Addressing the rain effects on the ocean scattering: a theoretical model of the ocean surface backscattering coefficient in presence of both wind and rain

F. Polverari[1,2,4], *F. S. Marzano*[1,2], *L. Pulvirenti*[3,1], *N. Pierdicca*[1], *B. W. Stiles*[4], *S. M. Hristova-Veleva*[4], *F. J. Turk*[4]

[1] DIET, Sapienza University of Rome, Rome, Italy
[2] CETEMPS, University of L'Aquila, L'Aquila, Italy
[3] CIMA Research Foundation, Savona, Italy
[4] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

E-mail: federica.polverari@jpl.nasa.gov
polverari@diet.uniroma1.it

SAPIENZA UNIVERSITÀ DI ROMA

Jet Propulsion Laboratory
California Institute of Technology

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Outline

- **Problem overview, objective and motivations**

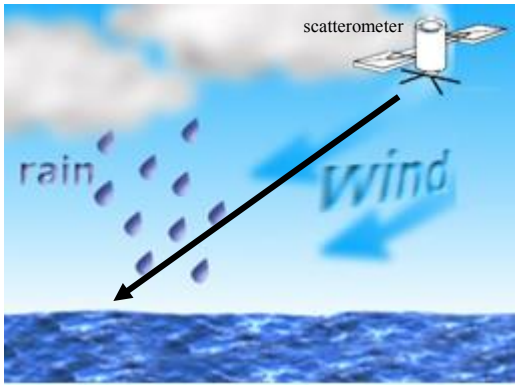
- **No Rain effects**
  - Theoretical model of the ocean surface backscattering coefficient
  - Ocean wave spectrum model and tuning approach
  - Validation at Ku and C band

- **Rain effects**
  - Methodology
  - Results at Ku and C band

- **Conclusions and future steps**

Introduction

Overview:
Rain strongly affects the wind scatterometry leading to erroneously wind retrievals if the rain effects are not compensated.



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

Objective:
Development of a **theoretical forward model** to describe the ocean surface backscattering coefficient in presence of both wind and rain.

Motivations:

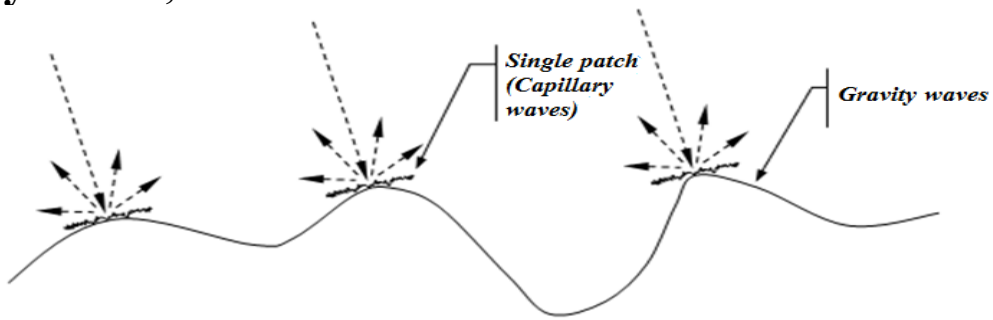
- Accurate approach in estimating winds and opportunity to *jointly estimate* wind/rain
- Possibility to *evaluate the uncertainty* of the rain rate estimates affecting the uncertainty in the wind retrievals.

Challenges:

- ***Accurate representation of the ocean surface roughness firstly in only wind conditions and then in rain conditions.***
- ***The ocean physics which may have a different impact on the scatterometer signal polarizations***

Ocean surface backscattering coefficient

- The ocean surface is assumed as composed by: small-scale **capillary waves** superimposed to large-scale **gravity waves**;



- The **Bragg mechanism** regulates the backscattered radiation: the capillary waves are resonant to the microwaves (k):

$$k_B = 2\pi k \sin\vartheta$$

- The **Two-scale model** is used to describe the ocean surface backscattering coefficient:

$$\sigma^0 = \int_{-\infty}^{+\infty} dS'_y \int_{-\infty}^{\cot\theta} dS'_x \, \alpha_p^s(\theta,\varphi)(1 - S'_x \tan\theta) P(S_x, S_y)$$

θ, φ: the zenithal and azimuthal observation angles

σ^0 is computed as the sum of the radiation from the small-scale patch $\alpha_p^s(\theta,\varphi)$, weighted by the slope distribution of the large-scale waves $P(S_x, S_y)$.

