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

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IOVWST Meeting, Portland, Oregon, May 19-21, 2015
Outline

- Problem overview, objective and motivations

- Modeling the surface backscattering coefficient

  Method
  - Two scale model
  - Ocean wind wave spectrum developed by Donelan and Pierson (1987)

  Results
  - Validation at VV and HH polarizations using QuikSCAT GMF

- Modeling the splash effects on the surface backscattering coefficient

  Method
  - Extension of the Donelan and Pierson spectrum to include both wave damping and ring waves

  Results
  - 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

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

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

$\sigma_{SRF}$ 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)*:

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

$$S(k) = \begin{cases} k^{-3} B_{lDP} & k < 10k_p \\ k^{-3} B_{hDP} & k > 10k_p \end{cases}$$

$$\Phi(k, \varphi) = \sec h^2(h_l \varphi) \Rightarrow \Phi(k, \varphi) = 1 + \Delta(k) \cos 2\varphi$$

**Main features**

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

The Up/Crosswind ratio $\Delta(k)$ has been tuned to improve the agreement
Validation using QSCAT GMF: HH pol

- 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

Extension 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:**

$$W(k,\varphi,RR) = \begin{cases} 
\frac{1}{2\pi k} [k^{-3} B_{l}^{DP}(k)] \Phi(k,\varphi) & k < 10k_{p} \\
\frac{1}{2\pi k} \{[k^{-3} B_{h}^{DP}(k) \Phi(k,\varphi)] e^{-A} + k^{3} S(k,RR)\} & k > 10k_{p}
\end{cases}$$
RR-Extended wave spectrum results

- Full spectrum enhancement at $k > 10^2\ \text{rad}^{-1}$ 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

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Ku-band sigma0 results with rain

Upwind, $U_{10} = 10.5 \text{ m s}^{-1}$

Crosswind, $U_{10} = 10.5 \text{ m s}^{-1}$

Sigma0 VV [dB]

Sigma0 HH [dB]

Incidence angle [degree]
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:
  o Including the volume backscattering as well as attenuation due to rain.
  o Comparison to real data (RapidScat, SeaWind, AMSR, GPM).
  o Development of an inversion algorithm to estimate both wind and rain, *simultaneously*.