

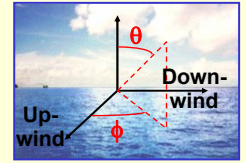
# LOCAL UNIFIED MODELS OF BACKSCATTERING FROM OCEAN-LIKE SURFACES AT MODERATE INCIDENCE ANGLES

**N. Pinel and C. Bourlier**

IREENA Laboratory, Fédération CNRS Atlanstic  
Polytech'Nantes, Rue Christian Pauc, BP 50609, 44306 Nantes Cedex 3, France  
[christophe.bourlier@univ-nantes.fr](mailto:christophe.bourlier@univ-nantes.fr)

**AIM: To rapidly derive the backscattering NRCS of ocean-like Gaussian surfaces from local unified models (SSA-2, LCA, ...)**

- ✓ Unified models require the computation of 4 (2 spatial and 2 frequency) numerical integrations
- ✓ From backscattering measurements, we have:  $\sigma^{pq}(\theta, \phi; u) = \sigma_0^{pq}(\theta; u) + \sigma_1^{pq}(\theta; u) \cos \phi + \sigma_2^{pq}(\theta; u) \cos(2\phi)$
- ✓ Use of the azimuthal property over  $\phi$  to efficiently compute the series coefficients  $\sigma_n(\theta, u)$



**DERIVATION:**  $\sigma^{pq}(\theta, \phi; u) = \sigma_{11}^{pq}(\theta, \phi; u) + \sigma_{12}^{pq}(\theta, \phi; u)$

**First-order kernel (SSA-1, LCA-1, ...)**

$$\begin{cases} \sigma_{11,0}^{pq}(\theta; u) = 2\pi A |\mathcal{N}_1^{pq}(\theta)|^2 e^{-Q_2^2 \sigma_n^2} \int_0^\infty J_0(k_{BR}r) [e^{Q_2^2 W_0(r)} I_0(Q_2^2 W_2(r)) - 1] r dr \\ \sigma_{11,1}^{pq}(\theta; u) = 0 \\ \sigma_{11,2}^{pq}(\theta; u) = 4\pi A |\mathcal{N}_1^{pq}(\theta)|^2 e^{-Q_2^2 \sigma_n^2} \int_0^\infty e^{Q_2^2 W_0(r)} J_2(k_{BR}r) I_1(Q_2^2 W_2(r)) r dr, \end{cases}$$

with

- $Q_2 = 2K \cos \theta$
- $A = 1/(\pi Q_2^2)$
- $\{J_n, I_n\}$ : Bessel functions

- Only 1 numerical integration over  $r$
- $\mathcal{N}_1(\theta)$  depends only on the kernel
- Sea height autocorrelation function:

$$\begin{cases} W_2(r, \phi_r) = W_0(r) - \cos(2\phi_r) W_2(r) \\ W_0(r) = \int_0^\infty \hat{W}_0(\xi) J_0(r\xi) d\xi \\ W_2(r) = \int_0^\infty \hat{W}_2(\xi) J_2(r\xi) d\xi, \end{cases}$$

- Sea height spectrum:  $\hat{W}(\xi, \phi_\xi) = \hat{W}_0(\xi) [1 + \hat{\Delta}(\xi) \cos(2\phi_\xi)] / (2\pi)$

**Second-order kernel (SSA-2, LCA-2, ...)**

$$\begin{aligned} \sigma_{12,n}^{pq}(\theta; u) &= 2A\pi e^{-Q_2^2 \sigma_n^2} \int_0^\infty \int_0^\infty r d\xi dr \\ &\times \left( \hat{W}_0(\xi) \left\{ e^{Q_2^2 W_0(r)} \left[ \Omega_n^{(0)}(a, b, c) - \hat{G}_0^{pq}(\xi) I_{\frac{n}{2}}(b) J_n(a) \right] + \hat{G}_0^{pq}(\xi) J_0(a) \delta_{n,0} \right\} \right. \\ &+ \hat{W}_2(\xi) \left\{ e^{Q_2^2 W_0(r)} \left[ \Omega_n^{(2)}(a, b, c) - \hat{G}_2^{pq}(\xi) \sum_{\gamma=\pm 1} J_{n\gamma+2}(a) I_{\frac{n\pm 2}{2}}(b) \right] \right. \\ &\left. \left. + \hat{G}_2^{pq}(\xi) J_0(a) \delta_{n,\pm 2} \right\} \right), n \text{ even,} \end{aligned}$$

with

$$\begin{aligned} a &= k_{BR} = 2Kr \sin \theta \\ b &= Q_2^2 W_2(r) \\ c &= \xi r \end{aligned}$$