An accurate representation of the ocean surface roughness is crucial

Ocean wave spectrum: model

- The ocean wind wave spectrum model developed by **Elfouhaily et al., 1997** is used (E);

Long waves curvature spectrum

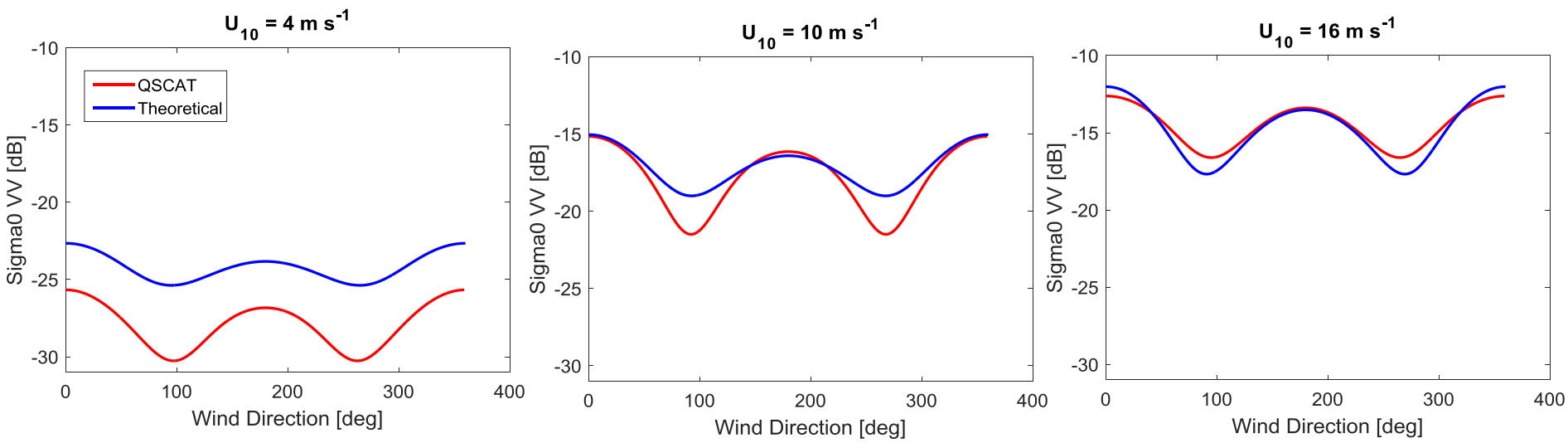
Short waves curvature spectrum

Upwind/Crosswind ratio

k: wavenumber
φ: the wind direction

$$W(k,\varphi) = \frac{1}{2\pi k^{-4}}[B_l + B_h][1 + \Delta(k)\cos 2\varphi]$$

- However, comparisons with the Ku-band QuikSCAT scatterometer show a disagreement between the GMF and the theoretical model where the E spectrum is used



The spectrum needs to be tuned in both directional and non-directional part

Ocean wave spectrum: tuning

- **<u>The goal</u>:**
  The spectrum has to be free of any instrumental constraint like fixed frequency, incidence angles, look angles, etc.

- **<u>Methodology</u>:**
  - Focusing on the spectrum in the capillary waves region
  - Tuning of the *equilibrium range parameter*:

A) Elfouhaily et al. 1997 expression: two range logarithmic law

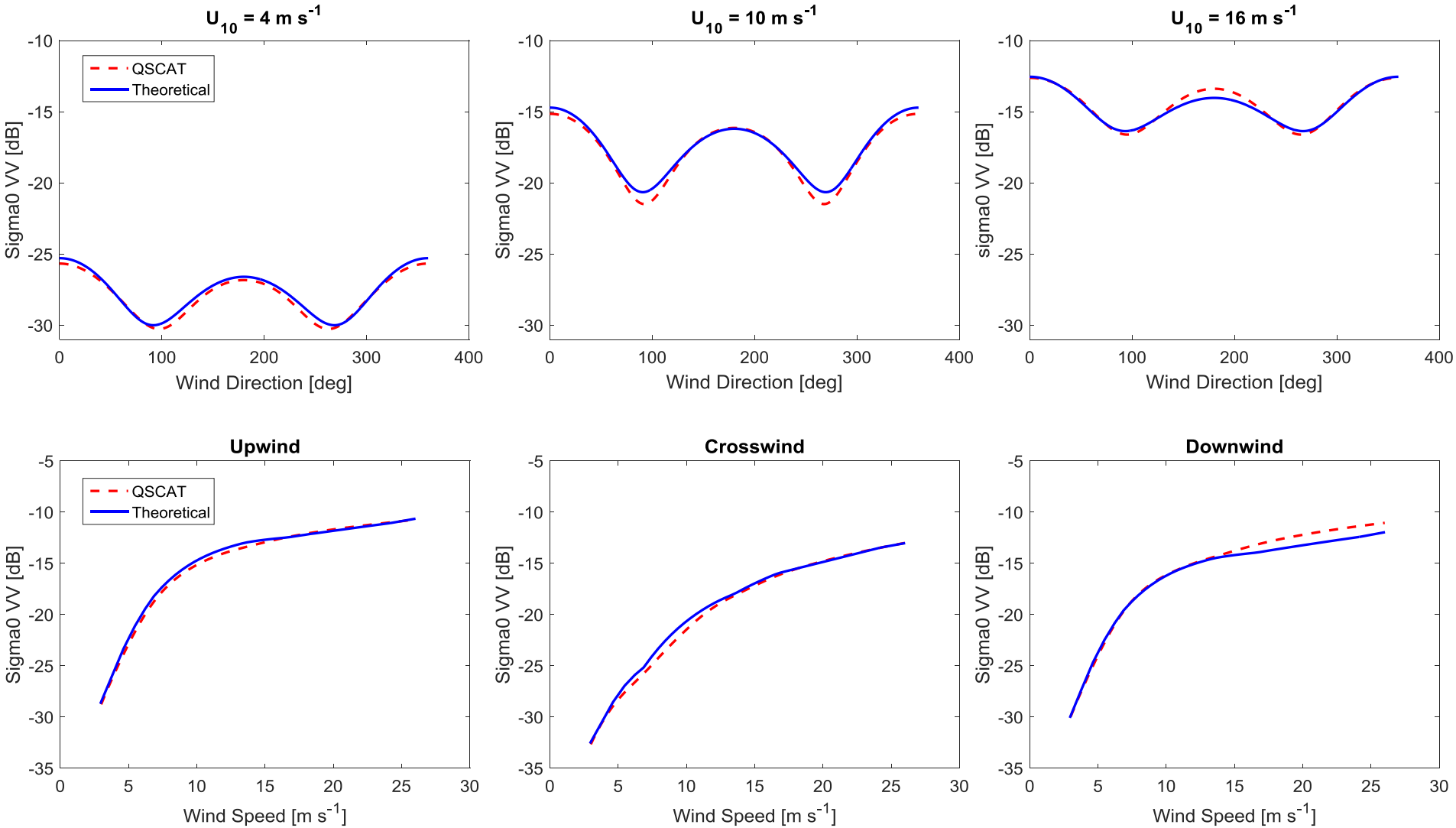
$$\alpha(k,u^*)_m = 10^{-2}\begin{cases} 1+\ln[F(u^*)] & low\ winds \\ 1+3\ln[F(u^*)] & high\ wids \end{cases}$$

B) Our new expression:

$$\alpha(k,u^*)_m = [1-h(u^*)]\underbrace{\alpha(k,u^*)_{me}}_{\substack{\text{Exponential}\\ \text{trends with } u^*}} + h(u^*)\underbrace{\alpha(k,u^*,k_B)_{ml}}_{\substack{\text{Linear}\\ \text{trends with } u^*}}$$

