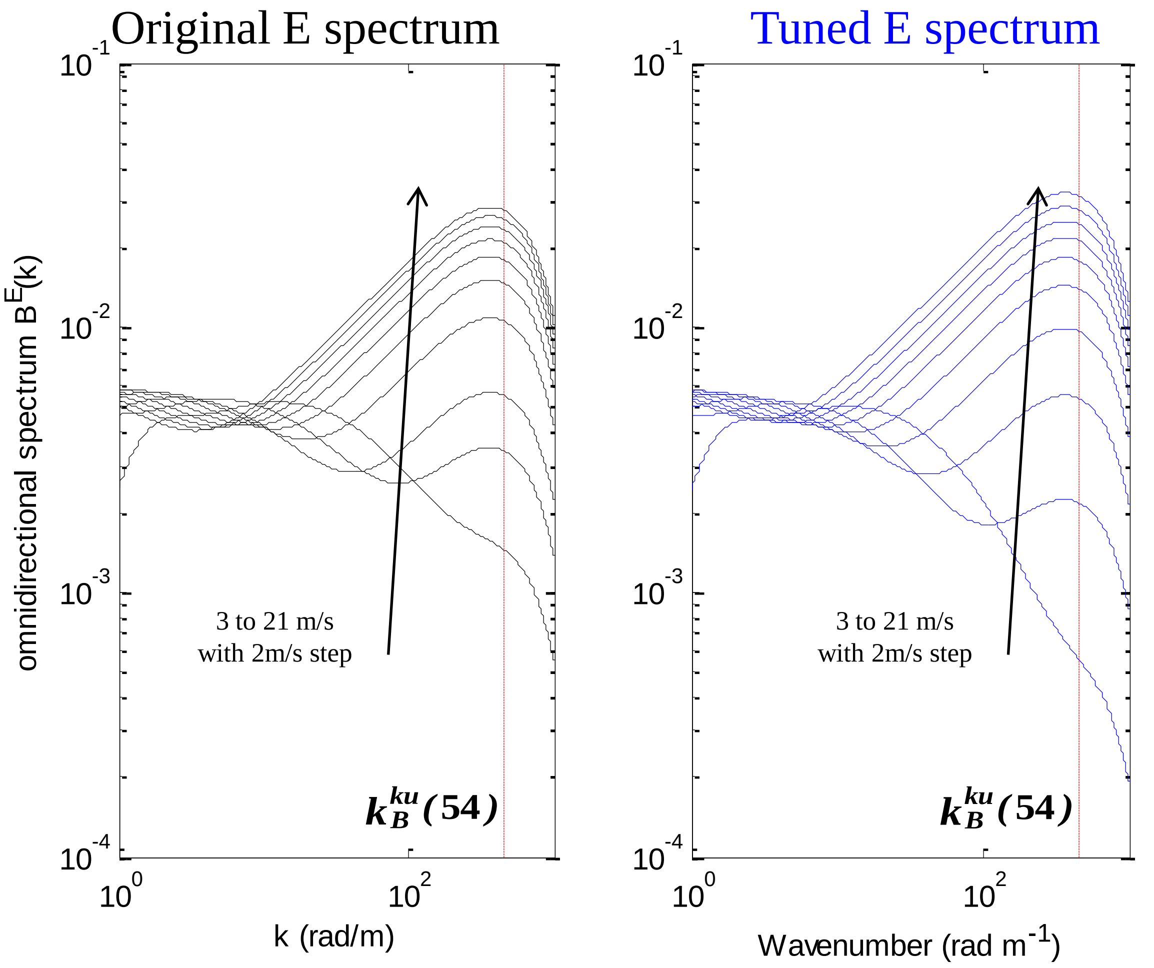
A two-range logaritmic law as proposed by Elfouhaily *et al.* causes an incosistency at 7 m/s

We have defined a new unified law

$$\alpha_{m\_NEW} = (1-h)\alpha_{m\_\exp} + h\alpha_{m\_lin}$$

***h*: a new patching function of the wind speed**

Our Modified Ocean Wave Spectrum (3/3)

