Hurricane Severity Index: A New Way of Estimating Hurricane Destructive Potential

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1. Introduction

Hurricane Katrina devastated the coasts of Mississippi and Louisiana as a Saffir-Simpson Category 3 hurricane in 2005. Katrina produced a larger and more extensive storm surge and considerably more damage than did Category 5 Hurricane Camille in 1969. Coastal residents found it difficult, if not impossible, to believe that such damage could be produced by "only a Category 3 hurricane". Clearly, the Saffir-Simpson hurricane scale is not the best way to measure a hurricane's true destructive potential.

There is a clear need for a new hurricane intensity/severity scale, one that takes into account not only a tropical cyclone's maximum sustained winds but also wind field size. The Hurricane Severity Index (HSI) was developed to address this need. The HSI is a 50-point scale. Of the 50 points, 25 points are contributed by tropical cyclone intensity and 25 points are contributed by the size of a tropical cyclone's wind field.

2. Historical Data

The source of historical tropical cyclone intensity and wind field data is the National Hurricane Center's best-track database, including all tropical cyclones from 1988 through 2005. Maximum sustained wind and the 35, 50, and 65 knot wind radii were recorded for every tropical cyclone in the database at each track point. Data from tropical storms was included, as the Hurricane Severity Index is designed for tropical storms as well as hurricanes.

3. Ranking Tropical Cyclone Intensity

We created a 25-point scale to assign points based upon maximum sustained wind between 30 and 150 knots. See **Figure 1**. Note that a 30 knot tropical depression receives 1 point and a 150 knot hurricane receives the maximum of 25 points for intensity. The scale is exponential (blue curve in **Figure 1**) and is based upon the known relationship of wind speed to the force exerted on an object. Wind force is related to the square of the wind velocity. This relationship is depicted by the red curve in **Figure 1**. Tropical cyclone intensity points are more heavily-weighted toward hurricane-force winds or greater.

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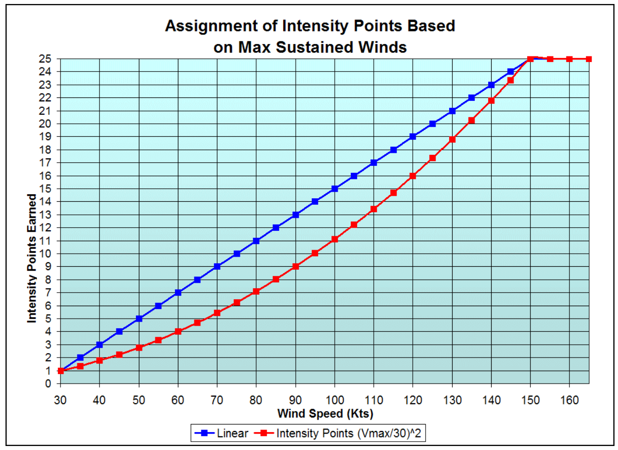

Figure 1

4. Ranking Tropical Cyclone Size

Determining how to assign points based upon wind field size was a much more difficult problem than assigning intensity points. The first step was a thorough study of past tropical cyclones. We used the National Hurricane Center's best-track dataset of all named storms from 1988 through 2005, removing all extratropical cyclones. From the dataset, we derived 35, 50, and 65 kt wind radii for nearly 3800 data points. In addition to the three standard wind radii, we also included the 87kt (100 mph) wind radius. The reason for this inclusion is that we've been forecasting the 100 mph wind radius for the past 10 years to better-define the core of a strong hurricane in our day-to-day site-specific forecasts of wind impact for our clients. The 100 mph radius provides a good estimate of the size of a hurricane's core of intense winds, an area of extreme structural damage.

Since 87 kt wind radii were not part of the NHC best-track database, those radii were measured from detailed Hurricane Research Division post-storm analyses for the 2001-2005 seasons. From these measurements, we generated a formula to estimate the 87 kt wind radii for any hurricane based upon the known 65 kt wind radii and the maximum sustained winds using a multiple linear regression equation. Once all wind radii were either measured or estimated, we calculated the average coverage of the 35, 50, 65, and 87 kt winds in every storm from 1988 through 2005. This provided a baseline for determining whether a tropical cyclone's wind field was below average, average, or above average.