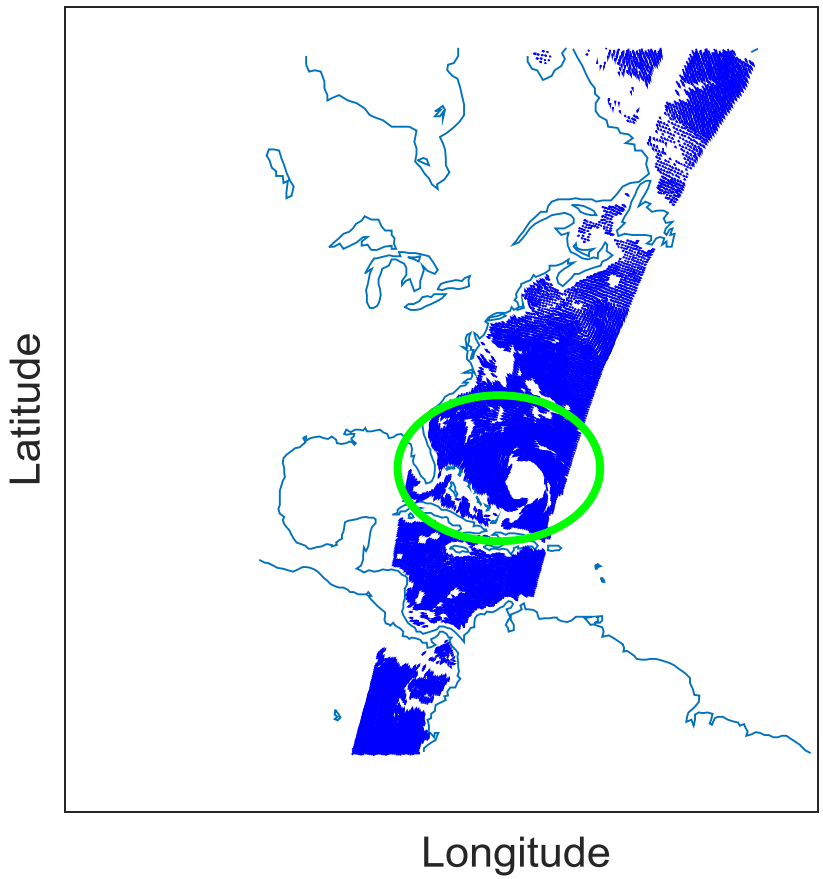
- ❖ Unified law
- ❖ Exponential trend (friction velocity u^*) in low winds and linear trend at high winds
- ❖ Patching function dependent on u^*
- ❖ High winds are dependent on the Bragg wavenumber → <u>match at C- and Ku-band</u>