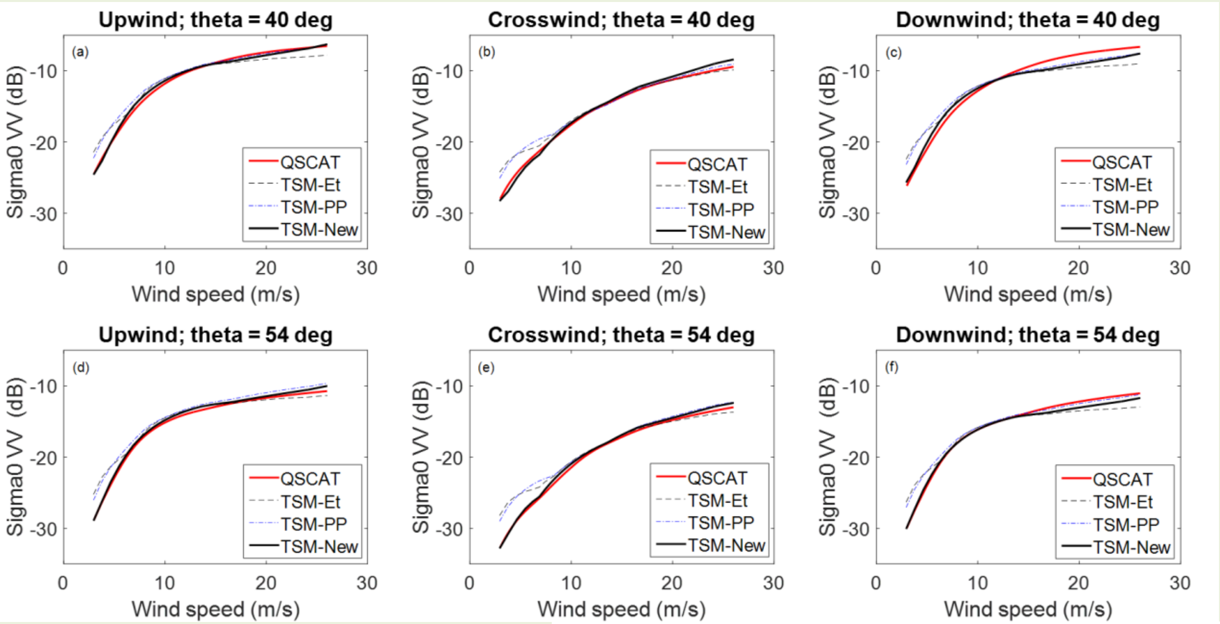


- We are basically **modifying the spectrum modulation with respect to the wind speed**. Such modulation affects the shape/sensitivity of the surface backscattering coefficient.

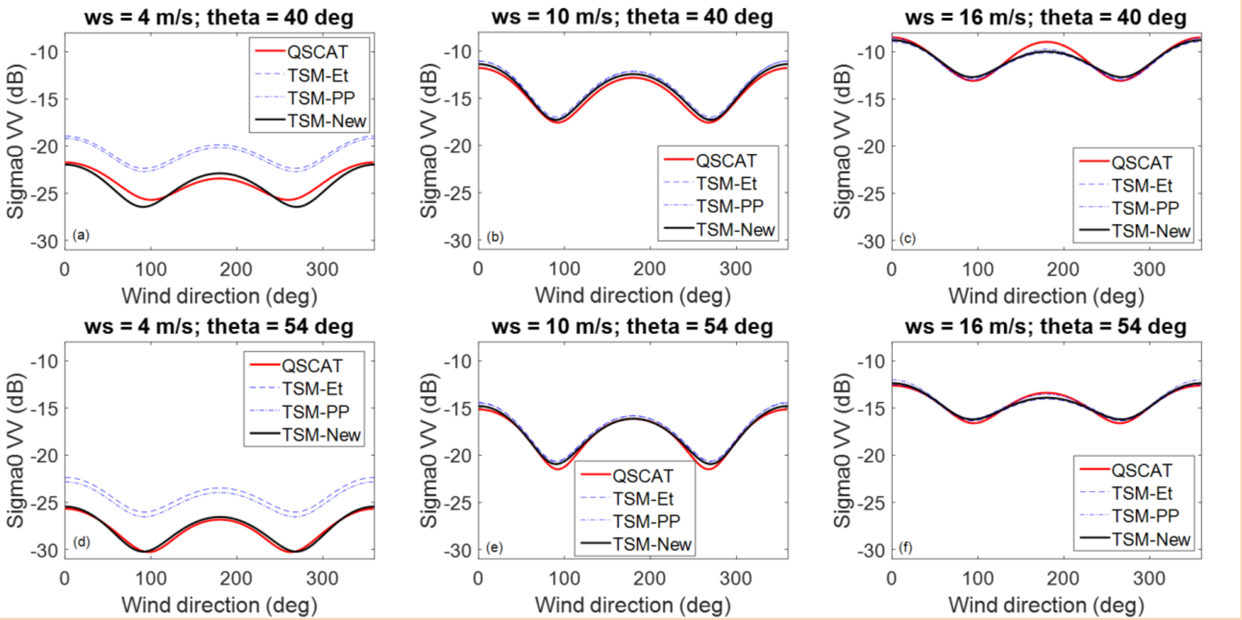
- Smoother transition between low and high winds

