# Time to Replace the Saffir-Simpson Hurricane Scale?

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The 2005 hurricane season set many new records, including the most named storms (26) and the most hurricanes in a season (14). Of the four hurricanes that made landfall in the U.S., three (Katrina, Rita, and Wilma) reached Category 5, struck the Gulf Coast, and inflicted severe damage and loss of life. Hurricane Wilma had an observed sea-level center pressure of 882 millibar (mbar) at its peak and is the strongest hurricane ever recorded in the Atlantic Ocean. Katrina damaged vast areas along the Mississippi coast, flooded large parts of New Orleans, and is the most destructive hurricane on record.

The 2004 Atlantic hurricane season was also busy, with 14 named storms, nine of which were hurricanes and four of which (Charley, Frances, Ivan, and Jeanne) brought heavy damage to the southeastern United States.

The frequency and severity of storms during these last two hurricane seasons have rekindled the debate on the effect that global warming may be having on the frequency and intensity of hurricanes [*Emanuel*, 2005; *Webster et al.,* 2005]. Rising sea surface temperatures in the tropical oceans have been proposed as the cause for the increases in the destructiveness of tropical cyclones and in the number of hurricanes in the past three decades that have reached Category 4 and 5 designations.

Now may be an ideal time to revisit and revise the hurricane categorization system. For over three decades, the United States has used the Saffir-Simpson Hurricane Scale (SSHS) for hurricane emergency response decisions. However, because this scale has many drawbacks and can be confusing at times, it may be time to replace it with a scale(s) that provides more consistent estimates of hurricane intensities and hazards.

A continuous scale with a dynamical basis would allow emergency response officials to make better evacuation decisions than are now possible with the current discrete and rather arbitrary SSHS. The creation of a more accurate index of the hazard of hurricanes would also be timely, especially in view of the incredible damage inflicted in 2005 by hurricanes Katrina, Rita, and Wilma. Such an index would help decision-makers to prepare for the aftermath of a hurricane.

## *Problems with the Saffir-Simpson Scale*

In 1969, a civil engineer named Herbert Saffir, inspired by the Richter earthquake magnitude scale, developed a hurricane intensity scale that could provide a rough estimate of a hurricane's potential for property damage. To give an approximation of the flooding that might be caused by a hurricane, Robert Simpson, then director of the U.S. National Hurricane Center, supplemented Saffir's scale with estimates of the storm surge expected at landfall.

The resulting Saffir-Simpson Hurricane Scale, summarized in Table 1, has been used extensively for hurricane emergency response. Along with information about the expected track and point of landfall, policy-makers have used this scale to make hard decisions on whether to evacuate the inhabitants of a coastal region and also to prepare for relief operations in the aftermath of hurricanes.

A peculiar aspect of the SSHS is that, unlike the Richter scale, the resulting magnitudes are quantized. Each hurricane category has a range of properties assigned to it. For example, Category 3 hurricanes can have center pressures ranging from 945 to 965 mbar and sustained wind speeds from 111 to 130 miles per hour (mph; 1 mile = 1.609 kilometers). This means that a change of just one mph in maximum speed (or one mbar in center pressure) near the transition value can make a unit change in the category. Thus, a Category 4 hurricane is downgraded to Category 3 once its maximum sustained wind speed decreases from 131 to 130 mph, even though its intensity has not changed much.

This situation is confusing to the public and to decision-makers. Should an evacuation be cancelled when the maximum speed decreases by a few mph? A more continuous scale akin to the Richter scale or its recent variant would be more useful.

Like the Richter scale for earthquakes, the SSHS also saturates at its higher end. Thus, no matter how much the maximum speed exceeds 156 mph, the hurricane is characterized as Category 5. Granted that a Category 5 hurricane is sufficiently destructive that further increases may not make much difference in decision-making, it is still desirable to devise a scale that does not saturate at the higher end. Geologists have realized that such saturation is undesirable and so have revised the Richter scale to better represent earthquake severity, even though very severe earthquakes are comparatively rare. The hurricane community must do the same for hurricane severity.