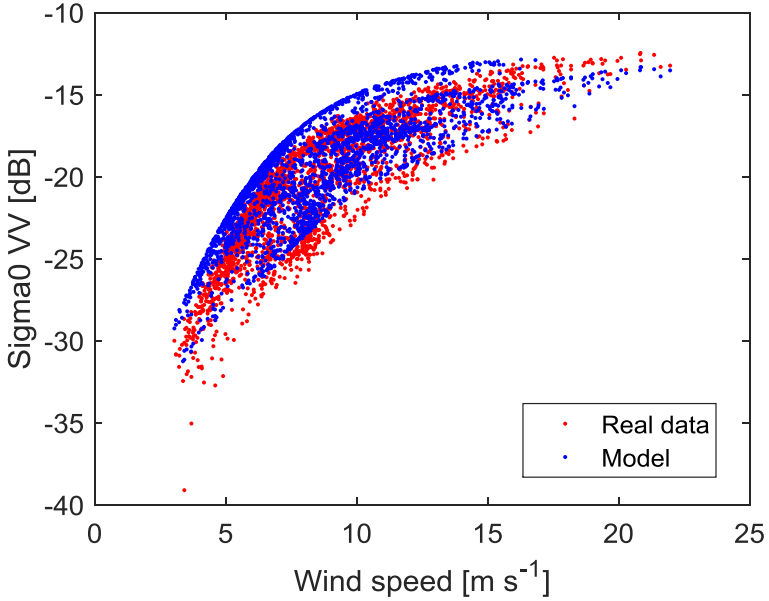
Ku-band validation: QuikSCAT GMF

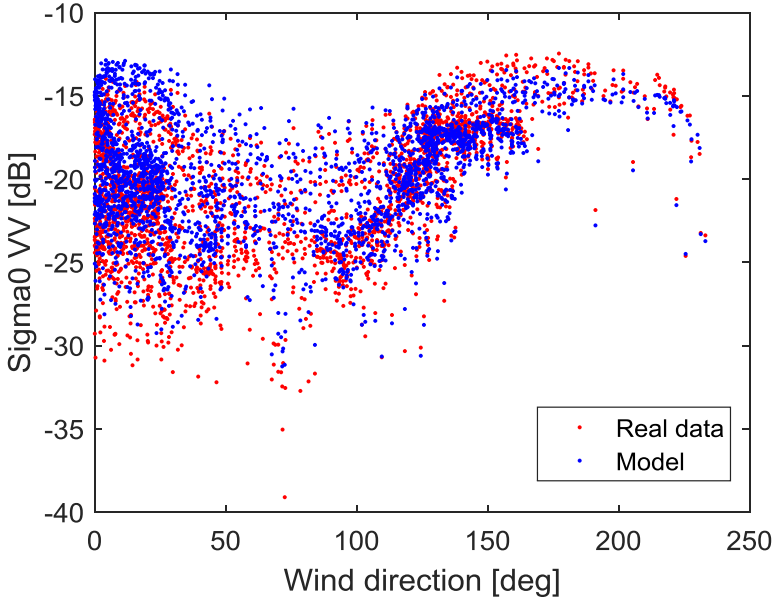


SeaWind data: Hurrican Isabel 2003

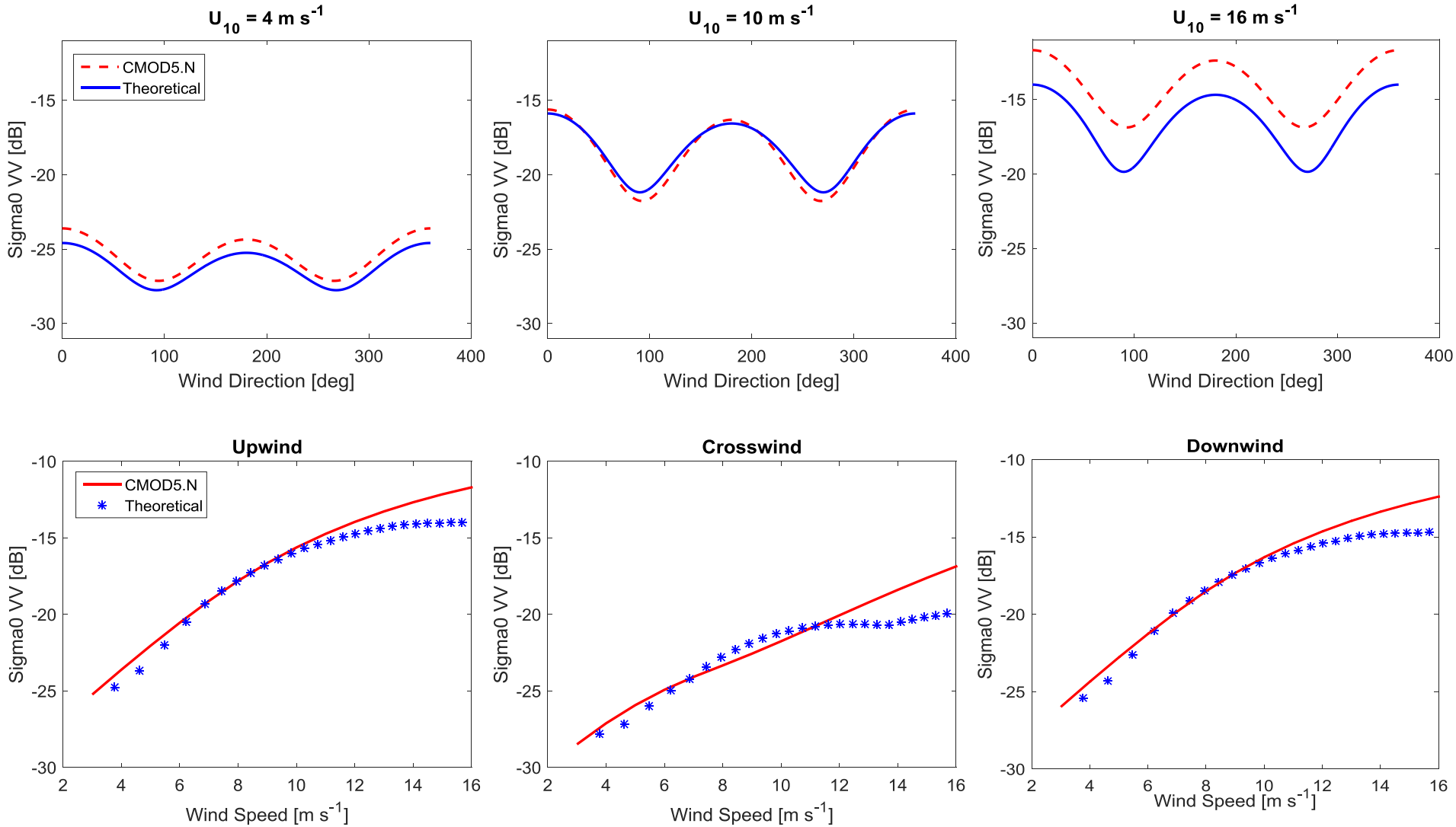
Orbit: SW_S2A03927E.20032581429-20032581611.20053350643







