An Algorithm for Estimating Maximum Wave Height and Wave Period inside Tropical Cyclones

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Hurricanes are among the most hazardous natural disasters. They cause tremendous damage and pose extreme challenges for operation. Presently, satellite monitoring addresses the wind velocity. To properly evaluate the damage potential of a hurricane, it is critical to consider not only wind but also sea state parameters such as the significant wave height and dominant wave period.

Through recent analyses of the wind and wave data collected in several hurricane reconnaissance missions, it has been established that the wave development inside hurricanes follows essentially the same fetch- or duration-limited principles governing the wave growth under steady wind forcing conditions (Hwang 2016; Hwang and Walsh 2016; Hwang and Fan 2017).

This is an important development because at the foundation of fetch- or duration limited wave growth is a pair of dimensionless equations describing the growth of wave height and wave period as fetch or duration increases. The three most important wind and wave parameters (the wind-wave triplets): wind speed U_{10}, significant wave height H_s, and dominant wave period T_p are thus connected by two equations for a given fetch or duration. Defining the fetch or duration of a hurricane wind field thus holds the key to accessing the robust and versatile wind wave growth functions for achieving [U_{10} <u>or</u> H_s <u>or</u> T_p] = [U_{10} <u>and</u> H_s <u>and</u> T_p].

Through reverse engineering using the simultaneous wind and wave data collected in four hurricane reconnaissance missions during Bonnie 1998 and Ivan 2004, a scaling model of the fetch and duration of hurricane wind fields has been developed (Hwang and Fan 2017). The key features of the fetch and duration scaling model are: (a) The fetch and duration increase linearly with the radial distance r from the hurricane center along any radial transect with a constant azimuth angle ϕ referenced to the hurricane heading; (b) The slope and intercept of the linear function vary systematically with the azimuth angle referenced to the hurricane heading; (c) The systematic azimuthal variation of the slope and intercept can be represented by Fourier harmonic functions, the coefficients of which vary systematically with a small number of the characteristic hurricane parameters; and (d) The most important characteristic hurricane parameters relevant to the fetch and duration are (in descending order of significance): the radius of maximum wind speed (r_m), the translation speed of the hurricane (V_h), and the maximum wind speed ($U_{10\max}$).

With the fetch and duration defined at any location inside the hurricane, H_s and T_p are given in simple algebraic equations of U_{10} and r. Because the radial dependence of the wind speed can be approximated by a simple power function of r, H_s and T_p along a radial transect are thus given as simple algebraic equations of r alone, and their maximum values can be obtained from seeking the locations where the gradient of the algebraic functions become zero. The final result of maximum wave height and wave period, H_{smax} and T_{pmax}, of a hurricane depends on the $U_{10\max}$ and r_m of the hurricane. An algorithm of estimating the maximum wave height and wave period insider hurricanes is developed based on the above considerations.

Using the computed results with r_m from 10 to 100 km and $U_{10\max}$ from 20 to 80 m/s as database, the result can be approximated by

$$Q_q\left(U_{10}, r_m\right) = A_{Qq}\left(r_m\right) U_{10\max}^{a_{Qq}(r_m)}, \qquad (1)$$

where Q can be H or T to represent H_{smax} or T_{pmax}, and q can be x or t to indicate whether Q is derived from fetch or duration function. The exponents are basically constant: a_{Hx}=1.19, a_{Ht}=1.47, a_{Tx}=0.53, and a_{Tt}=0.69. The proportionality coefficients A_{Qq} dependency on r_m can be represented by second order polynomials:

$$A_{Qq}\left(r_m\right) = p_2 r_m^2 + p_1 r_m + p_0 \,. \tag{2}$$

The fitting coefficients (p_2, p_1, p_0) are (1.10×10^{-5}, -2.99×10^{-4}, 9.76×10^{-2}) for A_{Hx}, (4.47×10^{-6}, -8.20×10^{-5}, 3.08×10^{-2}) for A_{Ht}, (1.19×10^{-4}, -7.94×10^{-3}, 1.82) for A_{Tx}, and (7.46×10^{-5}, -3.80×10^{-3}, 9.29×10^{-1}) for A_{Tt}. The predicted values are in good agreement with simultaneous wind and wave measurements conducted by hurricane reconnaissance aircraft in 11 missions. Fig. 1 shows the contour plots of the predicted $H_{smax}(U_{10\max}, r_m)$ and $T_{pmax}(U_{10\max}, r_m)$, and their comparison with hurricane reconnaissance and research measurements.

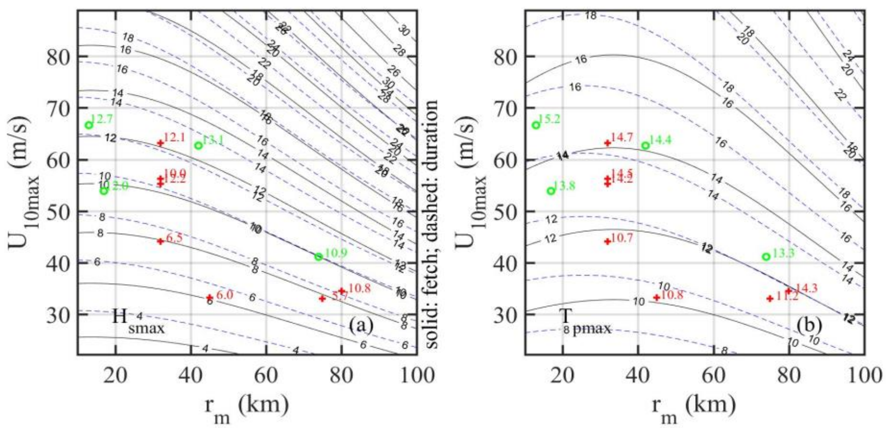

Fig. 1. Contour maps of (a) H_{smax} and (b) T_{pmax} showing their dependence on $U_{10\max}$ and r_m. Solid and dashed lines show the results computed with the fetch-limited and duration-limited functions, respectively. The red and green markers show the H_{smax} and T_{pmax} (with the corresponding values printed beside the markers) based on 11 hurricane reconnaissance missions, the 4 green ones are used in the algorithm development, the 7 red ones are not used in the algorithm development.

References

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