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The comparison of two parametric wind models for hurricane storm surge prediction

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सार — उष्णकटिबंधीय तूफानी तरंगों के मॉडल अधिकतम धरातलीय पवन और पवन प्रोफाइल के आकार पर मुख्य रूप से निर्भर करते हैं। चूँकि इनमें से किसी को भी मापना सरल कार्य नहीं है, अतः तूफानी तरंगों के पूर्वानुमान के लिए प्राचलिक पवन मॉडलों के अभिकल्पन में भिन्नताएं पाई जाती हैं। बहुत अधिक प्रयोग में आने वाले, परन्तु बिल्कुल विभिन्न प्रकृति के दो पवन मॉडलों की जाँच की गयी है। उनके प्राचलों के अध्ययन से यह पता चलता है कि उनसे उत्पन्न अधिकतम पवन और पवन प्रोफाइलों के आकार में समानता है। यह तथ्य विभिन्न तरंग मॉडलों के मूल्यांकन के लिए बहुत ही उपयोगी दिशा-निर्देश है।

ABSTRACT. The tropical storm surge models depend critically on the maximum surface wind and shape of the wind profile. Since none of them are easy to measure, designing the parametric wind models for the storm surge prediction becomes divergent. Two widely used, but very different, wind models are examined. The study of their parameters showed that their resulting maximum wind and the shape of the wind profiles are similar. This property is a very useful guide for evaluating different surge models.

Key words — Tropical storm surge, Wind profile, Parametric wind model, Maximum surface wind.

1. Introduction

It is generally accepted that the central pressure of a tropical storm is most conservative measure for intensity. However, the storm surge is generated primarily due to the surface stress from wind forcing. The storm surge model for operational prediction preferred the central pressure as primary input to maximum wind speed, and then derive wind/pressure in two dimensions. This is a very common practice, but choices vary widely. Two most significantly different approaches are : (*i*) using a standard pressure profile and (*ii*) using a standard wind profile. The former approach is more popular because pressure is a more conservative surface weather element. If reconnaissance data are available, flight level wind data can add the latter possibility.

Holland (1980), representing the former case in this study, introduced an additional parameter, B, implying the steepness of the pressure gradient near the inner core of the convection, based on the analysis of reconnaissance data from western North Pacific (Weatherford 1985). The early suggestion is that the intensity of storm, measured by Minimum Sea-Level Pressure (MSLP) may vary quite independently from the Outer Core Strength (OCS), winds (kt) 1-2.5° from center of the storm. But, as confirmed later, their relation did exist if the data is stratified with eye diameters (Fig. 1). For a fixed pressure, OCS is related with eye sizes. Jelesnianski and Taylor (1973), (JT), assumed a normalized wind profile, and the steepness of the wind profile is characterized by an inverse relationship between the maximum wind and the size.

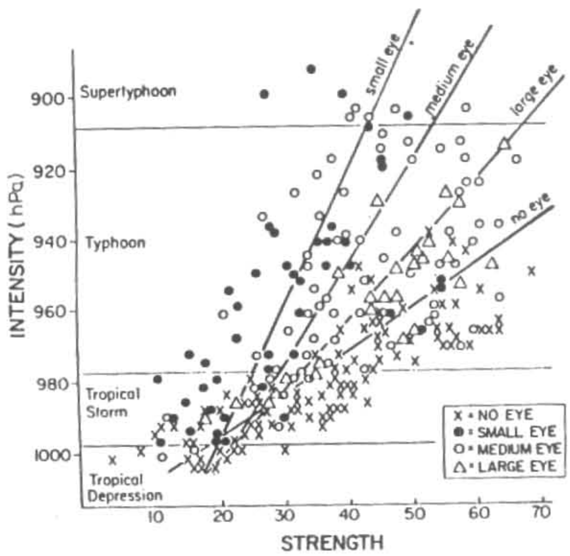


Fig. 1. Intensity *versus* strength differs by eye class (small eye 0-7.7 n mi; medium eye 7.5-15 n mi; large eye 15-50 n mi). Courtesy from Weatherfold 1985.

Fig. 2 (a) shows a family of wind profiles for a given pressure drop (Δp), the deficit of central pressure from the ambient pressure. JT's wind has been used in the surge models, called SPLASH and SLOSH. The peak surge generated on the coast has been shown sensitive to Δ p, but insensitive to a family of wind profiles, like Fig. 2 (Jelesnianski 1972). It was an intended design to not rely on less dependable size information.

Although Holland's parameter B infers only the core intensity, Weatherfold's study suggests that the intensity changes must result to some extent in contraction and expansion of the storm, the change in OCS. This fact coincides the designed property of JT for storm surge prediction.

