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Wavelength Scaling of Ocean Surface Friction Coefficient in Wind Sea and Mixed Sea

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The momentum exchange across the air-sea interface is represented by the wind stress. Over the ocean, the wind stress is rarely measured directly but calculated from wind speed, with additional modification on the air-sea stability and surface wave conditions when such information is available. Because of the boundary layer effect, wind speed varies as a function of elevation. After about 1980s, the neutral wind speed at 10 m elevation, U_{10}, is generally used as the reference and the friction coefficient is C_{10}. Extensive research has been conducted on the dependence of C_{10}, or alternatively, the dynamic roughness, on environmental parameters including wind speed, stability and surface waves. Somewhat surprisingly, after the stability correction or under neutral stability condition, the most practical expressions of the friction coefficient seem to be in the form of dimensionally inconsistent polynomial functions of wind speed, $C_{10}(U_{10})$. Sometimes wave parameters such as significant wave height and wave steepness are also included to produce regression equations of C_{10}.

Hwang (2004) suggests that the source of the difficulty in finding a dimensionally consistent similarity relation of the ocean surface friction coefficient may be the arbitrary 10-m reference elevation, which is selected as a matter of convenience or practical necessity rather than as a dynamically significant height in the wave-induced boundary layer (WBL). From fluid dynamics consideration, the proper reference velocity is the free-stream velocity, U_∞, outside the boundary layer. Although a full understanding of the WBL in the open ocean may not be available at this stage, it is well established that the dynamic effects of waves decay exponentially with distance from the interface and the rate of decay is proportional to the wavelength. At a distance of one half wavelengths, the wave dynamic effects are attenuated to 0.043 so that $U_{\lambda/2}$ is a good candidate for U_∞ in problems involving WBL such as the ocean surface friction coefficient. Subsequent application of wavelength scaling to an assembly of data sets under wind-generated wave conditions has produced positive outcome of a similarity relationship of dimensionally consistent ocean surface friction coefficient.

Here we presents an analysis of wavelength scaling for the ocean surface friction coefficient in mixed sea using the data from a recent field experiment of air-sea interaction in the Gulf of Tehuantepec (IntOA). For wind sea with mono-peak wave spectra, the natural choice of the scaling wavelength is that of the spectral peak component. For mixed sea with multi-peak spectra, the peak component in the wind sea portion of the wave spectrum is not a good reference wavelength. A better scaling wavelength is the weighted average of swell and wind sea following the consideration of equivalent momentum in the wave field.

While referencing wind speed at a fixed elevation such as U_{10} is of practical necessity,$U_{\lambda/2}$ is physically significant as the free-stream velocity in wave modulated boundary layer flows. A simple procedure to apply the similarity relation of $C_{\lambda/2}$ to obtain C_{10} is described. An application of the similarity relation of ocean surface friction coefficient to the growth functions of wind generated surface waves is discussed.