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Radar Backscattering Simulation of Sea Surface Oil Emulsions

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1. Introduction

Emulsion oil slick is one of the most common types of oil spills in the marine environment. Oil slicks can be observed as "dark" patches on SAR images because: a) oil slicks effectively damp capillary and short gravity sea waves responsible for backscattering energy; b) the relative permittivity of the contaminated area decreases significantly due to the smaller oil permittivity.

In this paper, to take both effects into consideration, the backscattering from the oil-covered sea surface is predicted using the Advanced Integral Equation Method (AIEM) model which is augmented with: a) the composite reflection coefficient of the two-layer medium that consists of adding an oil layer on top of the sea surface, where the seawater volume fraction in the oil emulsion modifies the dielectric properties; b) the sea spectrum model combined with the hydrodynamic model of local balance (MLB) which is employed to describe the damping of the small-scale roughness by an oil film.

2. Methodology

(1) Roughness Damping Model: MLB

$$y_s(K)=\frac{S_{clean}(K)}{S_{oil}(K)}=\frac{\beta^o-2\Delta^o c_g+\alpha^o}{\beta^w-2\Delta^w c_g+\alpha^w}$$

$S_{clean}(K)$ and $S_{oil}(K)$ represent the wave spectrum of the clean sea surface and oil-covered sea surface, respectively.

(2) Composite Reflection Coefficient

$$\tilde{R}=\frac{R_{01}+R_{12}\,e^{-2\gamma_1 d\cos\theta_1}}{1+R_{01}R_{12}\,e^{-2\gamma_1 d\cos\theta_1}}$$

R_{01} is the reflection coefficient for the air-oil interface, and R_{12} is the reflection coefficient for the oil-water interface

(3) Dielectric properties of oil on the sea surface

$$\varepsilon_{eff}=\frac{\varepsilon_e}{4}-(1-3f_v)(\varepsilon_i-\varepsilon_e)+\sqrt{[\varepsilon_e-(1-3f_v)(\varepsilon_i-\varepsilon_e)]^2+8\varepsilon_i\varepsilon_e}$$

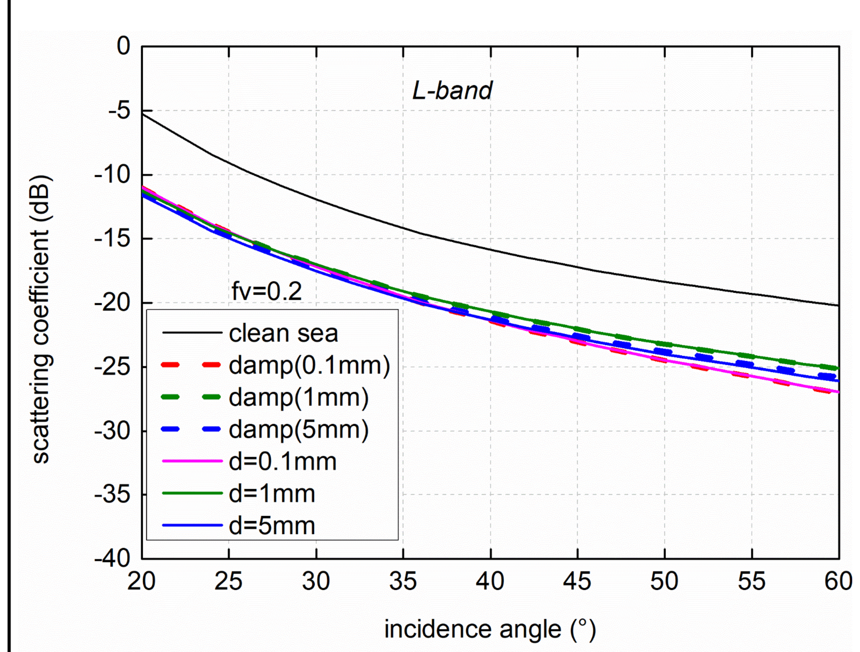
f_v is the volume fraction in the case of the homogeneous spherical inclusions ε_i, and in a homogeneous environment, ε_e