Validation at Ku-band using GMF

σ^0 VV vs. wind speed

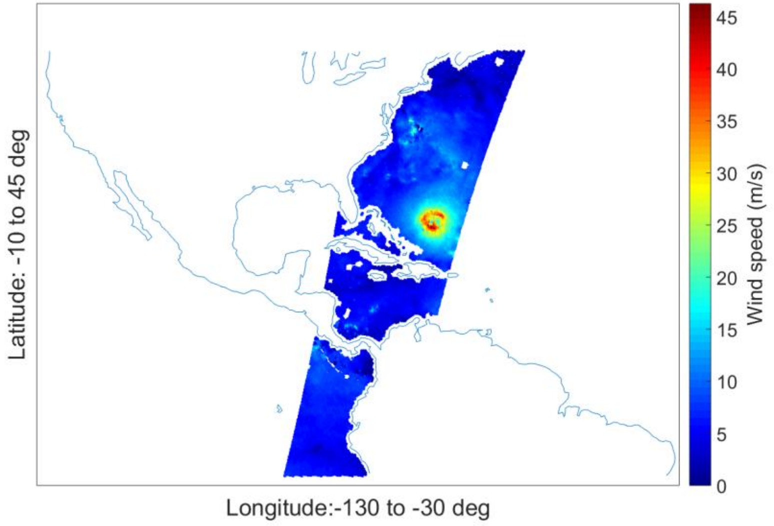


σ^0 VV vs. wind dir.



Improved agreement especially at low wind regimes

Validation at Ku-band using actual data



<u>Dataset:</u>

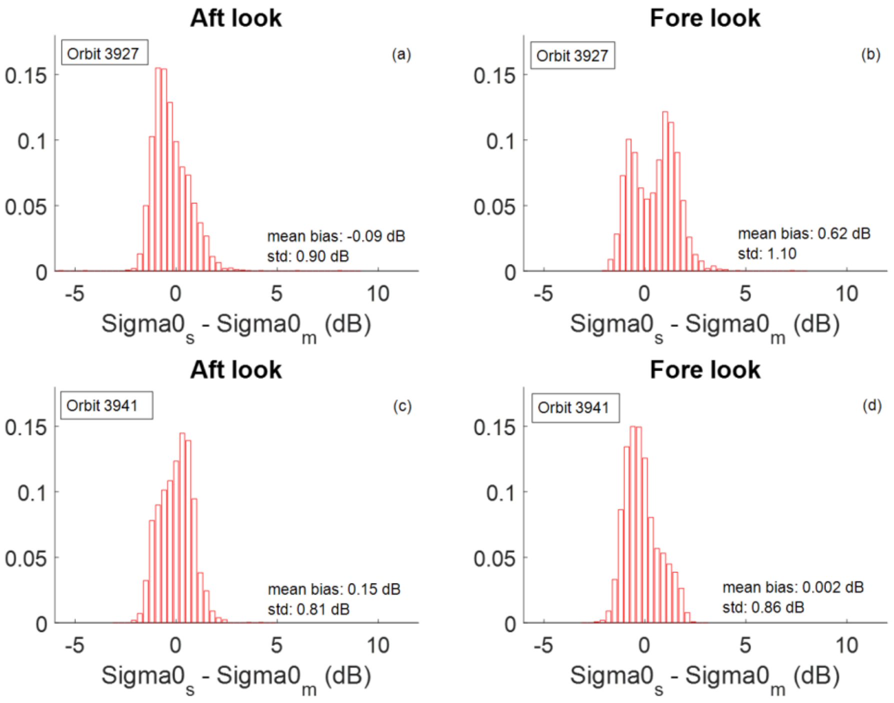
Hurricane Isabel (2003)
NASA Ku-band (~13.4 GHz) SeaWinds Scatterometer
Advanced Earth Observation Satellite Mission

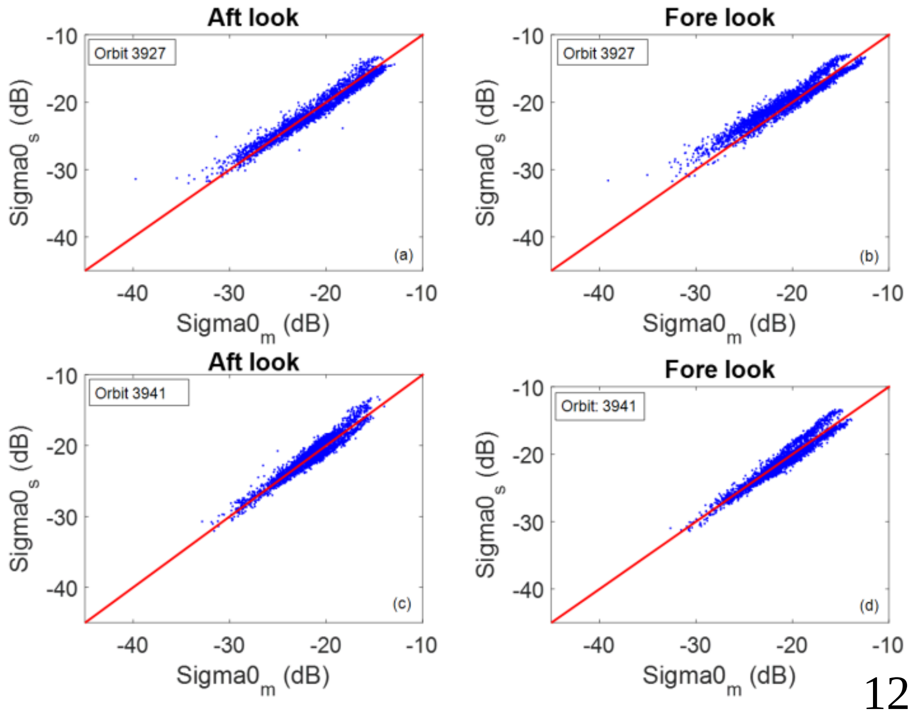
<u>Analysis:</u>

Comparison between measured σ^0 (sigma0_m) and TSM-simulated σ^0 (sigma0_s)