2. A Simple Model Estimate

A simple commonly used formula for the western Pacific typhoons (Atkinson and Holliday 1977) is

$$V_m = 3.44 \ (\Delta P)^{.644} \tag{1}$$

where, Δp is in hPa V_m, in m/s, is the sustained 1-minute surface wind. The exponent is empirical. It is a simple first order guess. For 10-minute wind comparison, the curves with 80% and 90% are chosen for comparison.

3. Gradient Balanced Vortex Model

Schloemer (1954) and Myers (1954), SM, used a pressure formula

$$p - p_c = (\Delta p)\exp(-R_m/r) \tag{2}$$

$$V_c = C \ (\Delta p)^{1/2} \tag{3}$$

where, p_c is the central pressure, V_c, is the maximum cyclostrophic wind speed near the steepest pressure gradient, $r = R_m$, C is an empirical constant. Holland (1980) generalized this form by introducing a 'steepness' parameter, B which measures the pressure gradient near the radius of maximum wind:

$$p - p_c = (\Delta p) \ \exp \ [-(R_m/r)^B] \tag{4}$$

$$V_{c-h} = C \ (\Delta p)^{1/2} \tag{5}$$

$$C = (B/\rho e)^{1/2} \tag{6}$$

where, ρ is the air density, e = 2.7183, $A = (R_m)^B$ in Holland's notation. When B = 1, it reduces to Schloemer and Myers' formula. V_{c-h} is the maximum cyclostrophic wind at R_m. Holland suggested that B value should normally range from 1 to 2.5. The gradient wind speed, V_g, can be determined by:

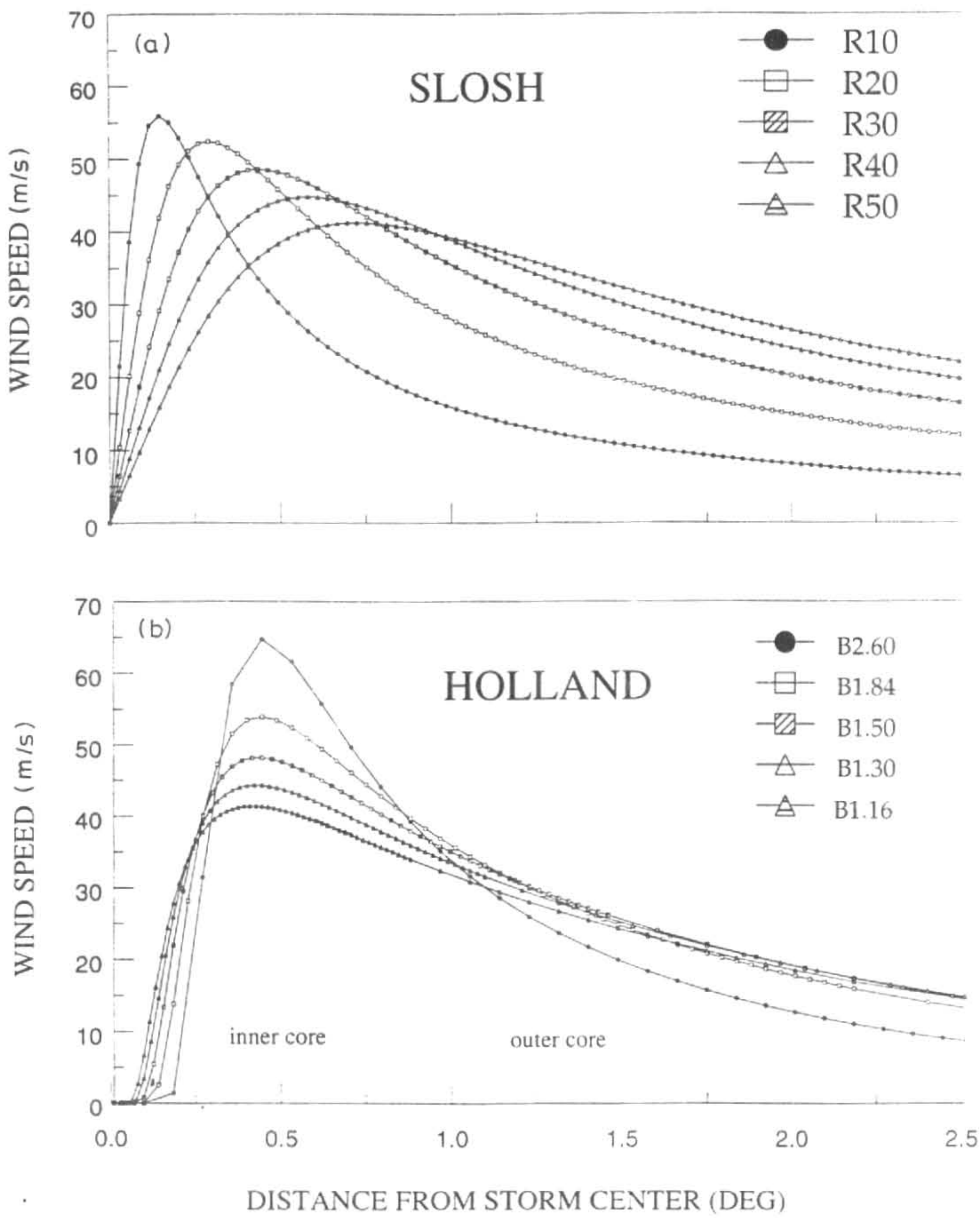
$$V_c = V_{c-h} [1/x \ \exp \ (1 - 1/x)]^{1/2}, \ x = (r/R_m)^B \tag{7}$$

