Combining wind and rain in spaceborne scatterometer observations: modeling the splash effects in the sea surface backscattering coefficient

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Outline

- **Problem overview, objective and motivations**

- **Modeling the surface backscattering coefficient**

  <u>*Method*</u>
  - Two scale model
  - Ocean wind wave spectrum developed by Donelan and Pierson (1987)

  <u>*Results*</u>
  - Validation at VV and HH polarizations using QuikSCAT GMF

- **Modeling the splash effects on the surface backscattering coefficient**

  <u>*Method*</u>
  - Extension of the Donelan and Pierson spectrum to include both wave damping and ring waves

  <u>*Results*</u>
  - RR extended wave spectrum
  - Ku band sigma0

Problem Overview:

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

- Rain *modifies* the ocean surface by impinging on it
- Rain *attenuates* the scatterometer signal as it passes through the atmosphere
- Rain *increases* the scatterometer signal by adding the backscatter from rain volume

Objective:

Development of a **theoretical forward model** simulating scatterometer observations in presence of rain

Motivations:

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

Modeling the surface backscattering

- The **scatterometer backscattering coefficient** σ_{SRF} has been modeled by implementing the sea surface ***two-scale model*** in the SEAWIND software:

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

$\alpha^s_p(\theta, \varphi)$: backscattered radiation from a single small-scale rough patch
θ, φ: the zenithal and azimuthal observation angles

σ_{SRF} is expressed by the sum of the radiation from small-scale (capillary) waves, which are superimposed to large-scale (gravity) waves, weighted by the large-scale slope.

- The **ocean directional wind wave spectrum** $W(k,\varphi)$ model has been implemented based on the spectrum developed by ***Donelan and Pierson (1987):***

$$W(k,\varphi) = \frac{1}{2\pi k} S(k) \Phi(k,\varphi)$$

where

$$S(k) = \begin{cases} k^{-3} B_l^{DP} & k < 10k_p \\ k^{-3} B_h^{DP} & k > 10k_p \end{cases}$$

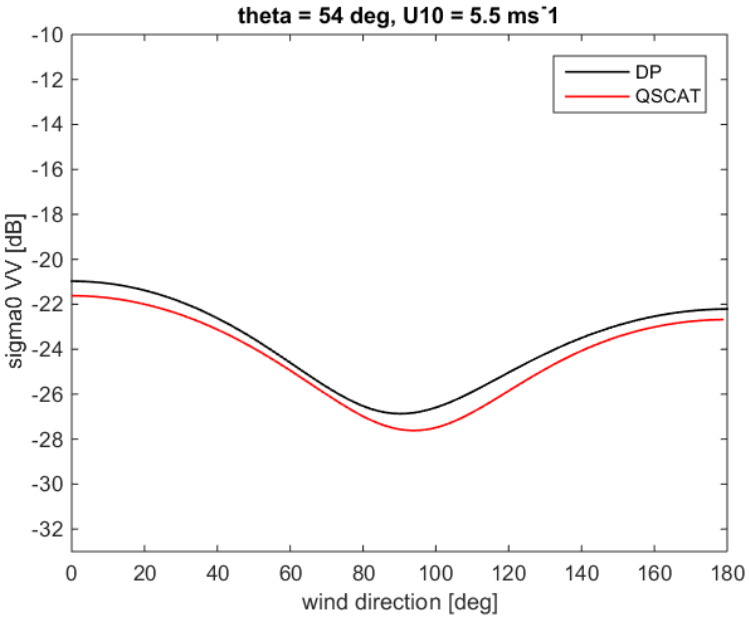
$$\Phi(k,\varphi) = \mathrm{sech}^2(h_1\varphi) \Rightarrow \Phi(k,\varphi) = 1 + \Delta(k)\cos 2\varphi$$