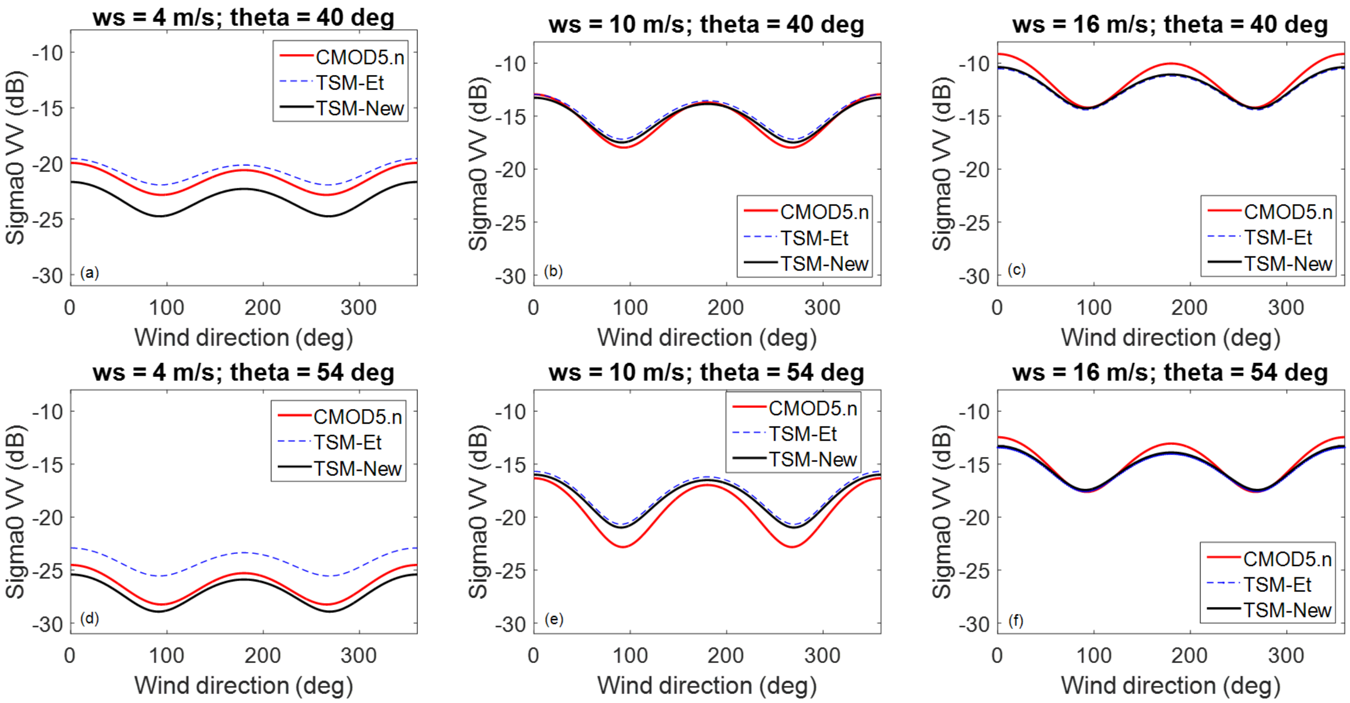
<u>Results:</u>

Good agreement at Ku-band



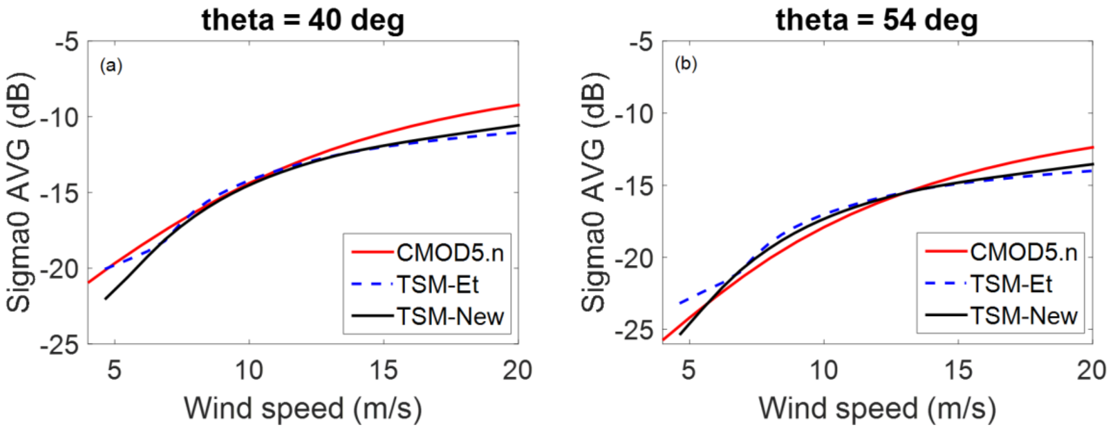


Validation at C-band using GMF

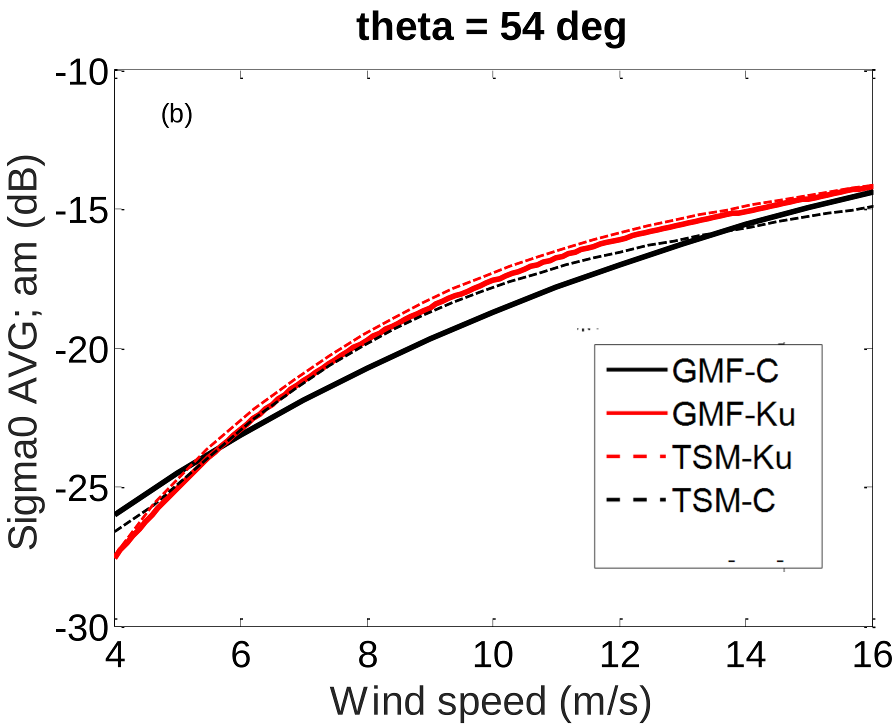


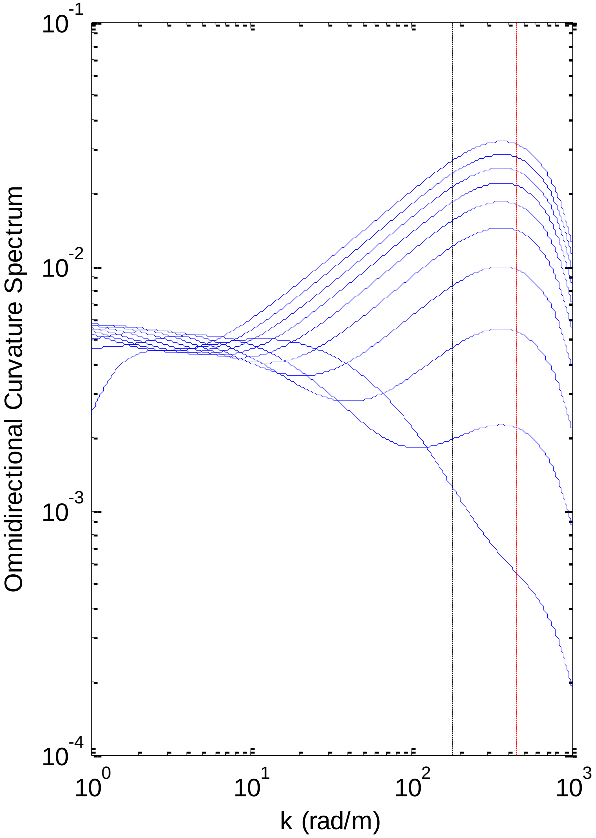
TSM-New slightly better agrees with CMOD5.n, especially for wind speeds higher than 8 m/s.

In both wind speed sensitivity and directional modulation, **the agreement in Ku-band is better than the C-band case.**



Addressing Sensitivity to Frequency





- If we want to reproduce the sensitivity at C-band we need to **change the shape/modulation of the spectrum** with respect to the wind speed in the C-band Bragg waves range.

- This can be done by modifying the equilibrium range parameter with respect to the ocean wavenumber.

