Reply

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Kantha's (2008, hereafter KAN) comment on our paper reiterates many items from another of his works (Kantha 2006), which were already commented upon in our paper. Here we will limit our response to discussion of damage and our proposed scale.

The idea of force being proportional to the square of the wind velocity has been incorporated in wind load standards [ANSI A58.1, see American National Standards Institute (1972) and ASCE 7-88, see American Society of Civil Engineers 1988) for quite some time. Damage occurs when the applied forces exceed the resistance, causing a failure or permanent displacement of the structure, component, etc. Damage results when something either ceases to be able to perform its intended purpose, tears, breaks loose, or separates enough to allow water and/or wind to intrude and damage nonstructural items or contents. The most common damage is directly related to an overload of the component or system and that boils down to the relationship between forces and resistance. Because work is defined as a force used to move an object, one could argue that a rigid structure that deforms a small amount under wind loading experiences very little work. This suggests a different perspective from the fluid mechanics

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definition of flow work that is the foundation for the definition used by KAN. While the fluid mechanics definition of the rate of work suggested by KAN may be useful for dealing with wind loads on the primary structural system of a building (the along-wind main wind force loads in the engineering vocabulary), across-wind loads, torsional loads, and the loads on components of the building, including cladding elements such as windows, roof panels, etc., are much more complicated and cannot be simply related to the along-wind approach flow (including gusts). For example, it has been clearly demonstrated [ASCE7-05 (American Society of Civil Engineers 2006) wind load provisions; Monroe 1996] that relatively small changes in geometry and/or turbulence properties of the flow can dramatically increase the local pressure and the across-wind or torsional loading. For most buildings, wind damage to the components and cladding elements dominate hurricane losses, and in some cases lead to limited or total structural collapse. This is further complicated by the fact that building components frequently fail in a brittle fashion and once damage is initiated, it can propagate quite rapidly.

Consequently, the use of fluid mechanics principals without consideration of these complications results in too simple a description for the process through which damage results from the interaction of a structure with the wind. Another way to say this is that the rate of work done by the wind on a structure depends on the wind resistance and the response of the various components of a structure, and how they interact. In addition, suction zones develop on a structure resulting from nonlinear processes associated with the shape of the building, the structure of the turbulence, and the influence of upstream terrain elements that can vary with wind speed, direction, and atmospheric stability.

We built these complexities into our model through multipliers based on observed nonlinear correlations of wind speed with hurricane damage (Fig. 3 of Powell and Reinhold 2007). We believe that this is a better approach than Kantha's (2006) speculation that monetary loss scales with the third power of the wind. Our method may be vulnerable to changes in either the building stock (better buildings should lead to less damage) or to the cost of repairs [large widespread damage may lead to availability issues for workers and materials (demand surge) that may increase costs] and the amount of damage to contents (as the values of contents increase), but for now it does a pretty good job of capturing the relative impacts of various storms. It may be possible to add demand surge and content replacement factors in the future, but they are clearly different than a simple relationship between damage and the square or cube of the wind speed.

KAN is correct that we misinterpreted the hurricane hazard index (HHI) = $(V_{max}/V_{max0})^3(R/R_0)$ as failing to consider the damage for storms below hurricane force, and we apologize for our omission. The equations used by KAN for HHI and HSI are not those presented in Kantha (2006). The HHI equation listed in Kantha (2006) contains storm motion in the denominator so it is problematic for slow-moving storms; the HSI equation was not published therein. The simplified HHI and HSI indices are an improvement over the HII = $(V_{max}/V_{max0})^2$ because they contain some information on size, but they are still too sensitive to the maximum sustained wind speed (which can vary by quadrant and observation platform type) and its radius (a poor measure of the overall size of the damaging part of the wind field). KAN mentions that the reason for using a linear dependence on radius is that damage is limited to linear strips along the coastline. A quick look at a map of coastal Mississippi and Louisiana shows that the coastline is anything but linear. Local effects dominate the ultimate damage inflicted, so we formulated our scales to be independent. A damage potential rating should never depend on the economic wealth of the threatened area (e.g., "a high value target such as Miami or low value real estate such as some swamplands along the Gulf Coast").

We agree with KAN that the integration of V^3 over grid cells could be conducted as some measure for wind damage potential, but our damage data show it would neglect the complex and frequently nonlinear interactions between wind and structures that result in failures and damage.

While a new and unbounded scale may have some desirable features, the truth is that the SSHS has been around for over 30 yr and is very familiar to the public. A new scale with a different numerical range could lead to confusion. Our scales cover a similar range to the SSHS, but implement KAN's suggestion of a continuous numerical range. During the 2007 hurricane season we have been testing the integrated kinetic energy (IKE)-based scales using the experimental H*Wind hurricane wind field analyses and believe there is room for improvement. We invite the atmospheric science community to helps us build on these ideas to improve the depiction of destructive potential in tropical cyclones.

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