$$V_g = V_c \ (1 + a^2)^{1/2} - a \tag{8}$$

$$a = .5 \ (fr)/V_c \tag{9}$$

The location of maximum gradient wind v_{g-h} can be proved very close to the location of maximum cyclostrophic wind V_{c-h}, R_m, because a < < 1 within the parameter ranges. The parameter B meaning the steepness of the pressure profile near R_m is associated with the storm intensity. For surface value, a simple reduction of 80 percent is used (Powell 1980) in this study.

The formulae for V_{c-h} and maximum V_{g-h} (V_g at R_m), depend on B, but not on the radius of maximum wind, R_m. The parameter B stands for an intensity measure of the storm, associated with inner core



Figs. 2(a&b). (a) A family of SLOSH's wind profiles with different radii of maximum wind for a fixed pressure drop (b) Same as (a) except for Holland's formula with different B values

dynamics. The vlaue of R_m is to measure the spread of winds from storm center. Holland implied that the storm's inner core intensity (referred by B) is somewhat independent of the outer core strength from the reconnaissance data by the early study of Weatherford and Gray (1988). The typical profiles of Holland are shown in Fig. 2 (b) for fixed Δp and R_m.

4. Surface Trajectory Model

Jelesnianski and Taylor (1973), (JT), used the equations derived for the surface spiral trajectory computation (Myers and Malking 1961) :

$$\frac{1}{\rho_a}\frac{dp}{dr}=\frac{k_s V^2}{\sin\phi}-V\frac{dV}{dr} \tag{10}$$