- This suggests that the **condition of equilibrium changes amongst the different ocean wave components**

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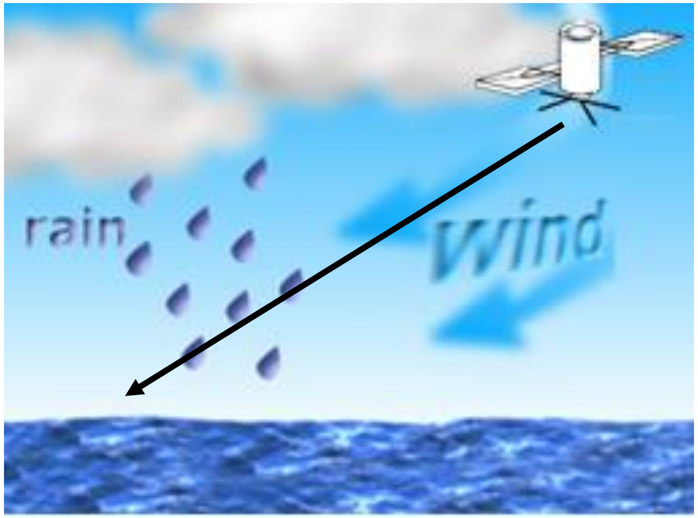
Rain Effects: Problem Overview

Objective:

Modeling the effects of the rain on the surface backscattering coefficient.



[image adapted from: http://www.aquatic.uoguelph.ca/oceans/PacificOceanWeb/NPProperties/Salinity.htm]

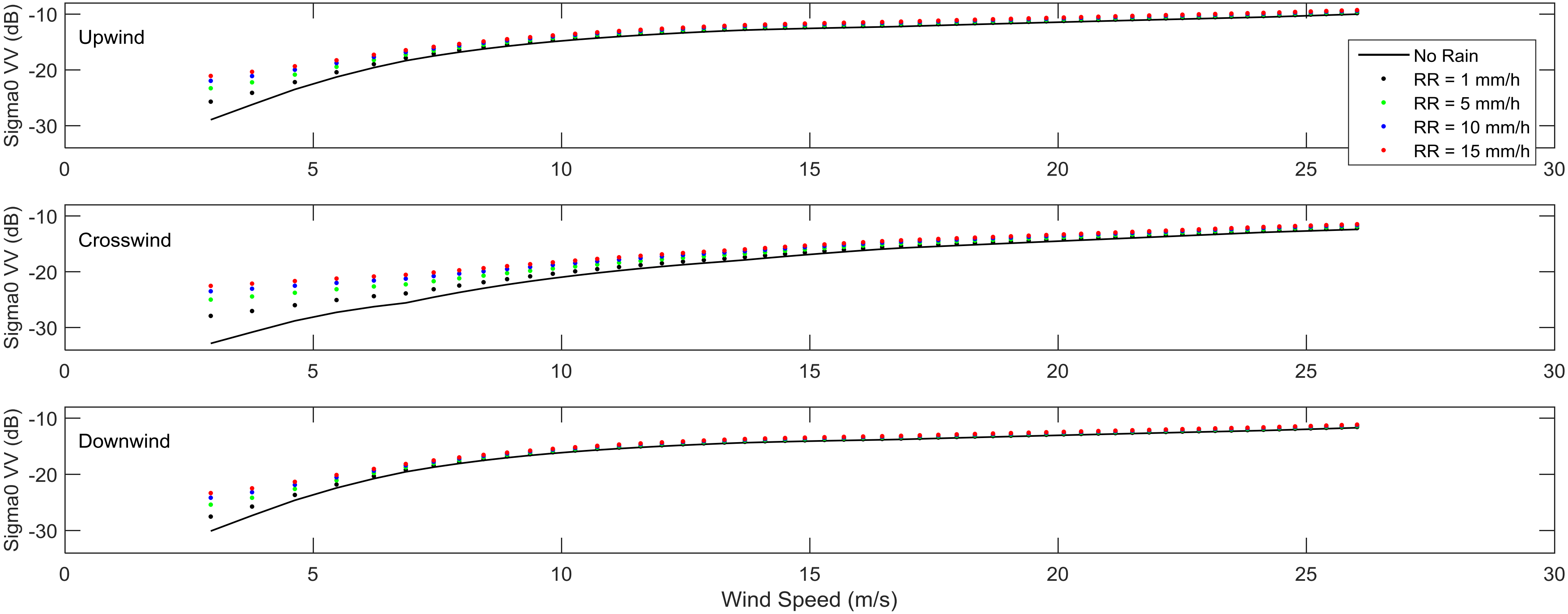
Methodology:

- We have focused on the surface effects.
- *The spectrum of the short waves has been modified in order to include <u>ring waves</u> and <u>wave damping</u> effects.*

Motivations:

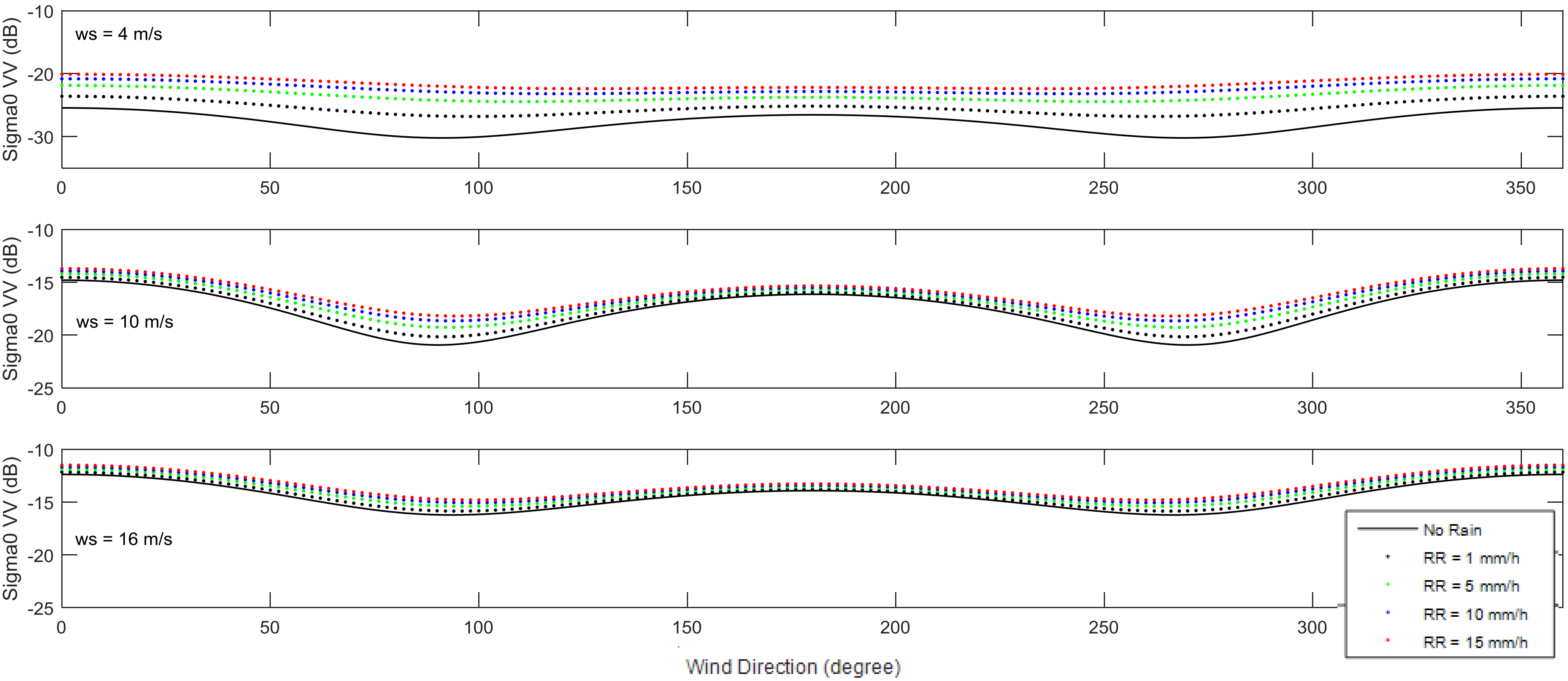
- More accurate approach in estimating wind than empirical methods
- Opportunity to ingest an inversion algorithm to *<u>jointly estimate</u>* wind/rain
- Opportunity to *<u>evaluate the uncertainty</u>* of the rain rate estimates which, in turn, affect the uncertainty in the wind speed and direction retrievals

Ocean Backscattering Sensitivity to Rain



- Rain increases the magnitude of the surface backscattering σ^0;
- Rain effects are more evident at low wind regime as it increases the roughness of the surface
- At higher wind regimes the wind-induced roughening effects are dominant.

