Tropical Cyclone Destructive Potential by Integrated Kinetic Energy

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The recent article on hurricane destruction potential by Powell and Reinhold (2007) in this journal is timely. It is a significant contribution to the debate initiated by Kantha (2006) on the desirability of replacing the Saffir–Simpson hurricane scale (SSHS). However, we believe the authors, unintentionally, have added to the confusion swirling around hurricane scales.

In high Reynolds number flows, such as in the atmosphere, the force exerted by the flow must be proportional to the dynamic pressure, as pointed out by Kantha (2006). Consequently, an accurate measure of the intensity of a hurricane is the square of the velocity maximum V_{max}. SSHS is not consistent with this principle and is purely empirical. Kantha (2006) proposed HII $= (V_{max}/V_{max0})^2$ as a measure of hurricane intensity instead, where V_{max0} is the reference value (taken as 33 m s^{-1}, corresponding to a hurricane of category 1, as defined at present by SSHS). This definition is consistent with the laws of fluid mechanics and has the additional advantage of yielding a continuous scale. It also does not saturate at the higher end as SSHS does at category 5. HII should replace SSHS, even if the differences are at times small.

However, Powell and Reinhold (2007) repeat the same mistake that has been made in the past by using the integrated kinetic energy (IKE) as an indicator of the destruction potential of a hurricane. The laws of physics dictate that the wind damage for a given structure must be proportional to the rate of work done by the wind (and not the force exerted by the wind) on the structure. This depends on the deflection of the structure under wind loading, but it is certainly not proportional to just the force. Because the deflection itself is proportional to the force exerted, its dependence on wind velocity must be higher than just its square. It could be equated to the dissipation rate of the wind kinetic energy, and hence taken as being proportional to the cube of the wind velocity, as suggested by Emanuel (2005). The wind damage for a given structure, no matter what its characteristics, cannot be proportional to just the kinetic energy of the wind. Therefore, neither SSHS (or HII) nor Powell and Reinhold's IKE (and hence W_{DP}) can be indicative of the wind damage potential of a tropical cyclone.

The damage potential, whether wind or surge, must also take into account the size of the tropical cyclone. The hurricane hazard index (HHI) (Kantha 2006) and hurricane surge index (HSI) indicate the wind and surge damage potential. In their simplest form, they are HHI $= (V_{max}/V_{max0})^3(R/R_0)$ and HSI $= (V_{max}/V_{max0})^2(R/R_0)$, where R is a measure of the hurricane size and R_0 is a reference value [note that Kantha (2006) defined only HHI; also the cyclone forward speed was included in the definition, which has been omitted here for simplicity; see L. Kantha 2006, unpublished manuscript (available on request), for details]. The reason for the linear dependence of HHI and HSI on the cyclone radius instead of quadratic dependence is simply due to the fact that intense hurricane wind and storm damage is most often confined to a broad but roughly linear strip along the coastline of impact. Incidentally, using kinetic energy integrated over the entire hurricane, as Powell and Reinhold (2007) have done, ignores this fact. Their IKE is more suited to hurricanes in the open ocean, but not during landfall. The IKE of Powell and Reinhold (2007) does account for the cyclone size.

Powell and Reinhold (2007) dismiss the velocity cube dependence by stating "Dependence on the cube of VMS also makes the HHI overly sensitive to

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a single wind speed value . . .” The remedy for this shortcoming is not to ignore physical laws, but to come up with a measure of velocity that is representative of the hurricane as a whole, not a small part of it. It is not clear to us why it is not possible to integrate the cube of the velocity and use that as a measure of the wind damage potential. Similarly, it is not clear to us why the damage potential index, such as HHI, has to be bounded. There is no physical reason for this, and to introduce artificial bounds is to repeat the mistake of SSHS, which bounds hurricane intensity at category 5, no matter what the actual maximum winds are.

Powell and Reinhold (2007) correctly point out that the winds in tropical cyclones are not necessarily axisymmetric, and therefore HHI may not be accurate enough. We do not understand why the same argument does not apply to hurricane intensity measures, such as SSHS. Moreover, the asymmetry can be accounted for rather easily by integration either over the tropical cyclone or over the portion of it most likely to have a major impact. For example, for the surge damage potential, it is the right-hand quadrant that is most important, and a measure of the values representative of this quadrant can be used in determining HSI.