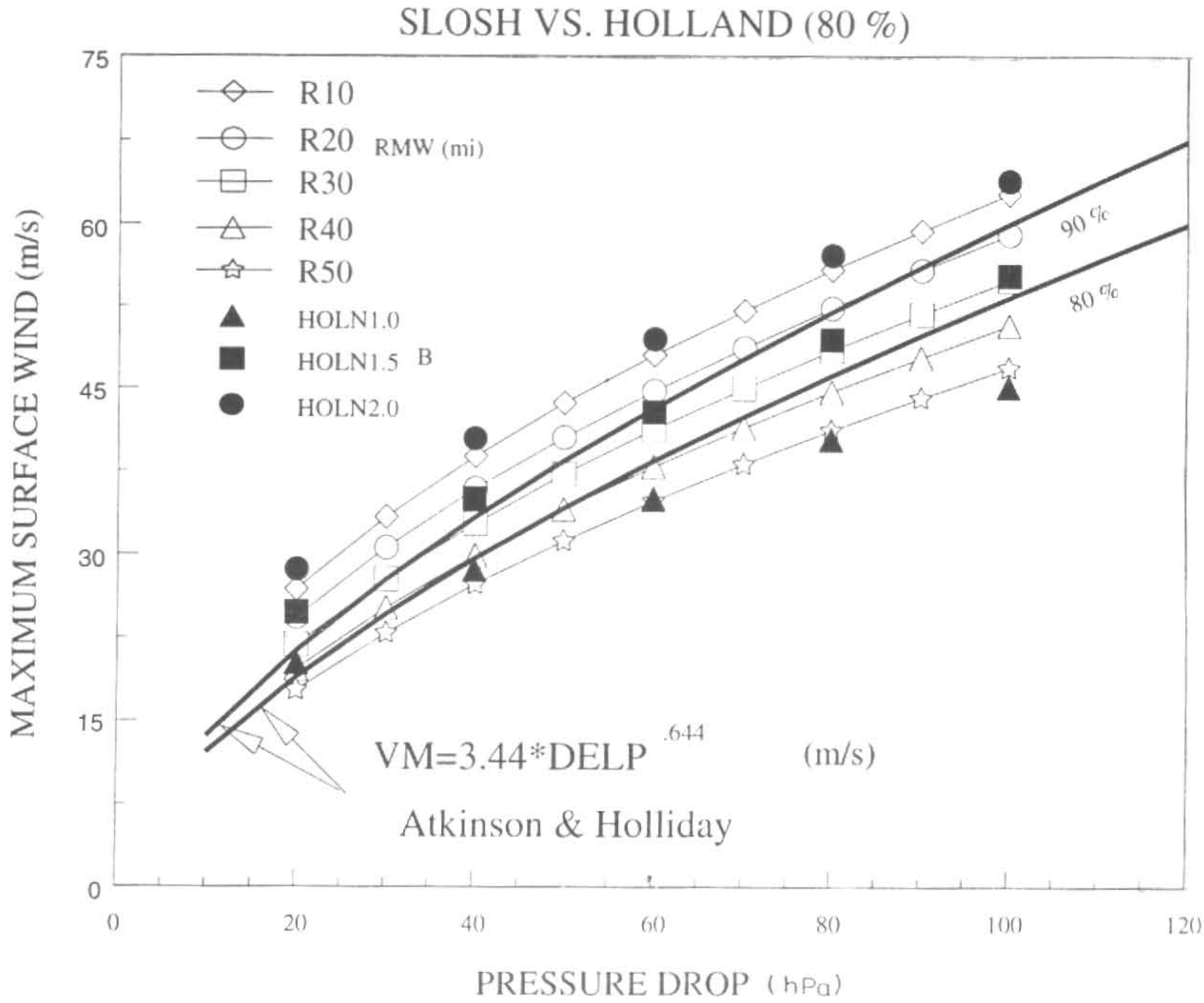


Fig. 3. Comparison of relations between maximum wind and pressure drop estimated by SLOSH with a range of R_m and by Holland with a range of B, against Atkinson and Holliday's curves

$$\frac{1}{\rho_a}\frac{dp}{dr}\cos\phi = fV + \frac{V^2}{r}\cos\phi - V^2\frac{d\phi}{dr}\sin\phi + k_n V^2 \quad (11)$$

The k_s and k_n are empirical friction constants, other notations are referred to the text of JT (1973). The wind speed profile, scaled by radius of maximum wind, R_m, is

$$V(r) = V_{m-sl} * 2x/(1+x^2),\ x = r/R_m \quad (12)$$

With V_{m-sl}, maximum wind speed, undetermined. Under iterative process, Eqns. (10) and (11) are integrated, with a specified pressure drop, Δp, and R_m. The maximum wind is determined in the process of matching the pressure gradients to the empirical friction and centrifugal terms. The inflow angle is so determined at the balance. If the friction is reduced, the wind approaches to one balanced by a pressure profile. The resulting maximum wind is roughly proportional to the square root of Δp, and mildly dependent on R_m. For smaller R_m, with same pressure drop, it results higher maximum wind speed.

5. Comparison

Both Holland and JT provide a range of variability of maximum wind estimate to pressure drop, based on parameter B, or R_m, respectively. Fig. (3) shows V_{m-sl} and V_{g-h} with Δp. for a range of R_m = 20, 30, 40, 50 mi and B = 1, 1.5, 2. The mean value is

