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WIND-WAVE INTERACTIONS UNDER THE INFLUENCE OF THE SOMALI LOW-LEVEL JET

S. A. Hsu

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INTRODUCTION

Since the speed of the Somali low-level jet may reach 40 m/s in certain regions over the Indian Ocean during the summer, a constant value for the drag coefficient, C_{10}, has been found inadequate for many air-sea interaction studies such as heat flux and evaporation computations. During MONEX 1979 (May and June), high-resolution rawinsonde stations were set up at Mogadishu and at Gardo, in Somalia, to measure the structure of this jet. These two stations were operated jointly by Louisiana State University and Florida State University. Simultaneous observations of surface winds and waves downwind from this jet were made by research and merchant ships.

It is the purpose of this paper to study the significant heights and periods of sea waves under the influence of the Somali jet. In order to improve input to the study of atmosphere-ocean systems, such as heat budget, wave and current forecasting, and numerical modeling of the marine boundary layer, a recently developed wind stress formulation which incorporates wave-breaking characteristics is also investigated.

WIND-WAVE INTERACTION

During May and June 1979 many sets of wind and wave data were obtained. They are available through the U.S. National Climatic Center (Marine Surface Observations from Tape Data Family -11). In this study they were reduced according to the guidance given in Kraus (1972). Significant wave height versus wind speed is shown in Figure 1, and wave period versus wind speed is given in Figure 2. It can be seen that, although the coefficients are different from those of "fully developed" seas, the basic equations are similar. From Figure 1

$$H_{1/3} = 0.92 + 0.0735 \frac{U^2}{g} \tag{1}$$

where $H_{1/3}$ is the significant wave height, U is the wind speed at deck height, and g is the gravitational acceleration. From Figure 2

$$T = 1.88 + 0.40 \frac{2\pi U}{g} \tag{2}$$

where T is the wave period. Note that the data incorporated in Figures 1 and 2 were based on sets obtained between June 12 and June 30 in a region between 6-12°N and 49-53°E, where the upwind wind measurements at Gardo, Somalia, were also made, so that the data used were in fact under the influence of the Somali low-level jet. For details about MONEX, see Fein and Kuettner (1980).

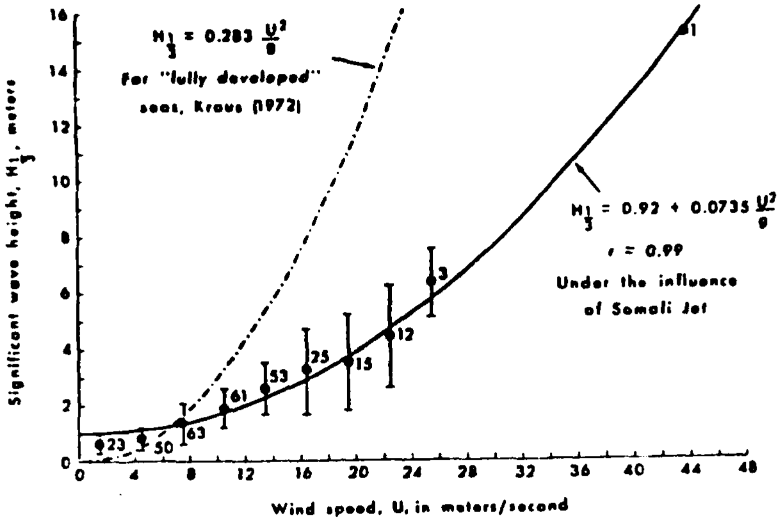

Figure 1. Variation of significant wave height with wind speed.

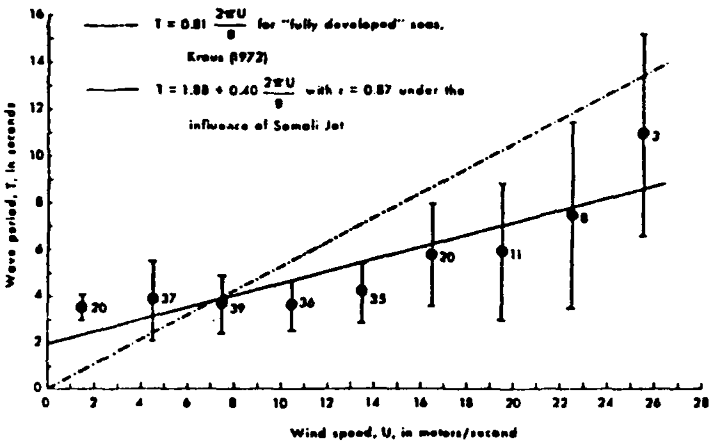

Figure 2. Variation of wave period with wind speed.

