Wind Stress over Water Surfaces: Comparisons of Various Estimation Methods

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Wind stress $\tau = \rho \ U^*^2 = \rho \ C_d \ U_{10}^2$

Where $\rho$ is the density of air, $U^*$ is the friction velocity, $C_d$ is the drag coefficient, and $U_{10}$ is the wind speed at 10m above the water surface.
1. Wind-wave Interaction Method

- When $U_{10}$ is less than 7.5 m/s, surface tension and thermal effects dominate the air-water interaction;
- When $U_{10} > 7.5$ m/s, mechanical turbulence takes over, so that the logarithmic wind profile prevails,

$$U_{10} = \frac{U^*}{k} \ln \left( \frac{10}{Z_o} \right)$$  \hspace{1cm} (1)

Where $k (=0.4)$ is the von Karman constant, $Z_o$ is the aerodynamic roughness length.
According to Taylor and Yelland (2001, JPO),

\[ \frac{Z_o}{H_s} = 1200 \left( \frac{H_s}{L_p} \right)^{4.5} \]  \hspace{1cm} (2)

\[ L_p = g \frac{T_p^2}{(2\pi)} = 1.56 \ T_p^2 \]  \hspace{1cm} (3)

Where \( H_s \) is significant wave height, \( L_p \) is peak wave length, \( g \) is gravitational acceleration, and \( T_p \) is dominant wave period.
2. Wave Method

According to Csanady (2001) and JONSWAP Wave Spectra (Carter, 1982), for $U_{10} > 20 \text{m/s}$ after wave breaker saturation (Amorocho and DeVries, 1980; and Geernaert et al., 1987),

$$g \frac{H_s}{U^*^2} = 0.053 \left( g \frac{T_p}{U^*} \right)^{3/2} \quad (4)$$

Therefore,

$$U^* = 36 \frac{H_s^2}{T_p^3} \quad (5)$$
3. Turbulence Intensity or Gust Factor Method

According to Hsu (1988, Coastal Meteorology) and Hsu (2003, Journal of Waterway, Port, Coastal, and Ocean Engineering),

\[ U^* = k \rho U_{10} \]  \hspace{1cm} (6)
\[ G = 1 + 2P \]  \hspace{1cm} (7)
\[ \frac{U_2}{U_1} = \left( \frac{Z_2}{Z_1} \right)^p \] \hspace{1cm} (8)
\[ P = \frac{\sigma u}{U_{10}} \] \hspace{1cm} (9)
\[ G = \frac{U_{\text{gust}}}{U_{\text{sustained}}} \] \hspace{1cm} (10)
Cd, based on gust factor measurements

U10, m/s, from 8/25/00Z to 8/28/05Z at Buoy 42003 during Katrina
\[ y = 0.9919x \]

\[ R^2 = 0.8452 \]

\[ R = 0.92 \]

\[ U^* = 36 Hs^2 / Tp^3, \text{ m/s, at Buoy 42003 during Katrina} \]
$y = 0.017x^{1.3213}$

$R^2 = 0.9643$

$R = 0.98$

$U^*$, m/s, vorticity and wind–wave interaction methods

$U_{10}$, m/s, based on Hurricanes Inez, Kate, Lili, and Rita
\[ U^* = 0.017 U^{1.32}, \text{ m/s} \]

\[ y = 1.0715 x \]

\[ R^2 = 0.9927 \]
$y = 1.0179x$

$R^2 = 0.8391$

$R = 0.92$
Surface current $= 0.55 U^*$, m/s

Hours from 9/15/00Z at Buoy 42040 during Ivan