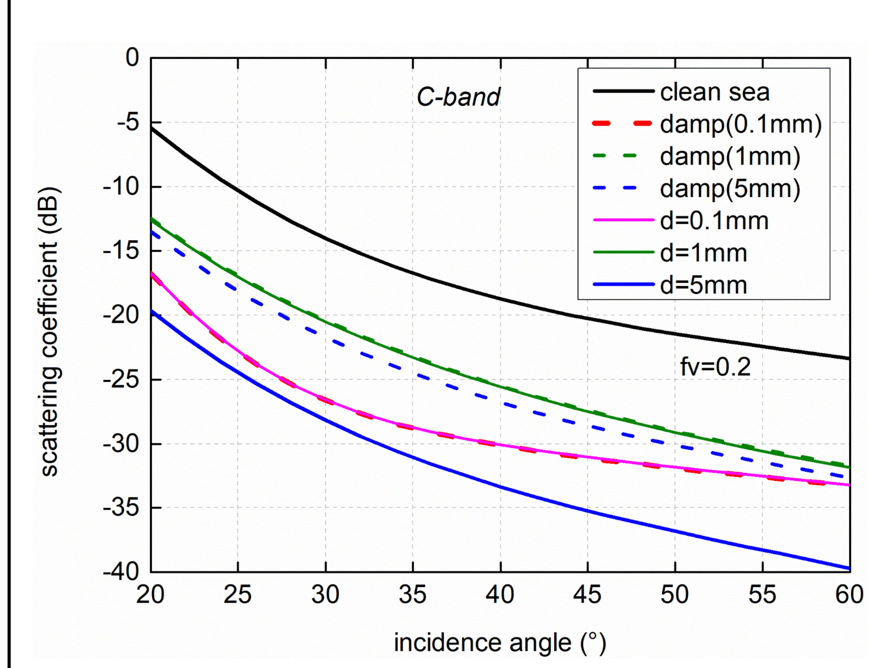
(4) Electromagnetic Scattering Model: AIEM

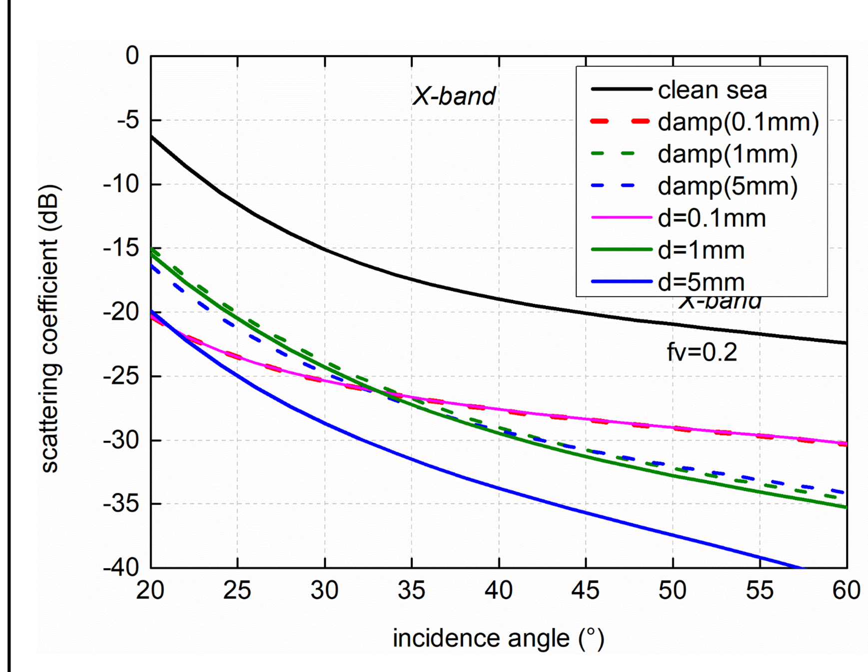
$$\sigma_{pq}^0=\frac{k^2}{2}\cdot exp\left[-\sigma^2\left(k_{iz}^2+k_{sz}^2\right)\right]\cdot\sum_{n=1}^{\infty}|I_{pq}^n|^2\frac{\sigma^{2n}W^{(n)}(k_{sx}-k_{ix},k_{sy}-k_{iy})}{n!}$$