The U.S. Tropical Prediction Center uses the maximum sustained near-surface wind speed $V_{\max}$ to categorize the hurricane intensity. A continuous scale that reproduces the current SSHS and yet does not saturate at the higher end can be easily devised by just fitting a polynomial equation to the SSHS values. However, the delineations of hurricane intensity in the SSHS are rather ad hoc. An attempt to retain the SSHS and merely make it a continuous scale by curve fitting leads to unrealistically high values at the higher end of the scale. For example, the strongest hurricane on record in the Atlantic, Wilma, which had an observed maximum sustained near-surface speed of 175 mph, becomes an unrealistic category 11.9 hurricane under this scheme. A more realistic, continuous scale is therefore desirable.

## *New Hurricane Scale(s)*

The forces exerted by the fluid are proportional to the dynamic pressure, according to the basic tenet of high Reynolds number fluid flows. Because the intensity of a hurricane must scale like the maximum dynamic pressure $\rho V_{\max}^2$, where $\rho$ is the density and $V_{\max}$ is the maximum sustained near-surface wind speed, it is possible to devise a hurricane scale based on this parameter : Hurricane Intensity Index (HII) = $(V_{\max}/V_{\max_0})^2$, where subscript 0 is the reference value.

Taking the reference value as 74 mph appropriate for a Category 1 hurricane, hurricanes Katrina, Rita, and Wilma become cate-

**Table 1. Saffir-Simpson Hurricane Scale**[a]

| *Type* | $P_c$, *mbar* | $V_{max}$, *m/s (mph)* | *Surge, m (feet)* |
|---|---|---|---|
| Tropical depression | 1007 | <17 (<39) | |
| Tropical storm | <1000 | 17–33 (39–73) | |
| Category 1 | 980 | 33–42 (74–95) | 1.2–1.5 (4–5) |
| Category 2 | 979–965 | 43–49 (96–110) | 1.8–2.4 (6–8) |
| Category 3 | 964–945 | 50–58 (111–130) | 2.7–3.7 (9–12) |
| Category 4 | 944–920 | 59–69 (131–155) | 4.0–5.5 (13–18) |
| Category 5 | <920 | >70 (>156) | >5.5 (>19) |

[a] 1″ Hg = 33.86 mbar.

**Table 2. New indices for some well-known hurricanes**

| *Name* | $V_{max}$, *mph* | R, *miles* | S, *mph* | *HHI* | *HHI* | *SSHS* |
|---|---|---|---|---|---|---|
| Andrew | 165 | 60 | 16 | 5.0 | 10.4 | 5 |
| Katrina | 125 | 120 | 15 | 2.9 | 19.3 | 3 |
| Rita | 120 | 85 | 12 | 2.6 | 9.9 | 3 |
| Wilma | 120 | 90 | 20 | 2.6 | 6.6 | 3 |

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gories 4.7, 5.3, and 5.6 at their peak and 2.9, 2.6, and 2.6 at landfall. These HII values are more reasonable than the ones obtained from curve-fitting the current SSHS, which are 5.7, 8.9, and 11.9 at their peak and 3.8, 3.5, and 3.5 at landfall, respectively. On this scale, a tropical storm would be a Category 0.3, and Hurricane Andrew at landfall would remain at Category 5.0.

The SSHS was devised principally to predict the expected intensity of hurricane wind damage to structures. While it has served reasonably well in emergency response decisions before landfall, the scale is not optimal for anticipating required relief to affected areas. As demonstrated by hurricanes Katrina and Wilma, the SSHS may be a grossly misleading index of hazard and hence the level of disaster relief that needs to be mobilized prior to the hurricane. One needs to know not just the intensity but also the extent of hurricane hazard so that adequate relief measures can be organized.

Judging by the economic cost, the HII Category 2.9 Hurricane Katrina did far more damage (even ignoring the damage done to the city of New Orleans by levee breaks) than the Category 5.0 Hurricane Andrew did in 1992. This anomaly can be partially explained by noting that Katrina was almost twice the size of Andrew, with hurricane winds extending to 125 miles in radius and tropical storm intensity winds extending to a radius of 230 miles. The result was that the damage extended along a larger stretch of the coastline.