C-band validation: CMOD5.N GMF

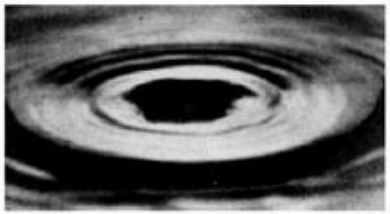


Rain effects: methodology

The ocean surface modifications induced by the rain are modeled in the ocean wind wave spectrum:

- Rain induced wave damping:
  Attenuation modeled as turbulence viscosity [Nystuen (1990)]

- Generation of ring waves:
  Additive Log-Gaussian spectral model [Bliven et al. (1997)]



Ring waves
[Contreras et al., 2003]

Rain – free:

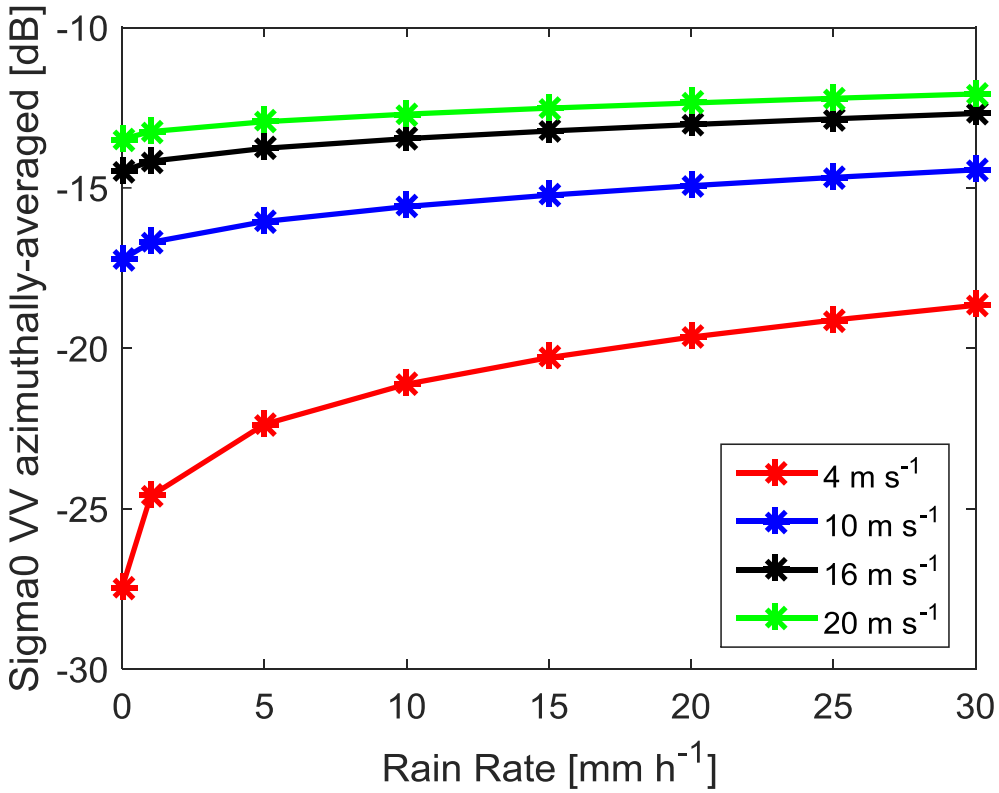
$$W(k,U,\varphi) = \frac{1}{2\pi k^{-4}}\left[B(k,U)_l + B(k,U)_{h_tuned}\right]\Phi(\varphi)$$

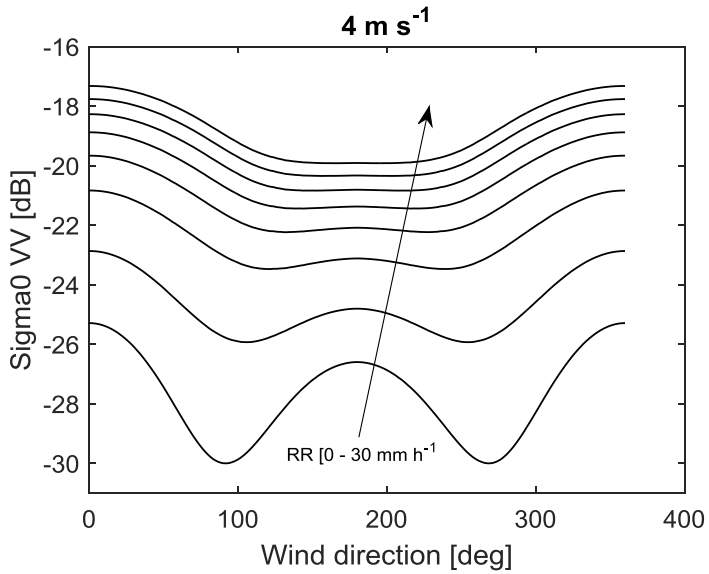
Rain Effects :
Rain Rate (RR) dependence