WIND STRESS OF THE JET

Pairs of $H_{1/3}$ and T were used to compute the average wave height, H, and the phase velocity of the waves for deep water, $C = g\,T/(2\pi)$. From these two parameters and the wind speed, U_z, at deck height, z, the shear (friction velocity), U_*, were obtained by using a nomogram such that

$$2\pi z\, C^2/H = U_*^2 \exp\,(\kappa\, U_z/U_*) \tag{3}$$

For more detail, see Hsu (1976).

Figure 3 shows the variation of U_* and $C_{10} = (U_*/U_{10})^2$, with the wind speed at 10 m. Many formulas were tried in the computation. However, only that of Amorocho and DeVries (1980, 1981) gives reasonably close fit. Their equation is

$$U_* = \left\{0.0015\left[1 + \exp\left(-\frac{U_{10} - 12.5}{1.56}\right)\right]^{-1} + 0.00104\right\}^{1/2} U_{10} \tag{4}$$

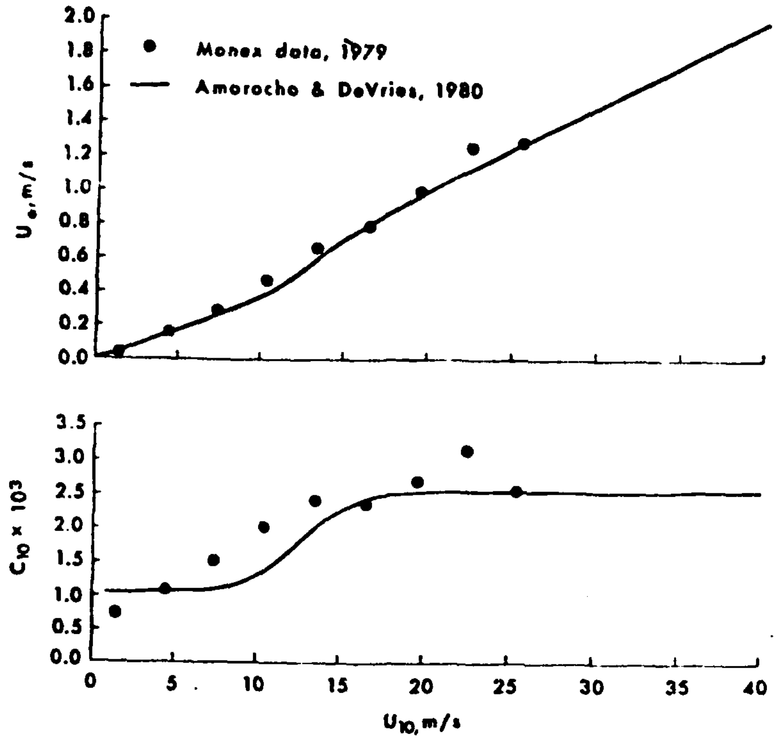

Figure 3. Variation of shear velocity, U_*, and drag coefficient, C_{10}, with wind speed.

The nonlinear characteristics reflect the onset of breakers and breaker saturation. The drag coefficient, C_{10}, as shown in Figure 3, can be simplified as

$$\left.\begin{aligned} &C_{10} \times 10^3 = 0.46 + 0.14\ U_{10} \\ &\text{For } U_{10} \leq 15 \text{ m/s} \\ \text{and} \\ &C_{10} \times 10^3 = 2.62\ . \\ &\text{For } U_{10} > 15 \text{ m/s} \end{aligned}\right\} \qquad (5)$$

The reason for this discontinuity between 12 and 15 m/s may be attributed to the formation of helical roll vortices, which in turn increase the turbulence level beyond this critical wind speed (SethuRaman, 1979). It is also possible that due to the steadiness of the jet during summer the sea waves begin to break at around 12-15 m/s. Saturation of the breakers may actually produce sheets of foam, which in turn separate the water and air so that the wind drags the foam rather than the real seawater. Certainly more study on this aspect of the problem is needed.

APPLICATIONS TO HEAT-FLUX AND EVAPORATION COMPUTATIONS

If Eq. (4) and Fig. 3 are accepted, U_* can be utilized directly in the computation of heat flux, H_s, and evaporation, E,

$$
\left.\begin{aligned} H_s &= \rho\, C_p\, U_*^2\, (\theta_s - \theta)/U_z \\ E &= \rho\, U_*^2\, (q_s - q)/U_z \end{aligned}\right\} \quad (6)
$$

where ρ is the air density, θ is the potential temperature, and q is the specific humidity. Subscript s is the sea surface. These equations apply to both adiabatic and nonadiabatic conditions and are particularly suitable if the wind stress U_* is known. For more detail, see Roll (1965). Note that to use U_* instead of C_{10} is in essence to bypass the uncertainty inherited in the formulation of the drag coefficient (Amorocho and DeVries, 1980), as shown in Figure 3.

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