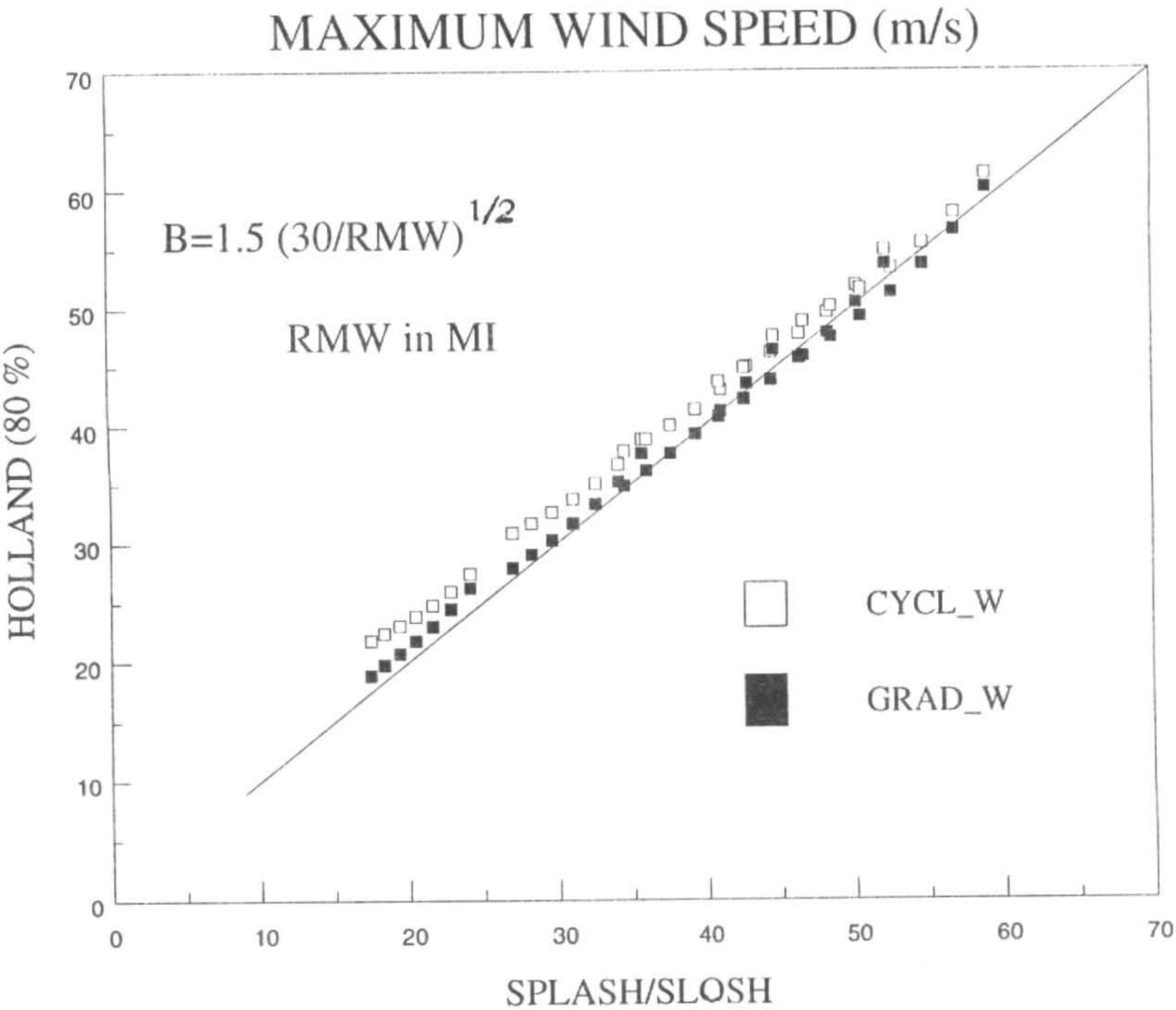


Fig. 4. Comparison of two methods by relating the parameter B and R_m

at B = 1.5, or R_m = 30 mi. It is clearly seen the similarity of their variabilities. The SM's formula, B = 1, underestimates the maximum wind compared with other two methods. Atkinson and Holliday's (AH) 80 and 90 percent reduction curves are included to represent 10-min averaged wind), and can be seen that AH's curves form a band through the middle of variations from different R_m's and B's, except the two extremes, small weak storms and strong large storms which are most unlikely.

JT's profiles shows that intensifying storms must cause storm to shrink in size; whereas the larger values of Holland's B reflect storm's intensification and but necessarily resulting the size changes (R_m or A). It seems Holland offers one more degree of freedom. However, from Fig. (1), Holland's R_m (A) can not be completely independent of B. Only for small eye class, or intense storms, this constraint is weaker, OCS would vary less dependently of inner core changes. This OCS's a typical behaviour, sometimes concerned by forecasters, can only be captured by an additional degree of freedom to the wind or pressure profile.

But, to the first order concern, if one sets

$$B = 1.5 \ (30/R_m)^{1/2} \qquad (13)$$

where, R_m in mi, and the limits of B will be between 1 and 2.5 for almost all storm sizes. The estimates of maximum surface wind by both methods come very close, as shown in Fig. (4). Maximum differences do not exceed 2 m/s, as B is kept under 2. When $B > 2$, or $R_m < 16.8$ mi, the change