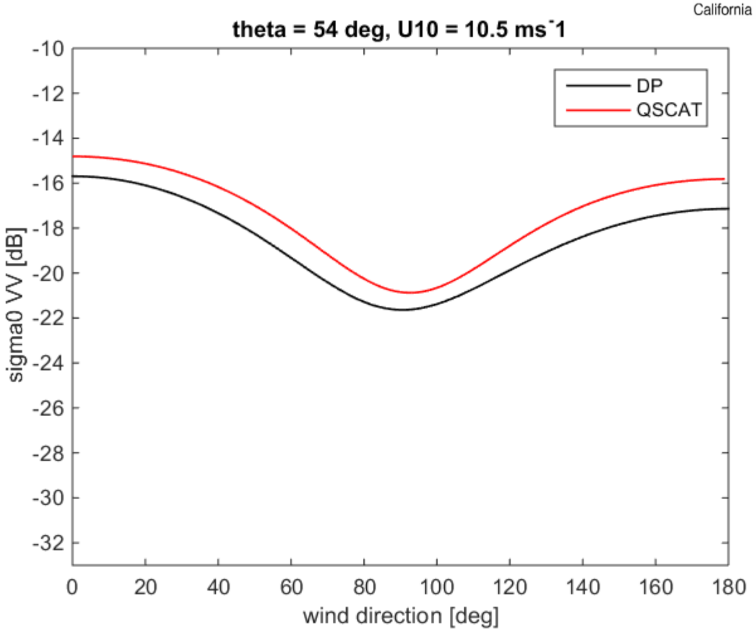
Main features

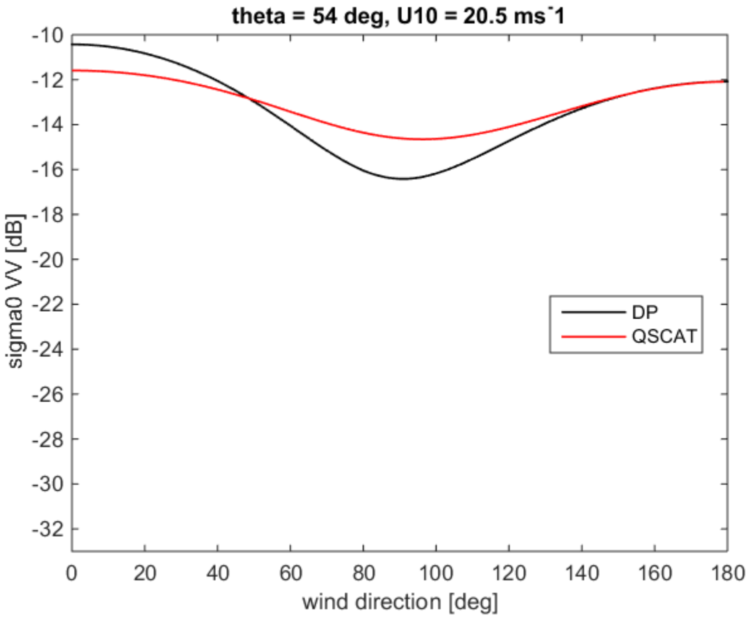
- Clear separation between gravity and capillary waves ranges
- Suitable for modeling the rain effects in the capillary waves region

k: wavenumber
φ: the wind direction
$S(k)$: omnidirectional spectrum
$\Phi(k, \varphi)$: spreading function
$\Delta(k)$ up/crosswind ratio

Validation using QSCAT GMF: VV pol







- Good agreement in VV pol
- The Up/Crosswind ratio $\Delta(k)$ has been tuned to improve the agreement

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Validation using QSCAT GMF: HH pol

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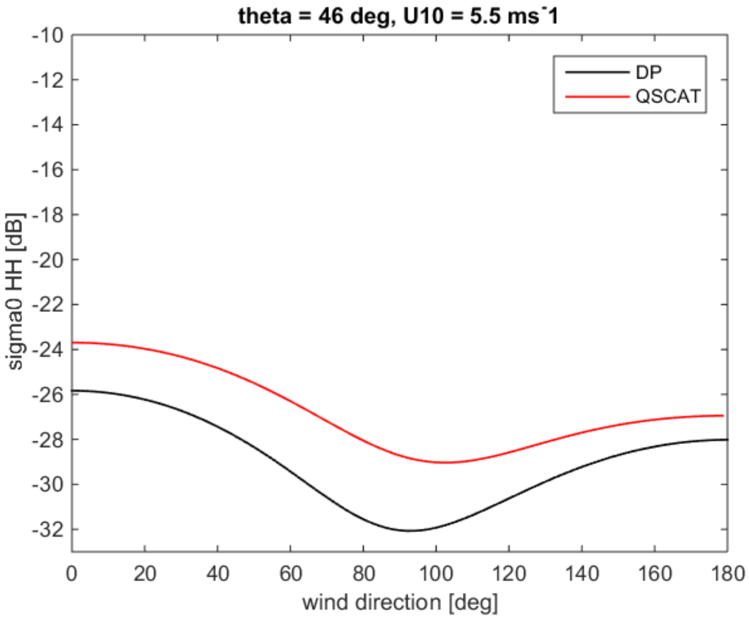