Ocean Backscattering Sensitivity to Rain

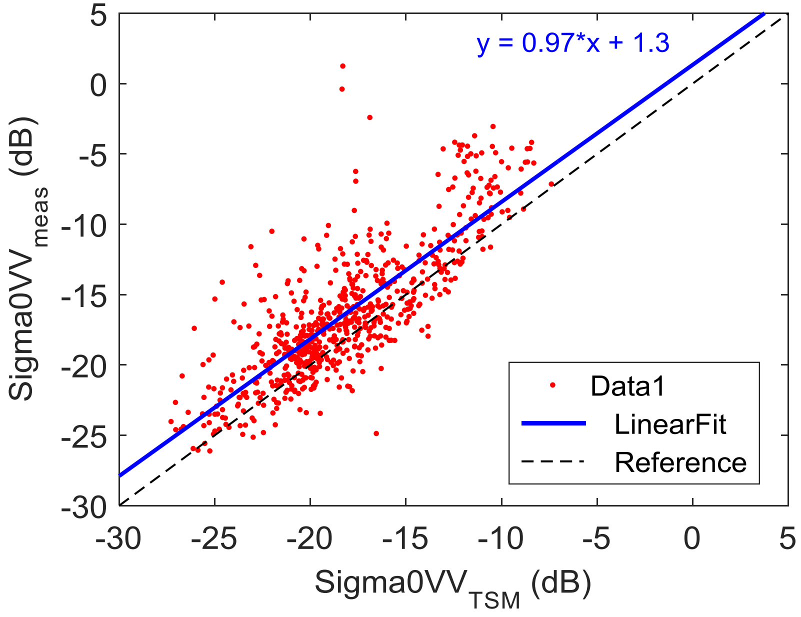


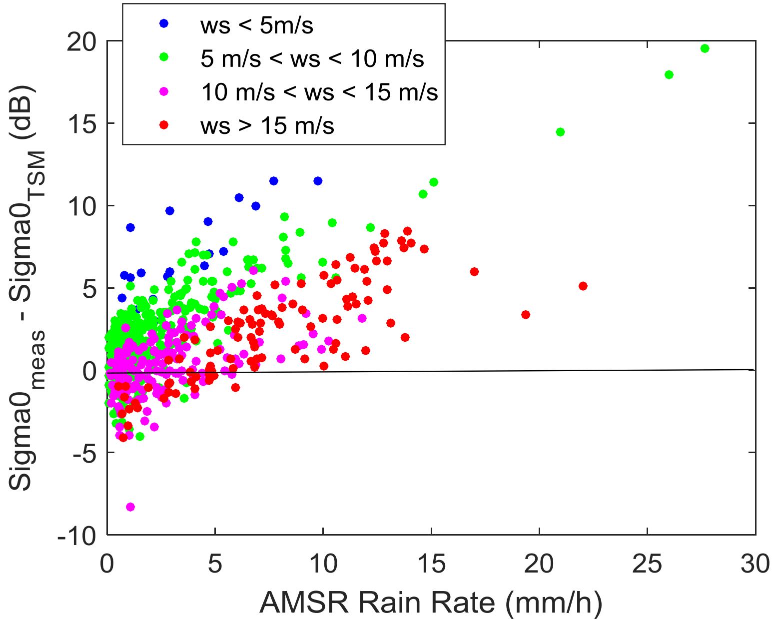
Rain reduces the upwind and crosswind asymmetry, which is essential to estimate wind direction from scatterometer observations;

Preliminary Results with Actual Data

Hurricane Isabel (2003)

Wind measurements: NASA Ku-band SeaWinds, Advanced Earth Observation SatelliteMission
Rain measurements: Advanced Microwave Scanning Radiometer





The model slightly underestimates the actual data. Mean bias = 1.8 dB and std = 2.8 dB

The disagreement increases as the rain rate becomes higher.
Additional roughening contributions such as craters and stalks need to be accounted for.

In agreement with [Contreras and Plant, (2006)]

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Conclusion

Development of a dual-frequency spectrum-based theoretical models of the ocean surface response in presence of both wind and rain

- ☐ **Non-rainy conditions:**
    - Good agreement between the proposed theoretical and the Ku-band QuikSCAT GMF as well as using SeaWinds actual data.
    - The agreement seen with the C-band GMF is not as good as the Ku-band case
    - The model has to account for the different sensitivity to the wind in both the directional and omnidirectional ocean wave spectrum components.
- ☐ **Rainy conditions:**
    - The proposed theoretical model consistently represent the rain effects on the surface backscattering
    - The rain increases the ocean backscattering and it reduces the directional component
    - The results with the SeaWinds/AMSR actual data are consistent to previous work [Contreras and Plant, 2006]

This work is intended to improve the scatterometer response in support of the current empirical GMFs

Acknowledgements

I really cannot find the right words to express how much grateful I am to my advisors **Dr. Joe Turk** (Jet Propulsion Laboratory) and **Dr. Svetla Hristova-Veleva** (Jet Propulsion Laboratory). Thank you for your technical help, valuable advices, your patience during our meetings and for letting me be part of the JPL ocean scatterometry group. This was a unique experience from the scientific and personal point of view. I will never forget anything of that. I would like to thank also **Dr. Ernesto Rodriguez** (Jet Propulsion Laboratory) and **Dr. Bryan Stiles** (Jet Propulsion Laboratory) for their valuable scientific support and for sharing their knowledge anytime I needed. Thanks to **Dr. Ziad Haddad** (Jet Propulsion Laboratory) for giving the chance to join his group.

I would like also to thank **Prof. Simona Bordoni** (California Institute of Technology) and **Prof. Mark Bourassa** (Florida State University) for their valuable contribution in reviewing this work.

I am mostly grateful to my advisor **Prof. Frank Marzano** (Sapienza University of Rome). We have worked together since I got the Bachelor degree and his guidance and help has always inspired me. Thank you for always supporting me in any new scientific challenge I decided to face. I really appreciated the availability and help of the Ph.D. Program Coordinator, **Prof. Maria-Gabriella Di Benedetto** (Sapienza University of Rome). I would like to express my gratitude for her support, guidance and prompt emails, which were essential during these years. Thanks also to **Prof. Nazzareno Pierdicca** (Sapienza University of Rome) and **Dr. Luca Pulvirenti** (CIMA Research Foundation) for giving me the opportunity to continue their work and for sharing their experience.

Many thanks to all of the **JPL colleagues** and friends, who have contributed to this unforgettable experience. Many thanks also to the **DIET colleagues** and friends.

Addressing Frequency Sensitivity