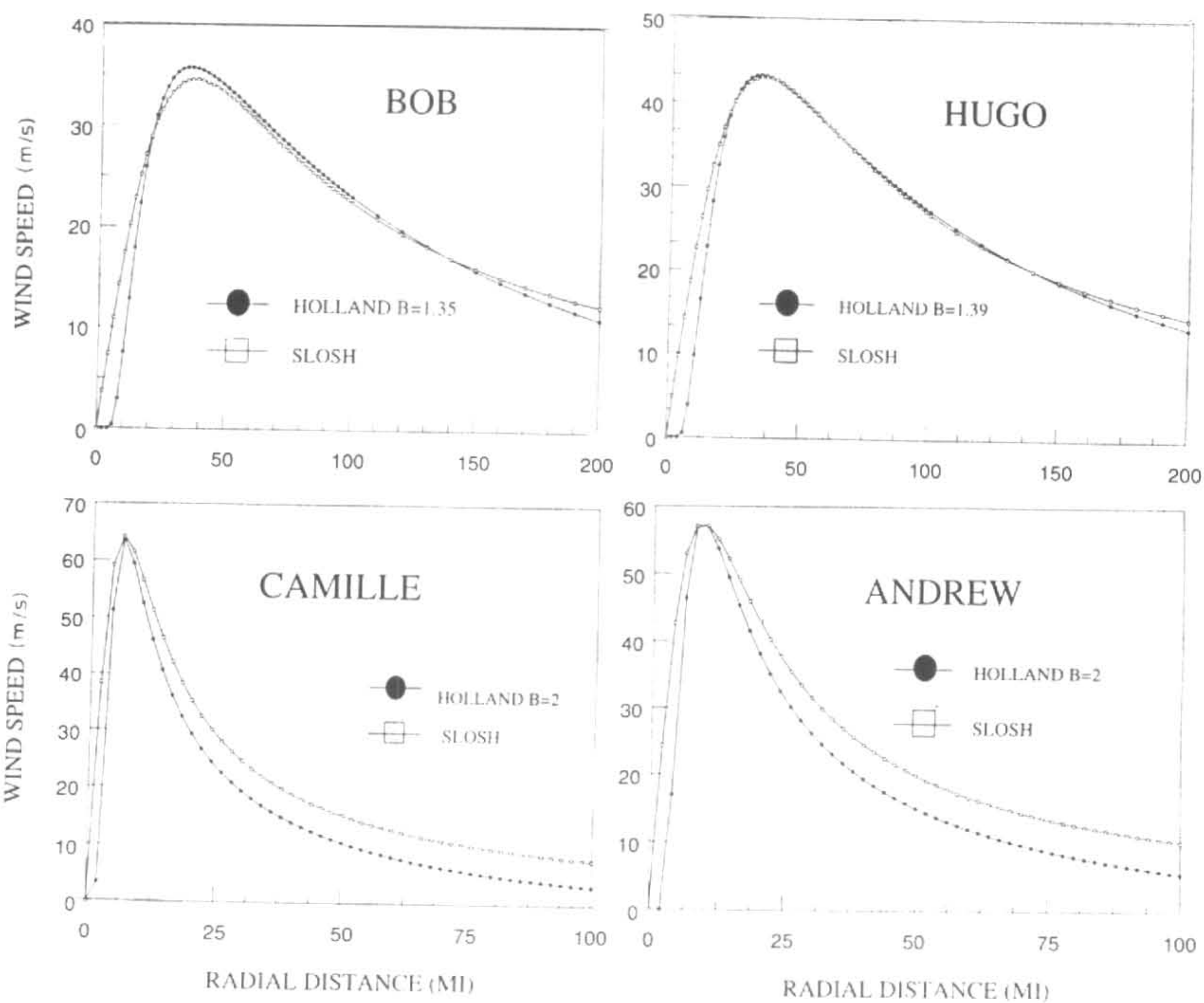


Fig. 5. Comparing SLOSH and Holland's wind profiles for four historical storms using Eqn. 13

of maximum winds becomes too sensitive to B, as experienced by many users. An upper limit of $B = 2$ seems to be reasonable for Camille-type storms. See Fig. 5 for four storms.

In practice, Holland's pressure profile fit with a set of B and A is not always feasible in the forecast mode. Estimating R_m from the radar image of inner cloud band (half the diameter plus 5 nm) would provide a simple option to estimate B.

For testing Australian storm orson, that $\Delta p = 105$ hPa ($p_c = 905$ hPa) RMW = 18 mi (30 km) gives $B = 1.94$, agreed with the pressure fit (Lance *et al.* 1997, unpublished). V_m is 64 m/s, but with 70% reduction, is then 56 m/s, confirmed by the surface observation. For western North Pacific Typhoon Herb, 1996, $\Delta p = 80$ hPa ($P_c = 930$ hPa) RMW = 15 mi (eye diameter estimated from radar is 30 km), B = 2.1, $V_m = 53$ m/s, 56 m/s with motion correction, which is consistent with estimated over 60 m/s in 1-min wind. However, the broad wind field is not captured with the model wind profile.