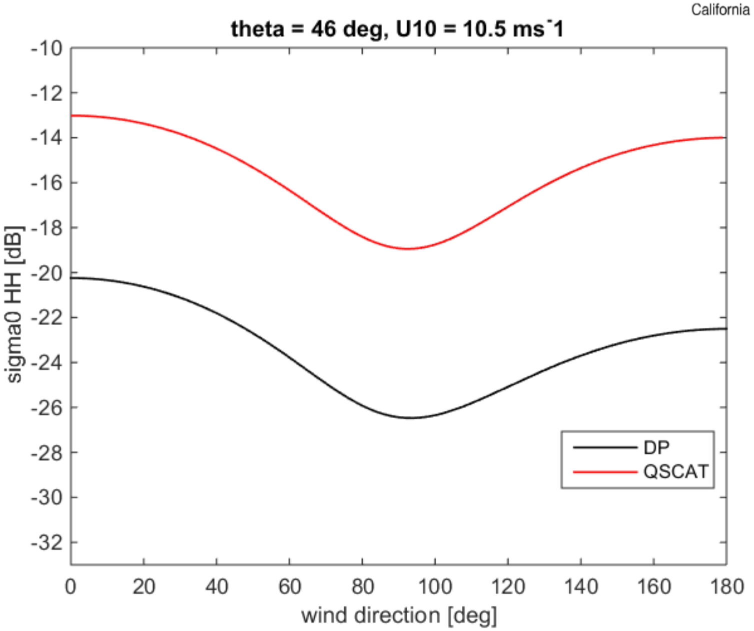

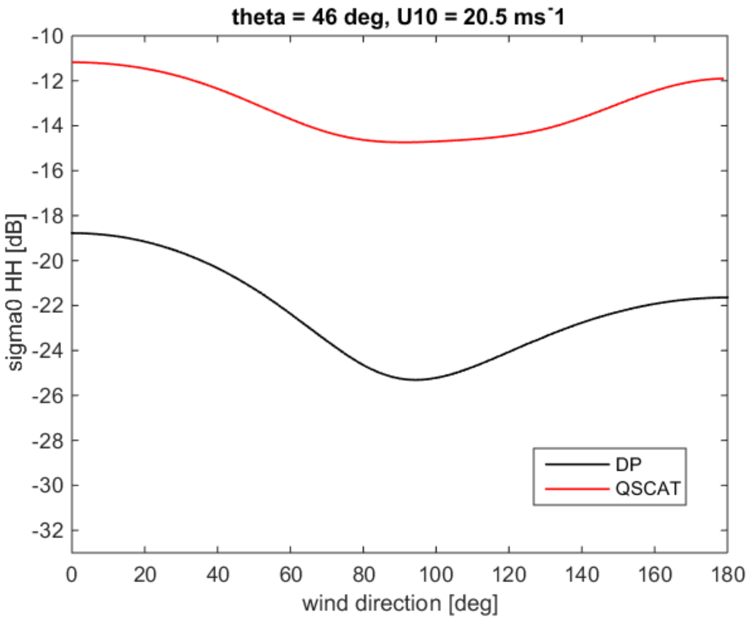

- Main discrepancies in HH pol
- Difference increases with the wind speed
- The Up/Crosswind ratio $\Delta(k)$ has been tuned to improve the agreement

Modeling the splash effects

Exstension of Donelan and Pierson spectrum model, in the region of the ocean surface capillary waves, B_h^{DP}, to include two main effects:

i) Rain induced wave damping

- Wave damping parameterization using an *attenuation factor* *A(k,RR)* defined by Nystuen (1990)

ii) Generation of ring waves

- Additive *log-Gaussian spectral model* *S(k,RR)* described by Bliven et al. (1997)

RR-Extended spectrum:

$$W(k,\varphi,RR)=\begin{cases}\dfrac{1}{2\pi k}[k^{-3}B_l^{DP}(k)]\Phi(k,\varphi) & k<10k_p\\ \dfrac{1}{2\pi k}\{[k^{-3}B_h^{DP}(k)\Phi(k,\varphi)]e^{-A}+k^3S(k,RR)\} & k>10k_p\end{cases}$$

