THERMAL IR EMISSIVITY OF OIL FILMS ON SEA SURFACES UNDER MODERATE WINDS

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1. INTRODUCTION

Oil slick detection, identification, and even quantization are of great interest in the context of oil spill countermeasures. As a first approximation, it can be assumed that at radar wavelengths, as the oil film thickness is much inferior to the wavelength, the electromagnetic wave cannot "see" the thickness H [1]; consequently, it could be concluded that the radar response is not significantly sensitive to H. By contrast, at infrared (IR) wavelengths, as the wavelength λ is in the same order as the oil film thickness H, the electromagnetic response sensitivity with respect to H can be hoped for.

Then, the thermal IR emissivity of clean and contaminated seas is studied for this purpose. The phenomenon of multiple scattering at the same interface is not taken into account here, making the model applicable for moderate winds (corresponding to gentle surface slopes). By contrast, the phenomenon of multiple scattering inside the inner layer between the upper and lower interfaces is taken into account in the model. Hereafter, the hydrodynamic modeling describing the surfaces is summed up in section 2, and the electromagnetic model based on the Geometric Optics (GO) approximation is given in section 3.

2. PHYSICAL HYDRODYNAMIC MODELING OF CLEAN AND CONTAMINATED SEA SURFACES

In order to derive a physical electromagnetic model of the thermal IR emissivity of oil films on sea surfaces, first, the important starting point is to correctly describe the surfaces: in other words, a realistic physical hydrodynamic model must be applied. For sea-like surfaces, several spectrum models can be used. The Elfouhaily *et al.* spectrum model [2], widely used in the sea surface scattering community, is a good candidate and is elected here. Then, for the specific case of oil films on sea surfaces, a physical hydrodynamic model which describes the damping of the surfaces due to the presence of the oil film must be chosen.

The Lombardini *et al.* damping model [3], which is applicable for monomolecular films and well suited for mono-molecular fluids [4, 5], is in consequence not a good candidate for oil films with various thicknesses. By contrast, the Model of Local Balance (MLB) [5], which describes the hydrodynamic behavior of the surfaces of oil films on sea surfaces by action of wind, takes the film thickness H into account, as well as other physical parameters. Then, this damping model is used in what follows.

Fig. 1 illustrates the surface spectrum damping due to the oil film on the sea surface, modeled by the MLB, for a wind speed $u_{10} = 5$ m/s. The wind direction ϕ is not given, as the model does not depend on this parameter. The oil film is characterized by a viscosity $\nu_{oil} = 0.5$ cm^2/s, and a film thickness H equal to either 100 μm or 500 μm. Similarly as written by Fuks and Zavorotny [6], it can be observed that the surface damping predicted by the MLB is very weak for small surface wavenumbers

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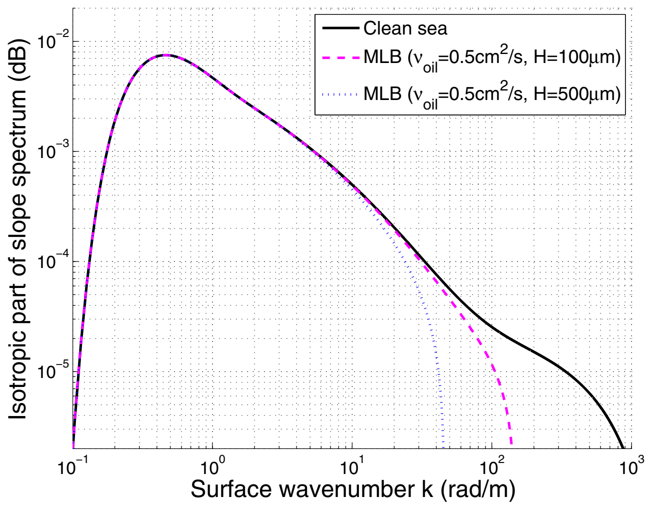

Fig. 1. Isotropic part of the surface slope spectrum of clean and contaminated seas versus the surface wavenumber k, for a wind speed $u_{10} = 5$ m/s. For the contaminated sea, the oil viscosity $\nu_{oil} = 0.5$ cm^2/s, and the oil film thickness $H = \{100, 500\}$ μm