Parallel runs for hurricane Fran, 1996 of east coast of U.S. showed good agreement on the maximum surge profile along the coast, Fig. 6. For Holland's run, a constant 25 degree cross- isobaric angle was used, and $B = 1.25$.

More comparing studies for historical storms are underway.

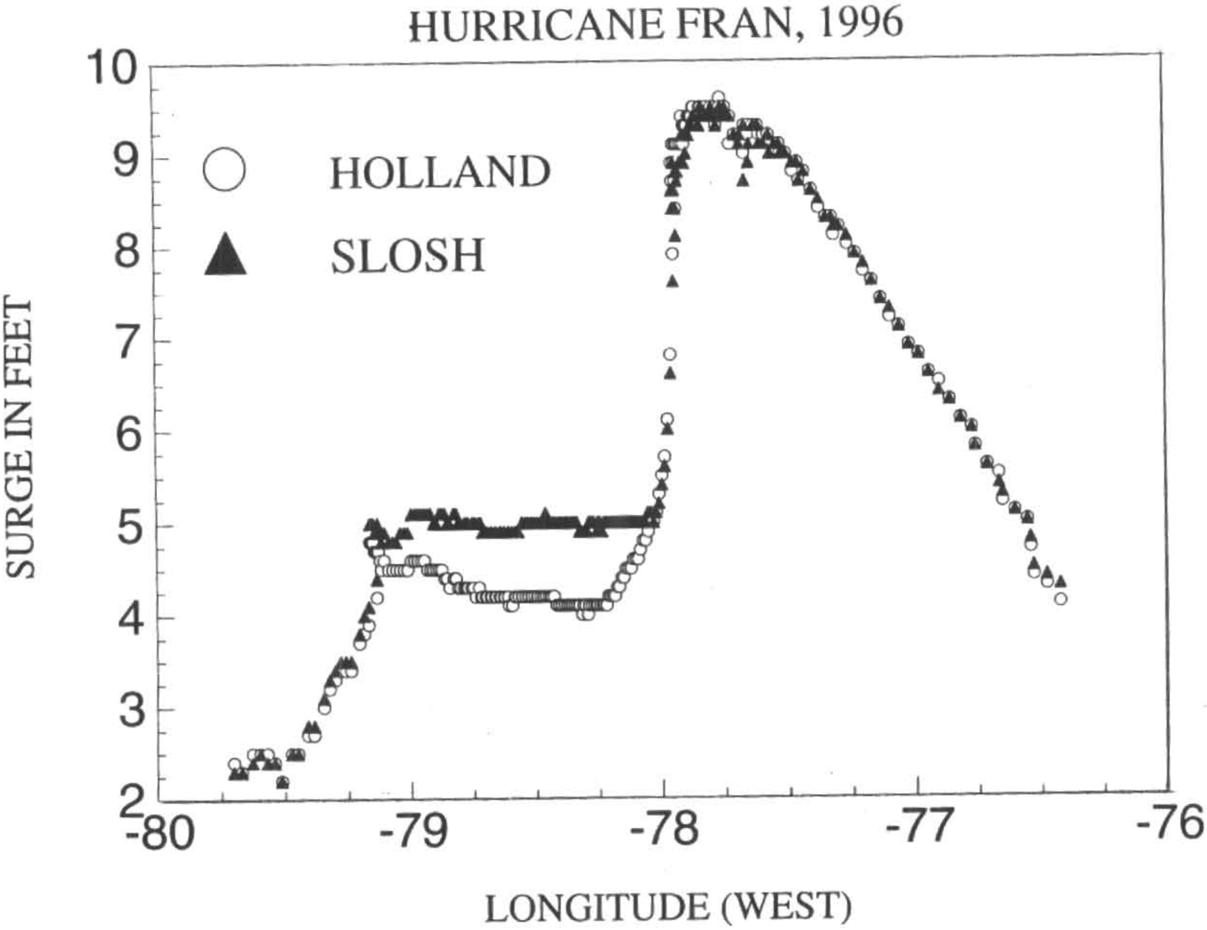


Fig. 6. Maximum storm surges on the coast from Huricane Fran, 1996, computed by SLOSH surge model with two wind models

6. Conclusion

The additional ability of Holland's pressure steepness parameter B to better fit the pressure profiles has been proven to provide the same quality of maximum wind variabilities as that used by Jelesnianski and Taylor with R_m. The maximum storm surges based on both schemes showed consistency so that a comparable measure of peak surges can be achieved. It is hoped the analysis used here can provide a basis for testing different parametric wind models for storm surge prediction and lead to agreement toward improvements.

