# Determining Typhoon's Radius of Maximum Wind from Satellites to Improve Sea State and Storm Surge Forecasting

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## Abstract

Under hurricane / typhoon conditions the simplified non-dimensional JONSWAP wave formulation performs equally well as compared to the more advanced third generation wave prediction model because the wind-waves are fetch-limited. Based on this finding and another simplified hydrodynamic equation for the storm surge, $\Delta S$, it is shown that $\Delta S$ can be approximated by $H_{sr}^2 / D$ where $H_{sr}$ is the deepwater significant wave height before shoaling at a distance of r from the storm center and D is the depth of the oceanic mixed layer. Since $H_{sr}$ is related to the radius of maximum wind, R, from the storm center to the eye wall region, satellite determination of R is presented. R can be determined from storm center to the region where lowest cloud top temperature is located due to maximum convection, therefore values of R have been estimated from NOAA's Polar Orbiters using one km resolution of AVHRR dataset from 9 typhoons between 1985 and 1994 over East China Sea. The results show that the mean R at the sea surface is 46 km and the standard deviation is 23 km. This mean R value is in good agreement with the values given in the literature.

## 1 Introduction

Under typhoon or hurricane conditions forecasts of sea state and storm surge require the knowledge of the radius of maximum wind, R. Traditionally, R is determined as follows (see, e.g. Coastal Engineering Research Center, CERC, 1984):

$$\frac{P - P_0}{P_n - P_0} = e^{-\frac{R}{r}} \qquad \textbf{(1)}$$

where P is the pressure at a point located at a distance r from the storm center, $P_0$ is the central pressure, and $P_n$ is the pressure at the outskirts of the storm.

From a satellite meteorology viewpoint, R can also be determined from the storm center to the eye wall region where the lowest cloud top temperature is located in the maximum convection area. The purpose of this paper is to provide some results of R values for typhoons as determined from NOAA's Polar Orbiters and their applications to sea state and storm surge forecasting.

## 2 Operational Forecasting Formulas

On the basis of approximate balance between the kinetic energy or wind stress as the input and the water level increase due to potential energy as the output, the generic hydrodynamic equation for storm surge is simplified as, (Hsu, in press)

$$\Delta S = S - S_0 = \frac{\left(\rho_a C_d V^2 F\right)}{\left(\rho_w g D\right)} \qquad \textbf{(2)}$$

where S is the water level or set-up; $S_0$ is the initial sea level; $C_d$ is the wind-stress drag coefficient; V is the wind speed; F is the fetch along the wind direction; g is the gravitational acceleration; D is the average water depth or the depth of oceanic mixed layer such as thermocline or pycnocline; and $\rho_a$ and $\rho_w$ are the air and water density, respectively. On the other hand, according to the spectral wave model such as the JONSWAP formulae (CERC, 1984):

$$\frac{g H_{sr}}{V^2} = K\left(\frac{gF}{V^2}\right)^{\frac{1}{2}} \qquad \textbf{(3)}$$

where K ( = $1.6 \times 10^{-3}$) is the non-dimensional wave height coefficient for fetch-limited waves such as under typhoon conditions, and $H_{sr}$ is the deep water significant wave height before shoaling at a distance r from the typhoon center. From Eqs. (2) and (3) we have

$$\Delta S = \left( \frac{\rho_a C_d H_{sr}^2}{\rho_w K^2 D} \right) \approx \frac{H_{sr}^2}{D} \qquad \textbf{(4)}$$

since $C_d \approx 2 \times 10^{-3}$ (Hsu, 1988), $\rho_a = 1.2$ kg / m³ and $\rho_w = 1000$ kg / m³.

For operational forecasting (Hsu, 1997):

$$\frac{H_{sr}}{H_{s\max}} = 1.06 - \left( 0.11 \left( \frac{r}{R} \right) \right) \qquad \textbf{(5)}$$

and

$$H_{s\max} = 0.20 \left( 1013 - P_0 \right) \qquad \textbf{(6)}$$

where $H_{s\max}$ is the deep water significant wave height at R, which is the typhoon's radius of maximum wind and $P_0$ in mb is the central pressure.