The algorithm proposed by Powell and Reinhold (2007) in deriving W_{DP} and S_{DP} from IKE is needlessly complex and rather ad hoc. The attractiveness of SSHS was that it was simple enough to be understood by the lay public. It would therefore be a mistake to use complex algorithms. It would also be a mistake to arbitrarily put a bound on the maximum damage potential index of around 5, simply to conform to the current SSHS philosophy. The public must be made aware that while HII can be around 5 or less,

Table 1. The indices HHI and HSI (see Kantha 2006) computed from the HII data in Table 1 of Powell and Reinhold (2007) using HHI = (HII)$^{3/2}$(R_{33}/R_{33ref}) and HSI = (HII)(R_{33}/R_{33ref}), because the V_{ms} values in their table are not consistent with their HII values. The R_{33} for Andrew is used as the reference value (this choice is, however, not unique). The Powell and Reinhold (2007) indices W_{DP} and S_{DP} are also shown for comparison.

Storm	Year	R_{33} (km)	SSHS	HII	HHI	HSI	W_{DP}	S_{DP}
Andrew	1992	77	5	5.2	11.9	5.2	5.0	2.5
Camille	1969	109	5	5.0	15.8	7.1	5.2	4.0
Charley	2004	40	4	4.1	4.3	2.1	4.1	1.9
Dennis	2005	33	3	2.7	1.9	1.2	0.3	3.4
Emily	2005	86	3	3.0	5.8	3.4	1.7	4.2
Fabian	2003	138	3	3.0	9.3	5.4	3.7	5.1
Frances	2004	139	2	2.0	5.1	3.6	2.5	4.7
Hugo	1989	146	4	3.5	12.4	6.6	4.7	4.7
Iris	2001	37	4	3.8	3.6	1.8	0.1	1.3
Isabel	2003	214	2	1.9	7.3	5.3	3.4	5.6
Ivan (AL)	2004	128	3	2.7	7.4	4.5	2.2	4.4
Ivan (Jamaica)	2004	121	4	3.8	11.6	6.0	5.6	4.7
Jeanne	2004	131	3	2.7	7.5	4.6	1.9	4.3
Katrina (FL)	2005	28	1	1.2	0.5	0.4	0.1	1.3
Katrina (LA)	2005	217	3	3.0	14.6	8.4	3.7	5.1
Katrina (peak)	2005	139	5	5.2	21.4	9.4	5.8	5.1
Keith (Belize)	2000	44	3	2.4	2.1	1.4	0.5	1.9
Michelle	2001	80	4	3.5	6.8	3.6	1.7	4.0
Opal	1995	169	3	2.4	8.2	5.3	3.5	5.0
Rita	2005	174	3	2.4	8.4	5.4	2.6	4.3
Wilma (peak)	2005	53	5	4.8	7.2	3.3	4.6	4.2
Wilma (FL)	2005	179	3	2.5	9.2	5.8	2.8	4.8
Wilma (Mexico)	2005	121	4	3.2	9.0	5.0	4.7	5.1

the damage that could be inflicted could be very high and, depending on the size of the hurricane, can bear no relationship to HII. Naturally, defining HHI and HSI suitably (this essentially boils down to selecting the value of R_0 appropriately), without bounding it, would drive home this point. It is worth noting here that whichever reference values are chosen, a value of the damage potential index of less than 1 does not mean that there is no damage, as mistakenly implied by Powell and Reinhold (2007), "The HHI also fails to consider that the wind damage can begin at winds less than the hurricane force."

For the convenience of the reader, we present Table 1, which shows indices HHI and HSI compared with indices W_{DP} and S_{DP} for the hurricanes in Table 1 of Powell and Reinhold (2007); their table did not include HHI and HSI values (information online at http://ocean.colorado.edu/hurricane for values corresponding to currently active hurricanes and typhoons in real time, in addition to those in the recent past).

CONCLUDING REMARKS. It is important to point out that neither HHI (HSI) nor W_{DP} (S_{DP}) is an indicator of the actual wind (surge) damage, which depends on many other factors such as the terrain over which the hurricane is passing and the properties of structures in the path of the tropical cyclone. Obviously the actual monetary damage depends on whether the hurricane passes over a high-value target, such as Miami, Florida, or a low-valued real estate area, such as some swamplands along the Gulf Coast. The actual surge, and hence the surge damage, depends on the local bathymetry and coastline shape. Nevertheless, HHI and HSI are useful for gauging the relative potential for damage, if not the actual damage. Clearly, prehurricane decisions for evacuation should be based on HII. Prehurricane preparations for posthurricane relief could be based on HHI, HSI, and rainfall forecasts. It is not good to use SSHS as a measure for both evacuation and relief preparations.

Finally, it would be useful to account for wind gustiness in defining the hurricane indices. A proper way of doing this is to use the time-integrated value for the square and the cube of the wind velocity in HII, HHI, and HSI (and not just the time-integrated value of velocity, as is currently done for the SSHS), with the time interval defined suitably. Also, while it is possible to define indices that take into account the rather complex structure and characteristics of a hurricane, such as its asymmetry and translation speed, it is probably better to keep them as simple as possible, yet consistent with the laws of physics.

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