RR-Extended wave spectrum results

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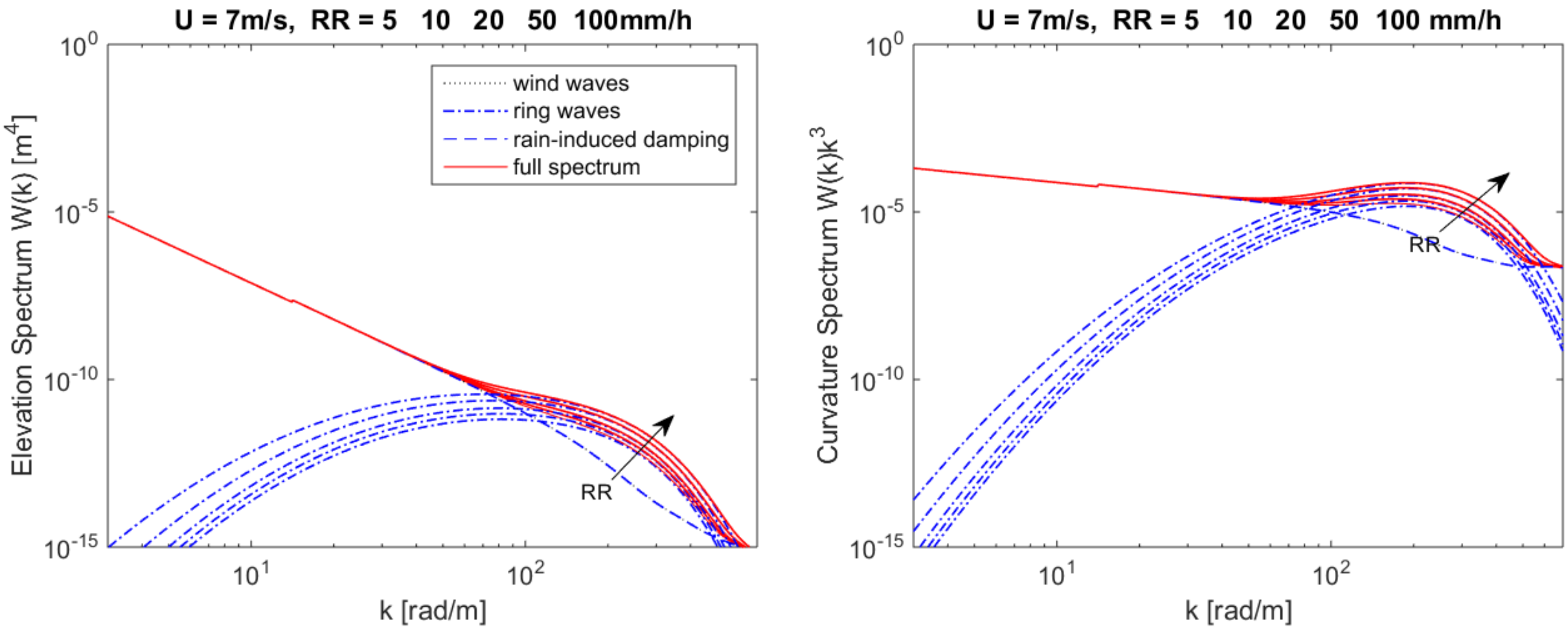

- Full spectrum *enhancement* at $k > 10^2$ rad m^{-1} for increasing rain rate, due to ring waves generation
- The ring wave effects are stronger than the rain-induced wave damping using:
  i. Drop size distribution (DSD): Marshall and Palmer (1948)
  ii. Drop diameter: 1.5 mm
- Additional test with different DSDs are planned