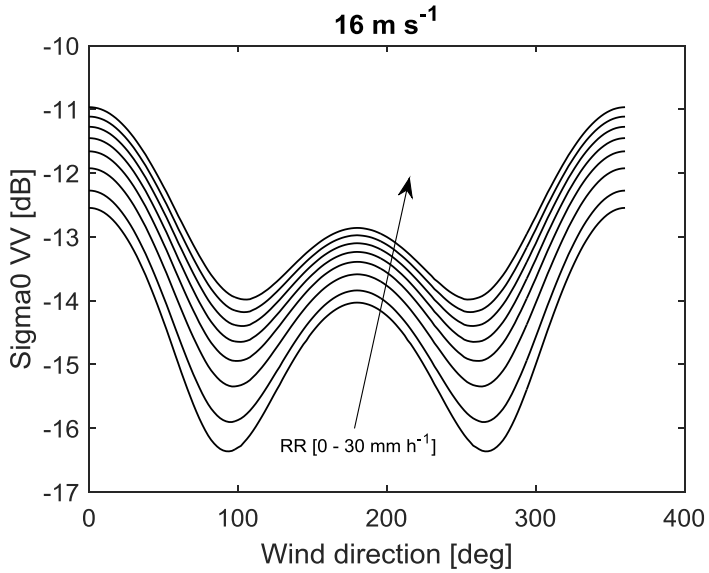
Rain – affected:

$$W(k,U,\varphi,\boldsymbol{RR}) = \frac{1}{2\pi k^{-4}}\left\{B(k,U)_l\Phi(\varphi) + \left[B(k,U)_{h_tuned}e^{-A(\boldsymbol{RR})}\Phi(\varphi) + B(k,\boldsymbol{RR})_{ring}\right]\right\}$$