A ranking system was devised to assign wind field size points based upon two primary factors:

- Areal coverage of wind radii compared to an "average" tropical cyclone
- The known relationship between wind speed and the force exerted on an object

We know that doubling the wind speed results in a quadrupling of the wind force on an object. Therefore, we wanted to assign total possible size points that were weighted more heavily toward the stronger 65+ and 87+ kt wind radii based upon this relationship. **Table 1**, below shows how the 25 size points are awarded:

Wind Radii	Size Point Range
35 kts	1-3
50 kts	1-4
65 kts	1-8
87 kts	1-10

Table 1

As tropical cyclones are quite often highly-asymmetrical, we needed a way of comparing the coverage of the various wind fields. To do this, we developed what we call an effective wind radius (R*e*). The effective radius is defined as follows:

$$\text{Re} = \frac{1}{2}\sqrt{(RNE^2 + RSE^2 + RSW^2 + RNW^2)}$$

The effective radius defines the radius of a circle that has the same areal coverage as the tropical cyclone's wind field. For example, let's say that a hurricane has a 65 kt wind field that extends 30 nautical miles (nm) only in the northeast and southeast quadrants. Winds in the southwest and northwest quadrants are below 65 kts. Using the equation above would yield an effective radius of just over 21 nm. That is, a circle with a radius of 21 nm would have the same areal coverage of 65 kt winds as a hurricane with 65 kt winds extending out 30 nm from the center in the northeast and southeast quadrants. Effective radius gives us an easier way to compare one storm to another.

To calculate how many size points a tropical cyclone would receive for each of the four wind radii above, we examined all of the radii values for each of the four wind fields. The top 5 percent of the wind radii were then removed, as there were clearly a few extratropical cyclones with very much larger than average wind fields that would have skewed the results toward ranges that were too high. Similarly, we removed the lower 5 percent of the wind radii to eliminate any unusually small tropical cyclones. With the upper and lower 5 percent of wind radii removed, we then had a realistic range for each of the four wind radii. The resulting ranges were divided equally according to the number of size points possible in **Table 1**. The 35 kt wind radius range was divided into three equal ranges, the 50 kt into four equal ranges, the 65 kt into eight equal ranges, and the 87 kt radii were divided into ten equal ranges. These values may be found in **Figure 2**.

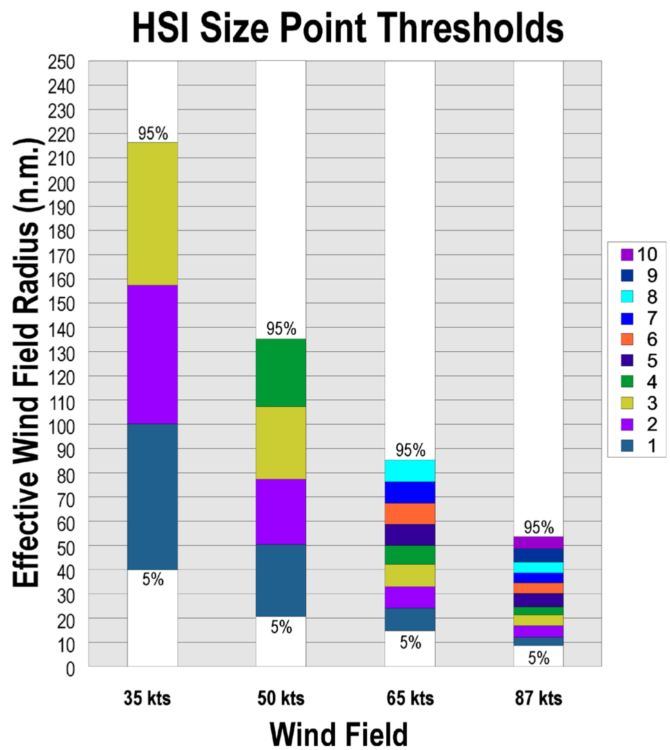

Figure 2

Points are awarded for each of the four wind radii depending on the extent of each wind field. For example, if a hurricane with 100 kt winds has a 35 kt effective wind radius that is in the top 1/3 of the 35 kt range, it would get three points for its 35 kt wind field. If its 50 kt effective wind radius is in the lower ¼ of the 50 kt range, then it gets an additional one point. If its 65 kt effective wind radius is in the second 1/8 of the 65 kt range, then it gets an additional two points. Finally, if its 87 kt effective wind radius is in the third 1/10 of the 87 kt range, then it is assigned an additional three points. This 100 kt hurricane would receive a total of 3+1+2+3 = 9 size points. A complete breakdown of the possible points for any tropical cyclone from a Tropical Depression to a Saffir-Simpson Category 5 hurricane is given in **Table 2**.