and with

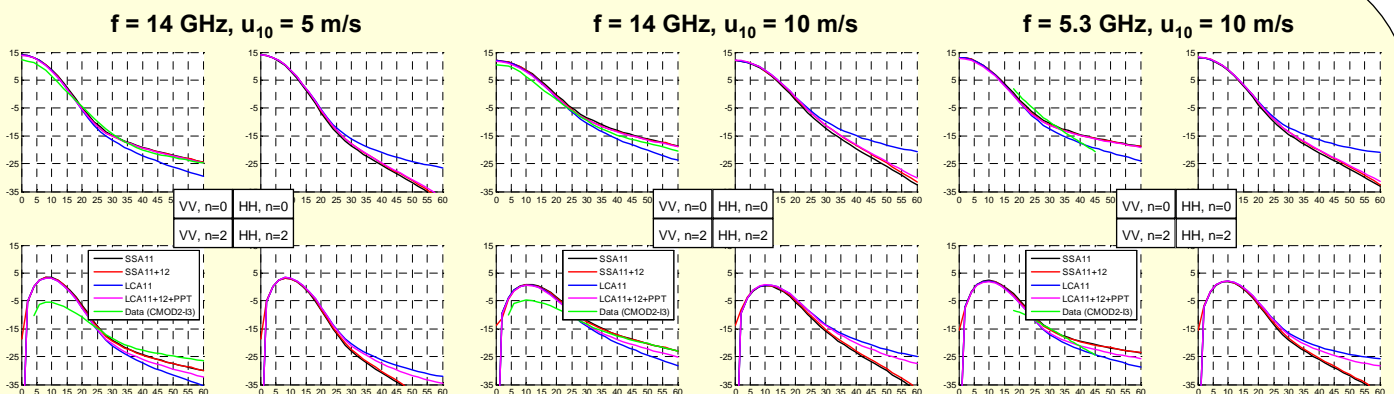
$$\begin{aligned} \Omega_n^{(0)}(a, b, c) &= \sum_{s=-\infty}^{+\infty} \frac{(-1)^s \hat{G}_s^{pq}(\xi)}{2} J_s(c) \sum_{j=\pm 1} J_{n\gamma+s}(a) I_{\frac{n}{2}}(b) \\ \Omega_n^{(2)}(a, b, c) &= \sum_{s=-\infty}^{+\infty} \frac{(-1)^s \hat{G}_s^{pq}(\xi)}{4} \sum_{\gamma_1=\pm 1, \gamma_2=\pm 1} J_{s+2\gamma_2}(c) J_{n\gamma_1+s}(a) I_{\frac{n-2\gamma_2}{2}}(b) \end{aligned}$$

- More complex than the first-order kernel
- Only 2 numerical integrations over  $\{r, \xi\}$
- $\hat{G}_s$  expressed from a Fourier series of  $\hat{G}$ :

$$\begin{cases} \hat{G}^{pq}(\xi, \phi_\xi) = -2Q_2 \text{Im} \left[ (\mathcal{N}_1^{pq})^* \mathcal{N}_2^{pq}(\xi, \phi_\xi) \right] \\ \hat{G}^{pq}(\xi, \phi_\xi) = -2Q_2 \text{Im} \left[ (\mathcal{N}_1^{pq})^* \mathcal{N}_2^{pq}(\xi, \phi_\xi) \right] + |\mathcal{N}_2^{pq}(\xi, \phi_\xi)|^2 \text{ PPT} \end{cases}$$

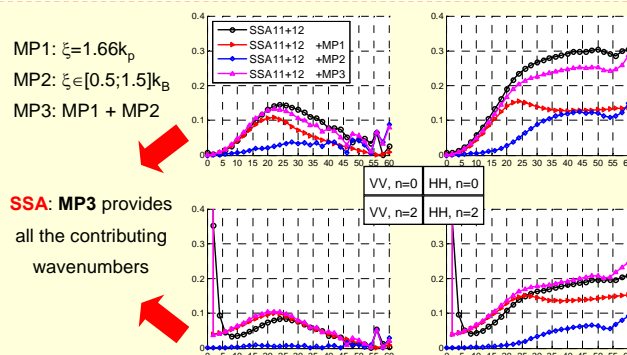
Bourlier et al., WRCM, 2009  
Voronovich et al., WRCM, 2001  
Wentz et al., JGR, 1984  
Quilfen et al., JGR, 1998

## NUMERICAL RESULTS: BNRCS versus the observation angle



- For VV, SSA11  $\approx$  SSA11 + SSA12  
 ➔ The second-order SSA12 is negligible
- For HH, SSA11 < SSA11 + SSA12  
 ➔ The second-order SSA12 contributes
- For VV, LCA11 < LCA11 + LCA1  
 ➔ The second-order LCA12 contributes
- For HH, LCA11  $\ll$  LCA11 + LCA12  
 ➔ The second-order LCA12 strongly contributes
- For HH and  $n=0$ , LCA and SSA under-predict the data  
 ➔ steep waves contribution
- For  $n=2$  and  $0 \leq \phi \leq 20^\circ$ , overestimation of the BNRCS  
 ➔ sea spectrum

## OPTIMIZATION OF THE INTEGRATION COMPUTATION OVER $\xi$ : $\sigma_{12}/\sigma_{11}$ versus $\theta$



- MP1:  $\xi = 1.66k_B$
  - MP2:  $\xi \in [0.5; 1.5]k_B$
  - MP3: MP1 + MP2
- SSA:** MP3 provides all the contributing wavenumbers

**LCA:** MP2 provides All the contributing wavenumbers

Computing time:  
- 1s without optimization  
- 0.1s with optimization