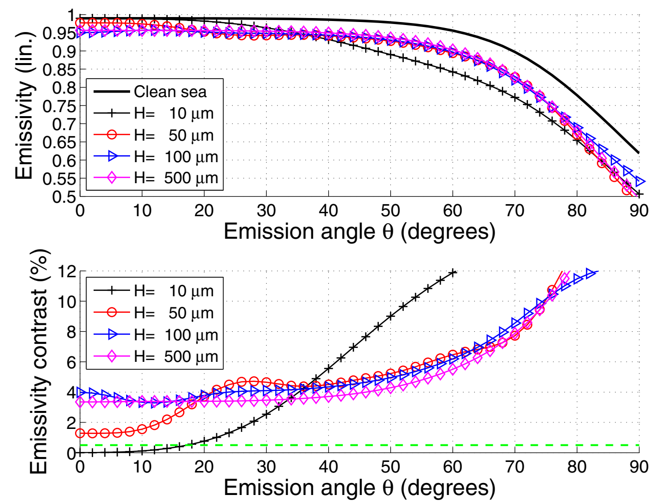

Fig. 2. Unpolarized emissivity (upper sub-figure) of clean and contaminated seas and emissivity contrast of contaminated seas with respect to clean seas (lower sub-figure) versus the emission angle θ for a wavelength $\lambda = 10$ μm and for wind speed $u_{10} = 5$ m/s and direction $\phi = 0$. For the contaminated sea, the oil viscosity $\nu_{oil} = 0.5$ cm^2/s, and the oil film thickness $H = \{10, 50, 100, 500\}$ μm.

k, corresponding to large surface correlation lengths L_c. Then, for k superior to a few tens of rad/m (corresponding to L_c inferior to a few centimeters or decimeters), a very strong surface damping occurs. Here for $H = 100$ μm, k is in the order of $30 - 40$ rad/m, and for $H = 500$ μm, k is in the order of 100 rad/m. Thus, surface components with correlation length L_c inferior to a few centimeters can be neglected (see Fig. 1). This limit depends on the film thickness H as illustrated here in Fig. 1, but also on the viscosity ν_{oil}. This is in qualitative agreement with Fuks and Zavorotny [6]. Nevertheless, comparatively to Fuks and Zavorotny who take correlation length limits $L_c = \{30, 60, 100\}$ cm (and which correspond to surface wavenumbers $k = \{20.9, 10.5, 6.3\}$ rad/m), the results of the MLB plotted in Fig. 1 suggest that L_c should be taken a bit smaller: in the order of ten times smaller for small to moderate wind speeds, as checked here for $u_{10} = 5$ m/s. Moreover, the use of the MLB allows us to show the quantitative dependence of L_c with respect to both the film thickness H and viscosity ν_{oil}. Last, this model predicts a strong decrease of the surface spectrum around L_c rather than a cutting-off at L_c, which seems a more realistic damping behavior.

3. IR EMISSIVITY MODELING OF CLEAN AND CONTAMINATED SEAS UNDER THE GO APPROXIMATION

Thus, this hydrodynamic modeling is used for the electromagnetic modeling. Here, the thermal IR emissivity of clean and contaminated seas is studied in the IR atmospheric transmission windows $[3; 5]$ μm and $[8; 13]$ μm. Fig. 2 presents numerical results in the second atmospheric window, at $\lambda = 10$ μm. The wind speed is the same as in Fig. 1, and for the oil film, the viscosity and the thicknesses are also the same. Moreover, two curves with lower film thicknesses $H = 10$ μm and $H = 50$ μm are added. The numerical results are presented in the wind direction, i.e. $\phi = 0$.

Comparatively to the clean sea, the results of the contaminated sea for various thicknesses H highlight general significant differences, except for $H = 10$ μm at emission angles θ close to 0. This clearly appears in the lower sub-figure which represents the emissivity contrast of contaminated seas with respect to clean seas. Indeed, the contrast is lower than the limit of detectability of classical sensors (equal to 0.5% [7] and represented in green dashed line) only for this case.

Moreover, comparing the curves for different thicknesses with respect to one another, general significant differences appear in their behavior with respect to the emission angle θ, and in particular for the lower thicknesses. Then, from measurements at different emission angles, the oil film evaluation can be hoped for.

Last, other simulations [4] (not presented here) with different oil types (characterized by different oil viscosities ν_{oil}) highlight the influence of the oil viscosity on the IR emissivity, which means that the oil characterization can also be hoped for.

4. REFERENCES

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