Saffir-Simpson Hurricane Scale vs. HSI						
Classification	HSI Size		HSI Intensity		Total HSI	
	Low	High	Low	High	Low	High
Depression	0	0	1	1	1	1
TS	1	7	1	4	2	11
Cat. 1 Hurricane	3	15	5	7	8	22
Cat. 2 Hurricane	3	25	8	10	11	35
Cat. 3 Hurricane	4	25	11	13	15	38
Cat. 4 Hurricane	4	25	15	20	19	45
Cat. 5 Hurricane	4	25	22	25	26	50

Table 2

5. Comparison of Past Tropical Cyclones

With an understanding of how the HSI is calculated, it is interesting to see how some past tropical cyclones would have been ranked. **Table 3** lists the HSI values for some of the more famous hurricanes as they made landfall on the U.S. Coast. Reliable wind radii data were only available from 1988 forward. Radii for hurricanes prior to 1988 were derived from the current SLOSH dataset and should be considered rough estimates. Even since 1988, there is always considerable uncertainty as to the various wind radii. However, since the table lists values at landfall, we can assume that the maximum amount of data was available for each hurricane (recon, coastal radar, buoy data, etc.). So the values in the table below are probably more reliable than for tropical cyclones far out to sea during the same period.

HSI Values at Landfall for U.S. Hurricanes

Name - Year	Wind (kts) SS Category	HSI		
		Intensity	Size	Total
Carla 1961*	125 – Cat 4	17	25	42
Hugo 1989	120 – Cat 4	16	24	40
Betsy 1965*	115 – Cat 4	15	25	40
Camille 1969*	140 – Cat 5	22	14	36
Katrina 2005	110 – Cat 3	13	23	36
Opal 2005	100 – Cat 3	11	25	36
Great Miami 1926*	115 – Cat 3	15	19	34
Audrey1957	125 – Cat 4	17	16	33
Fran 1996	100 – Cat 3	11	22	33
Wilma 2005	105 – Cat 3	12	21	33
Ivan 2004	105 – Cat 3	12	20	32
Andrew 1992	145 – Cat 5	23	8	31
Floyd 1999	90 – Cat 2	9	20	29
Bonnie 1998	95 – Cat 2	10	19	29
Jeanne 2004	105 – Cat 3	12	17	29
Isabel 2003	90 – Cat 2	9	19	28
Bertha 1996	90 – Cat 2	9	19	28
Rita 2005	105 – Cat 3	12	16	28
Frances 2004	90 – Cat 2	9	17	26
Charley 2004	130 – Cat 4	19	4	23
Georges 1998	90 – Cat 2	9	13	22
Alicia 1983*	100 – Cat 3	11	11	22
Dennis 2005	105 – Cat 3	12	6	18
Lili 2002	80 – Cat 1	7	8	15
Bret 1999	100 – Cat 3	11	4	15
Chesapeake 1933*	70 – Cat 1	5	9	14
Bob 1991	90 – Cat 2	9	4	13
Irene 1999	70 – Cat 1	5	8	13

* Wind radii derived from SLOSH database

Table 3

One final point about **Table 3**. Compare hurricanes Katrina and Camille. Both hit about the same point on the Mississippi coast, but Katrina caused significantly more damage than did Camille. Notice that they had the identical HSI value at landfall – 36. However, the size and intensity point totals were reversed. This demonstrates the importance of knowing the wind field size.

Of all the tropical cyclones in the dataset, the highest-ranking hurricane to hit the U.S. Coast was Hurricane Carla in 1961. Carla was one of only three U.S. land-falling hurricanes to have a total of 25 size points. It's fortunate for Texas that Carla weakened some prior to landfall. As **Table 4** indicates, Carla was one of two tropical cyclones in the dataset to reach the maximum of 50 HSI points while over water. Carla reached 50 points within 24 hours of landfall but weakened as it neared the Texas coast. Hurricane Allen reached a peak HSI of 50 points while in the northwest Caribbean in 1980.

Examine the HSI values in **Table 4**. Note where Wilma, the most intense hurricane ever recorded in the Atlantic Basin, ranks. Wilma's intensity was well over 150 kts, giving it 25 points for intensity. But look at Wilma's size points at its peak intensity – only 5. Wilma had one of the smaller wind fields ever measured for such an intense hurricane.

Highest HSI Values Over Water

Name - Year	Wind (kts) SS Category	HSI		
		Intensity	Size	Total
Carla 1961	150 – Cat 5	25	25	50
Allen 1980	155 – Cat 5	25	25	50
Gilbert 1988	155 – Cat 5	25	24	49
Katrina 2005	150 – Cat 5	25	22	47
Ivan 2004	140 – Cat 5	22	23	45
Isabel 2003	140 – Cat 5	22	23	45
Opal 1995	130 – Cat 4	19	25	44
Luis 1995	120 – Cat 4	16	25	41
Rita 2005	145 – Cat 5	23	17	40
Mitch 1998	155 – Cat 5	25	15	40
Camille 1969	165 – Cat 5	25	14	39
Wilma 2005 (max HSI)	125 – Cat 4	17	19	36
Wilma 2005 (max intensity)	160 – Cat 5	25	5	30