Rain effects: Ku-band results



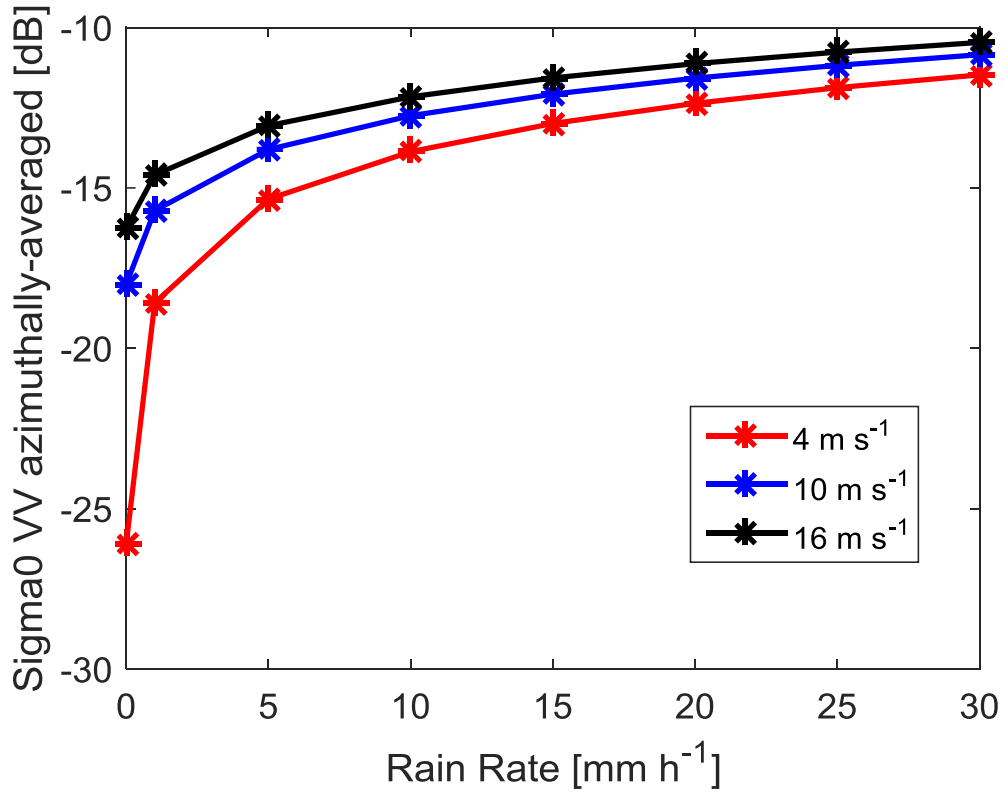


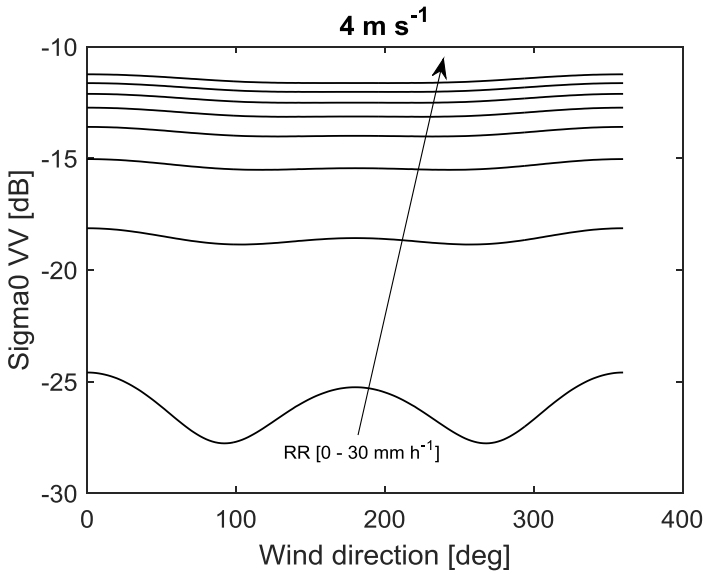


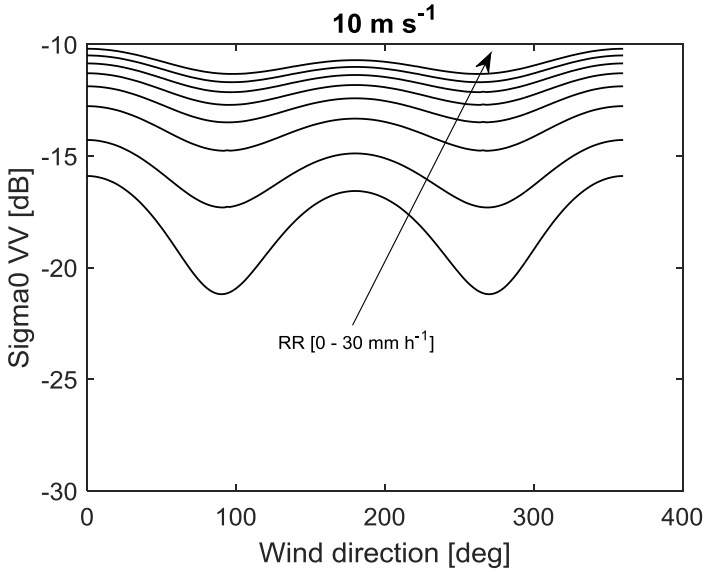
<u>Rain affects more low winds than high winds</u>:

- light rains have strong impact on the backscattering coefficient
- clear increase of the backscattering with the rain rate
- rain smooths the backscattering directional component

Rain effects: C-band results







The backscattering directional component is more affected by rain at C band than Ku band

Conclusions and future steps

❑ Non-rainy conditions:

- A new definition of the equilibrium range parameter leads to an very good agreement between the theoretical and empirical model;
- The Bragg wavenumber reveals to be the key point to correctly model different frequencies.
- Good results obtained by a preliminary analysis with real data

❑ Rainy conditions:

- Reasonable results are shown by the theoretical model:
- Both the Ku band and C band reveal to be affected by the rain
- The directional contribution is compromised by the rain especially at lower winds

❑ Next:

- **Analysis at different frequency: L band and Ka band**
- **Exploitation of a sensor synergy**
- **Study of the braking waves to model the horizontal polarization**
- **Additional tests with real data at different frequency**