3. Results

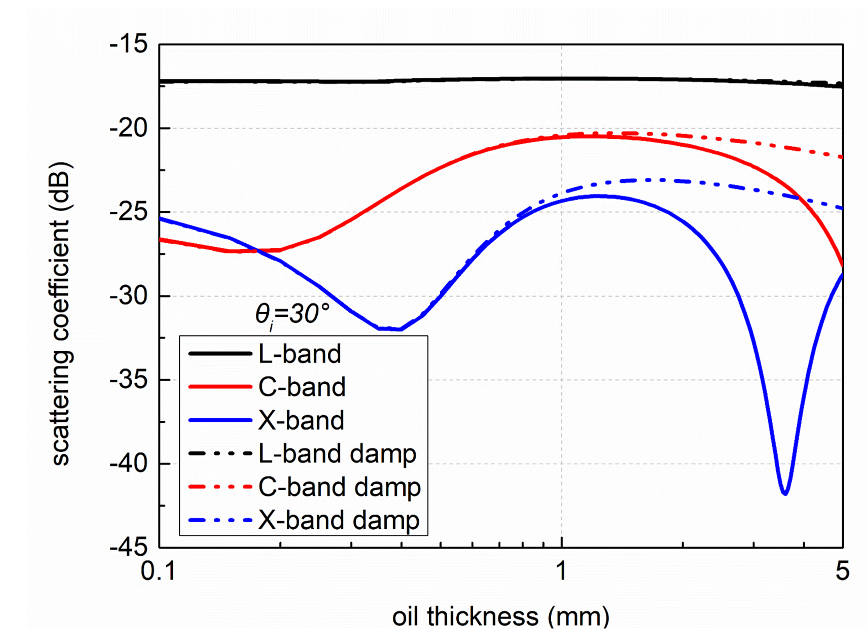
(1) Radar frequency dependency

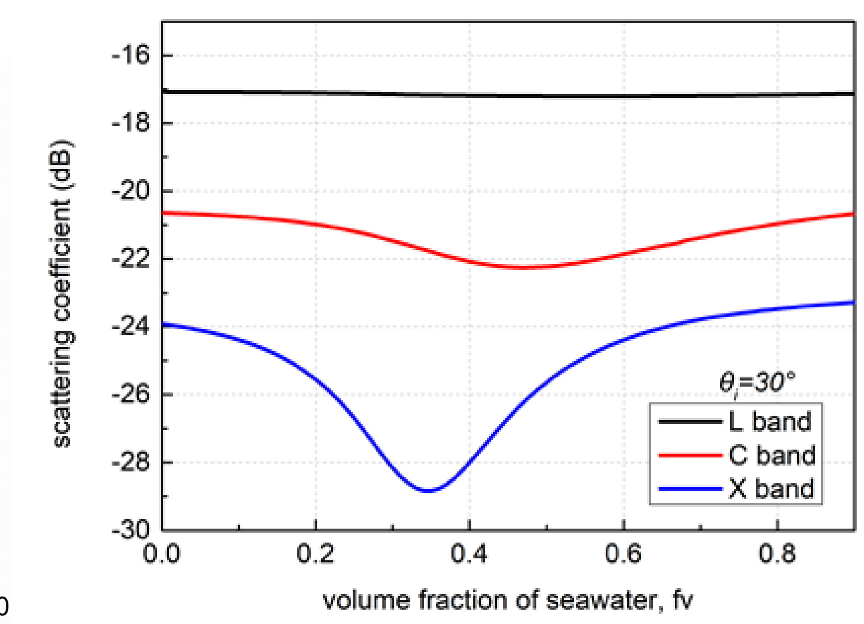




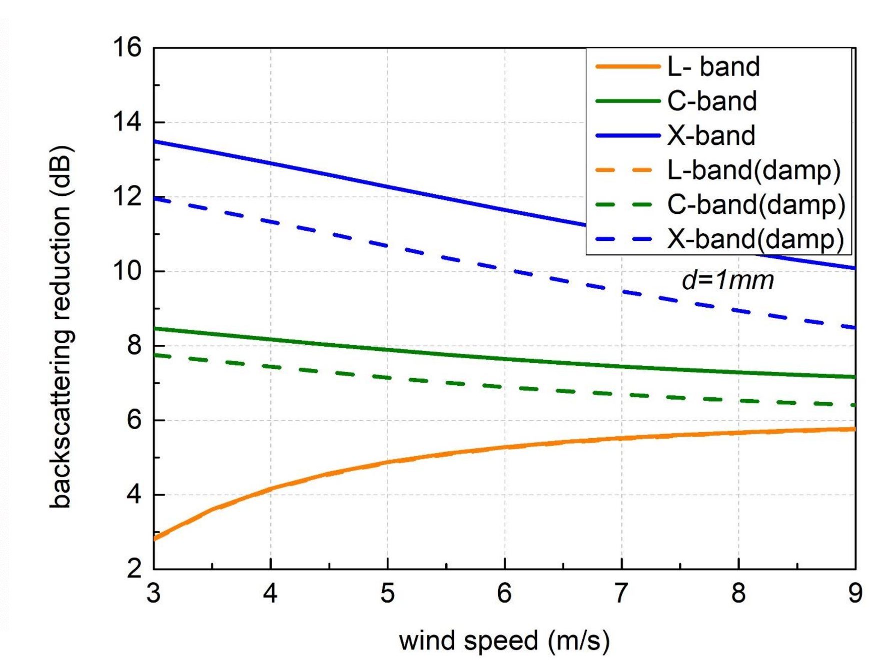


(2) Effect of oil thickness and water content





(3) Effect of wind speed



4. Conclusion

- The sensitivity of oil-covered sea surface backscattering to oil thickness and water content of emulsion increases as the increasing radar frequency with a reduced L-band sensitivity;
- The backscattering signals exhibit a nonlinear behavior with respect to oil thickness because oil films affect the backscattering in a twofold way;
- The incidence angle has a relatively minor impact on deviating the contaminated sea's backscattering;
- The high wind speed can generally narrow the difference between the radar backscattering from the clean and oil-covered sea surface.

References

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