

## A Coupled Model for the Wave-Induced Drift of Oil Slicks

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### ABSTRACT

We present a theoretical model for the wave-induced drift and horizontal deformation of an oil slick. The waves and the mean flow are coupled through the influence of the mean flow on the concentration of slick material, and the waves are forced by the wind. We simultaneously obtain the slick drift velocity, as well as the temporal and spatial changes in the concentration of slick material. The results demonstrate that the waves cause significant nonuniform changes in the horizontal distribution of slick material, and hence also on the horizontal shape of the slick. The timescale of these changes is comparable to that of the wave-induced slick drift.

KEY WORDS: Oil slicks; wind waves; wave drift.

### INTRODUCTION

The drift of oil spills in the ocean is a complex problem. By changing the dynamical conditions at the surface, the oil influences the momentum fluxes between the atmosphere to the ocean, which has consequences both for the surface waves, the mean currents, and the wind profile in the atmospheric boundary layer (e.g. Saetra 1998). Most contemporary models for oil slick drift assume constant wind-dependent stresses at the air-sea interface, and that the slick is passively advected by the ocean currents (e.g. ASCE 1996). We show here that when waves are present, this cannot be the case, since the wave-induced stresses are strongly dependent on both wavelength and slick material concentration. Since the sea surface usually support waves of many different frequencies, the horizontal distribution of the wave-induced stresses (and implicitly therefore also the wind-induced stresses) will vary greatly both in space and time. Ultimately, this variation leads to a redistribution of slick material. It is therefore necessary to couple the equations governing the oil slick properties to the dynamical equations to obtain a realistic model for the drift of an oil slick. It is the purpose of this paper to show the effect of the waves on the drift and deformation of an oil slick when such a coupling is made. We extend the model developed by Christensen and Terrile (manuscript submitted to J. Fluid Mech., hereinafter CT). In CT the momentum flux from wind to waves is neglected. Due to the dissipation of wave energy in the viscous surface boundary layer, the waves are then damped even

when no slick is present. Although the results demonstrate how the waves act to redistribute slick material, this situation is not representative for most oceanic conditions. In this paper we take into account wind forcing of the waves such that a balanced state between wind forcing and viscous dissipation prevents wave amplitude decay in the regions not covered by the slick. The effect of the wind is through the form stress on the waves (e.g. Phillips, 1977, Sec. 3.4), and alters the wave attenuation rate, and the mean drift through changed dynamic boundary conditions.

Short surface waves are strongly damped under an oil slick. This damping is due to the strong shear, and associated viscous dissipation, in the oscillatory surface boundary layer (Dorrestein 1951). Most types of oil form a very thin elastic layer at the surface, and the deformation of the surface caused by the capillary-gravity waves induce elastic longitudinal waves at the air-sea interface (Lucassen 1968). The wave-induced drift strongly depends on the slick elasticity (Weber and Saetra 1995). The slick elasticity is proportional to the surface tension gradient, and since the surface tension depends on the concentration of slick material, the slick elasticity at any point in the slick can be calculated if the mean concentration is known. In previous theoretical studies it has been assumed that the concentration of slick material is constant, without regard to the advection of slick material by the mean currents (e.g. Weber and Saetra 1995; Christensen 2005). CT show that there are substantial differences between a coupled model and a model in which the slick elasticity is assumed constant. For example, due to the spatial changes in the wave-induced stresses, the horizontal shape of the slick can change on the same timescale as that of the slick drift.

Our intention is to present the simplest possible coupling between the waves and the slick in order to demonstrate how the waves act to redistribute slick material, thus we want to avoid unnecessary complexity in the presentation. Several mechanisms are therefore neglected, either because they are shown not to be important, or because they are not directly relevant to the dynamics we wish to study. For instance, we neglect Coriolis forces, which means that the results are not directly applicable to large oil slicks (Christensen and Weber 2005). Furthermore, we assume that the eddy viscosity  $\nu$  is constant, and we neglect changes in mean surface height, and nonlinear interaction between different wave components (e.g. Melsom 1992). A