At present, policy-makers and emergency response teams planning relief operations have no indicator of hurricane hazard that they can use in the planning of relief operations. To provide such an indicator, the size of the hurricane must be incorporated into the index. It is relatively straightforward [*Dvorak,* 1975] to deduce the size of a hurricane from satellite measurements. Unfortunately, though, hurricane researchers [e.g., *Landsea et al.*, 2004] have concentrated more on the intensity and the track of hurricanes, and estimates of hurricane sizes are hard to find in the historical hurricane database.

While the assessment of hurricane damage for insurance purposes can involve complex models and methodologies, a simple a priori estimate of the hazard would be useful for response planning purposes. As pointed out by *Emanuel* [2005], the total energy dissipation rate in storms scales like the cube of the wind speed, as does the monetary loss. The hazard depends also on the residence time of the hurricane as well as on its size. A measure of the destructiveness of a hurricane can therefore be easily devised based on the maximum sustained near-surface rotational wind speed, the radius to which hurricane intensity winds extend, and the translation speed of the hurricane: Hurricane Hazard Index (HHI) = $(R/R_0)^2(V_{max}/V_{max_0})^3(S_0/S)$, where $R$ is the radius to which hurricane force winds extend, $S$ is the translation speed that takes the hurricane from one place to another, $V$ is the maximum velocity of the rotating wind, and subscript 0 indicates reference values. This index, combined with the characteristics of the regions along the hurricane track (such as population density, density and value of structures) would be useful for hurricane relief operations.

Using this equation with the reference values of 74 mph, 60 miles, and 15 mph for the maximum surface wind speed, the radius of hurricane winds and the translation speed of the hurricane, respectively, HHI is 1.0 for a Category 1.0 hurricane with a radius of 60 miles traveling at 15 mph. On this scale, a hurricane of the same size but Category 5.0 with a speed of 156 mph would have an HHI of 9.4. But if the same hurricane had a radius twice as large, HHI would be 37.5. Thus the hurricane size figures prominently in this index.

Hurricane Andrew with landfall wind speed [*Landsea et al.,* 2004] of 165 mph but a radius of only 60 miles would have an HHI of 10.4, whereas Katrina with a radius of 120 miles but a landfall speed of only 125 mph would have HHI = 19.3, nearly 85 percent higher than that of Andrew. These numbers could have made it clear to the public and to emergency response officials why the Category 2.9 Katrina was likely to be more destructive than the Category 5.0 Andrew; HHI would have provided a more accurate estimate of the destruction to be expected from hurricane winds.

Table 2 provides the HII and HHI for a few well-known hurricanes at landfall. Unfortunately, since the size of the hurricane is most often missing from the archival hurricane databases, it is difficult to compute the HHI for most historical hurricanes. As a practical matter, a small number (say, 1.0) should be added to the translation speeds $S$ to prevent the HHI from becoming infinite when a hurricane stalls.

## *Recommendations for future hurricane categorization*

The indices HII and HHI (or something similar) would be better measures of the hurricane intensity and the wind damage potential than the SSHS, which is currently used for both. Preparations for evacuation prior to the landfall could use HII for guidance, but preparations for relief in the aftermath could use HHI, even though factors such as the habitation density of the coast would also need to be factored in.

It appears that it might be time to retire with dignity and replace the SSHS. The continuous intensity scale HII, which is dynamically consistent and also does not saturate at the higher end, should replace SSHS, and should be augmented by HHI. Perhaps the realization by responsible officials that HHI was so large for Katrina, even though HII was not alarmingly large, might have prompted them to prepare appropriately and help prevent a lot of suffering during the aftermath of Katrina due to shortfalls in the emergency preparedness.

Torrential rainfall and consequent flooding also contribute to the damage inflicted by hurricanes. In some cases, the flooding damage may far exceed the wind damage. This is certainly true of tropical storms and weak hurricanes that move slowly through a region. Consequently, a third index indicating the total rainfall to be expected from the hurricane would also be useful for emergency response. Thus, one could have a multiple hurricane scale index comprising the HII, the HHI, and the rainfall potential.

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