Ku-band sigma0 results with rain

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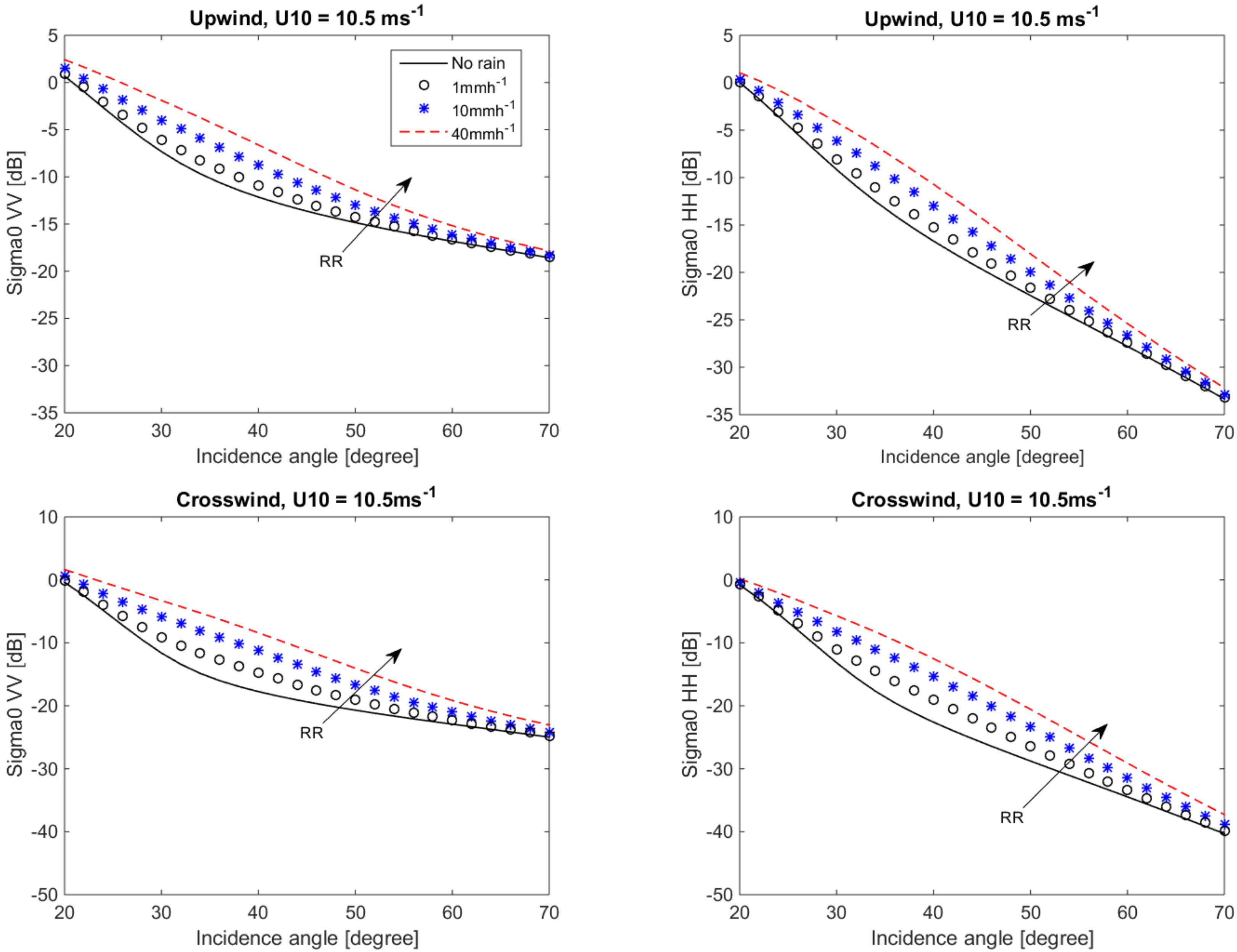

Conclusion and future steps

- In order to simulate the scatterometer observations, the two-scale model of the sea surface and the sea surface wave spectrum developed by Donelan and Pierson (1997) have been used
- The validation results show a good agreement between the no-rain model and the QSCAT GMF, especially at VV polarization
- The Up/Crosswind ratio needs to be tuned. A fine tuning with respect to friction velocity seems to be a valid approach [Pierdicca and Pulvirenti, 2008]
- The splash effects have been modeled by extending the wave spectrum in the range of capillary waves. Rain induced wave damping and generation of ring waves have been included
- Numerical results confirm that the proposed model is physically consistent. For different wind regimes, Ku band co-polar surface backscattering coefficients increases when the rain rate becomes higher due to the increasing roughness
- Future steps:
  - Including the volume backscattering as well as attenuation due to rain
  - Comparison to real data (RapidScat, SeaWind, AMSR, GPM)
  - Development of an inversion algorithm to estimate both wind and rain, *simultaneously*