Because the parameter D in Eq. (4) is not readily available during tropical storms due to the interaction between wind wave and thermocline or pycnocline, i.e. the erosion of the oceanic mixed layer, further simplification is necessary. This is accomplished as follows: according to Bishop (1984), the open ocean peak surge associated with Hurricane Camille in August 1969 in the Gulf of Mexico was estimated at 6.7 m above the mean sea level. At the same time, the measured significant wave height from an oil platform on the right hand side of the storm in the deeper Gulf before shoaling was 13.6 m with dominant wave period of 14.3 second (see WAMDI Group, 1988). Therefore, from Eq. (4) $D = 13.6^2 / 6.7 = 28$ m. Since the wave length $L = (g/2\pi)T^2 = 319$ m, we have $D / L = 28 / 319$ or $D = 0.0878L = 0.0878(g/2\pi)T^2$. However, under the hurricane condition, $T = 12.1 (H_{sr} / g)^{1/2}$ (see CERC, 1984). Thus,

$$\Delta S \approx 0.5 H_{sr} \qquad \textbf{(7)}$$

Now, we can estimate both sea state and storm surge using Eqs. (5) through (7) if we have values of the storm's central pressure $P_0$ and the radius of maximum wind, R. Also, from Eqs. (5) through (7), it is interesting to note that ΔS is nearly linearly proportional to $\Delta P$ (= 1013 - $P_0$) as used in the operational SPLASH model by U.S. NOAA although the coefficient may be different.

## 3 Determining R Values from Satellites

Since R can be determined from storm center to the region where the lowest cloud top temperature is located due to maximum convection, values of R have been estimated from NOAA's Polar Orbiters using one km resolution of AVHRR dataset from 9 typhoons between 1985 and 1994 over the East China Sea (see Table 1). The results show that the mean R is 83 km and the standard deviation is 43 km. Since the R value at the sea surface is approximately 55% of that at the cloud top (Anthes, 1982, Fig. 2.7), the mean R value for Eq. (5) is thus about 46 km, in good agreement with the values given in the literature from Anthes (1982, p. 22) for R ≈ 40 km and Simpson and Riehl (1981, p. 99) for R ≈ 50 km. However, since the standard deviation is not small, this mean R value is provided here only as a guide. Detailed discussion based on color slides for the R determination from NOAA satellites will be presented in the talk.

## 4 Conclusions

On the basis of 9 typhoons between 1985 and 1994 over the East China Sea, it is found that satellite determination of the radius of maximum wind has a mean value of 46 km with a standard deviation of 23 km. Since this mean value is in good agreement with the literature value of between 40 to 50 km, this method of using satellite cloud top temperature analysis may be applied for sea state and storm surge forecastings, which are provided in Eqs. (4) through (6). For quick operational estimation, it is also found that the open ocean storm surge may be approximated as half of the significant wave height before shoaling. Certainly, more field verification must be undertaken to further substantiate the results presented here.

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Table 1.
Satellite Determination of R for 9 Typhoons From 1985 Through 1994
Over The East China Sea

| Date / Time | Minimum Cloud Top Temperature °C | R km |
|---|---|---|
| 31 July 1985 / 2256Z | -77 | 100 |
| 24 June 1986 / 0620Z | -65 | 126 |
| 27 July 1989 / 2302Z | -71 | 36 |
| 30 August 1990 / 0545Z | -82 | 80 |
| 30 August 1990 / 1014Z | -79 | 118 |
| 27 July 1991 / 0548Z | -86 | 48 |
| 28 July 1991 / 0537Z | -72 | 53 |
| 26 September 1991 / 0549Z | -78 | 71 |
| 7 August 1992 / 2325Z | -81 | 25 |
| 31 July 1994 / 2259Z | -78 | 164 |
| 13 August 1994 / 2318Z | -75 | 57 |
| 14 August 1994 / 2259Z | -67 | 122 |