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APPENDIX

For past Atlantic storms used on storm surge verifications, the JT's estimates of maximum wind are plotted against central pressure, assuming ambient value is 1010 hPa [Fig. (7)]. It compares against WMO TCP-31 for Atlantic hurricanes and NW Pacific typhoons (86% used to convert 1-min to 10-min wind). SLOSH's estimate is consistent with TCP-31 for Atlantic storms for small size storms (< 30 mi), but for large size storms (> 30 mi), TCP-31 may overestimate the maximum wind. SLOSH surge model has claimed to calculate the peak surge conservatively due to the compensating property in this study, and with larger inflow angles for larger size storms. It becomes part of surge model calibration. To calculate sea surface stress, an additional unknown constant, drag coefficient, should also be chosen in the calibration.

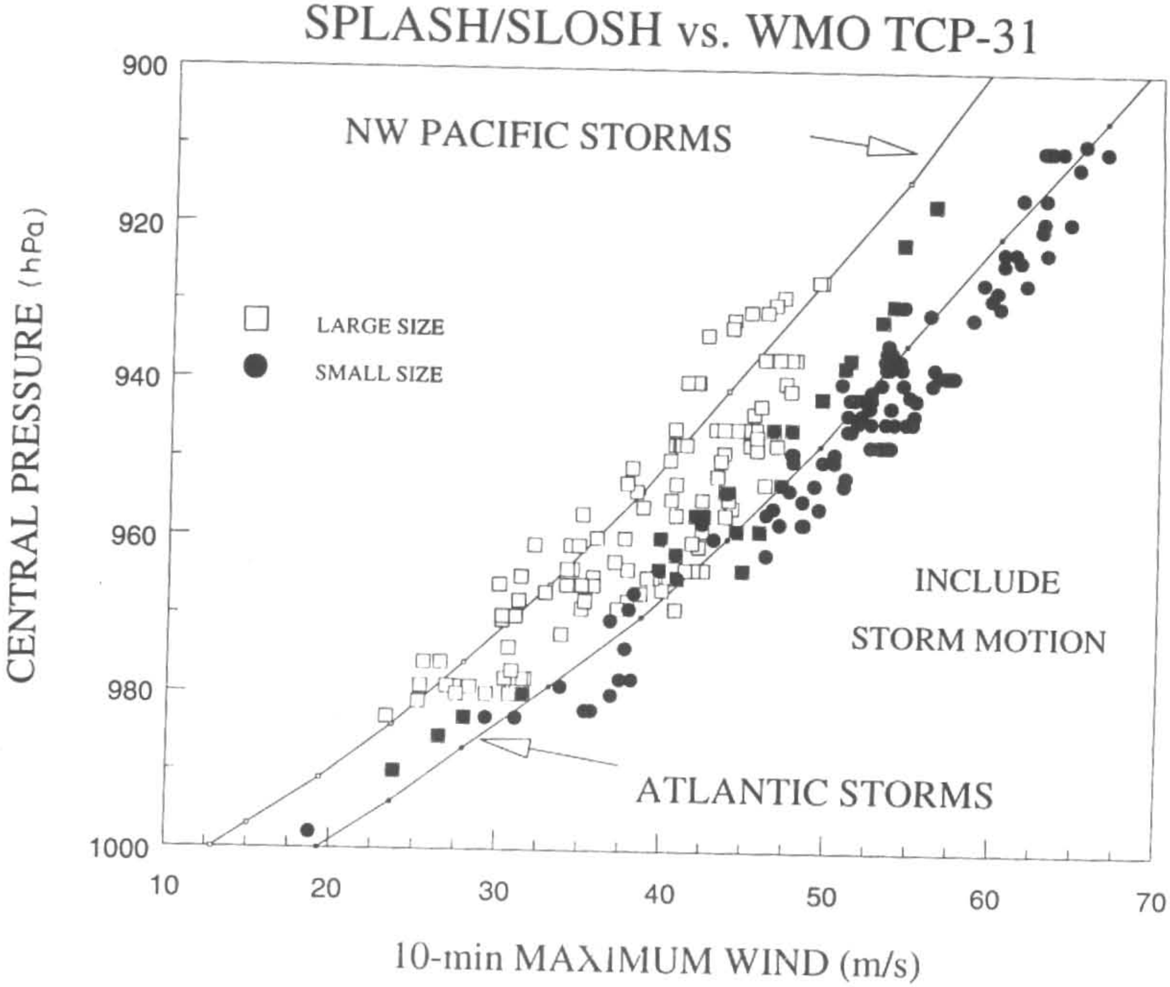

Fig. 7. Maximum wind estimates by SLOSH from historical storms differ by large (> 30 mi) and small (< 30 mi) of R_m's, as compared with WMO TCP-31 for Atlantic and NW Pacific storms

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