Table 4

We can also compare the HSI values of tropical cyclones graphically, as it **Figure 3:**

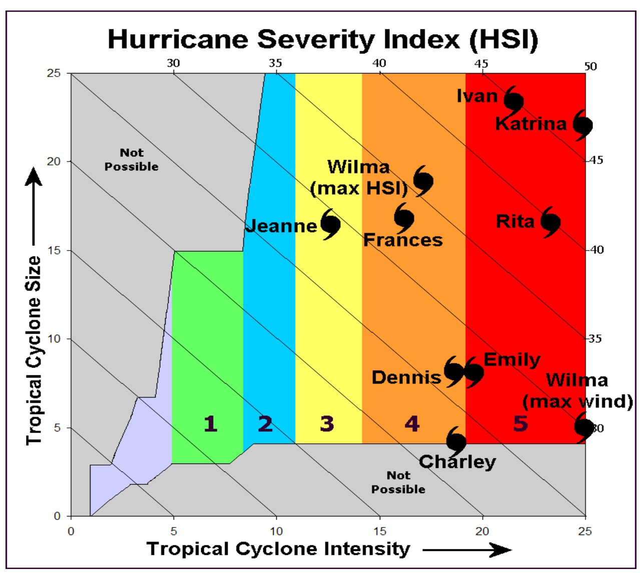

Figure 3

In **Figure 3**, the horizontal scale represents a tropical cyclone's intensity points – from a 30 kt tropical depression to a Saffir-Simpson Category 5 hurricane. The Saffir-Simpson ranges are color-coded on the graphic for easy reference. The vertical scale represents tropical cyclone wind field size points. Several hurricanes stand out on this graphic. Hurricane Charley was a powerful Category 4 hurricane when it hit the coast of Florida in 2004. However, Charley was about as small as a Category 4 hurricane could be, with only 4 total size points, one for each of the four wind fields. Though Wilma was the most intense hurricane ever measured in the Atlantic Basin, it was almost as small as Charley as far as its wind field. On the upper right of the graphic, it's clear why Ivan and Katrina caused so much damage to offshore lease areas in the Gulf of Mexico. Their massive wind fields produced wave heights approaching 100 feet across the lease areas of the northern Gulf of Mexico.

Another way that the HSI for a tropical cyclone can be displayed is with a time series graphic We know the current and past intensity and wind field size of a tropical cyclone, so the HSI values are known for the current and past advisories. Using the current 120-hr forecast of intensity and wind field size, we can project HSI values out to 120 hours as in **Figure 4**.

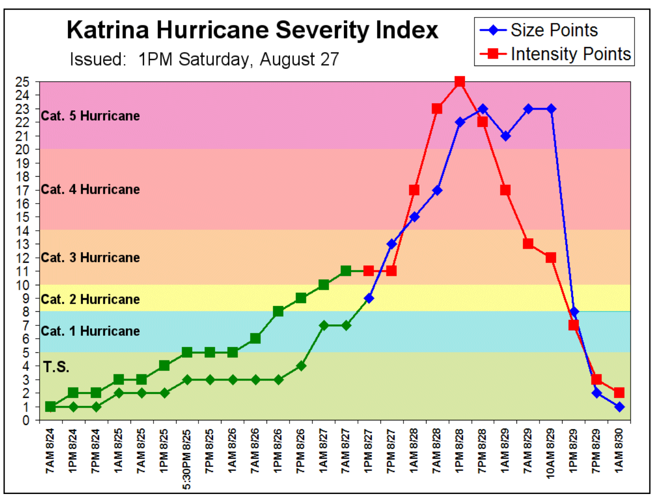

Figure 4

Figure 4 is a plot of Hurricane Katrina's HSI from a forecast made at 1PM CDT Saturday, August 27th. The green curves represent past intensity and size points. The red curve represents forecast HSI intensity points based upon the projected maximum sustained wind through 120 hours. The blue curve represents the forecast HSI size points based upon the projected wind radii through 120 hours. From the graphic, one can easily see that Katrina is forecast to become a very large and powerful hurricane over the next 24-48 hours, approaching the maximum of 50 points on the Hurricane Severity Index.

5. Conclusions and Future Work

While the current Saffir-Simpson Hurricane Scale does provide some information as to the severity of an approaching tropical cyclone, it doesn't tell the whole story. Knowing only a tropical cyclone's peak sustained wind, it's not possible to accurately estimate offshore wave heights, the height or expanse of coastal storm surge, the potential duration of winds at a location, or the probability of a specific wind field affecting a specific location. Because the Hurricane Severity Index takes into account wind field size, it is a tool that can be used to provide an estimate of a tropical cyclone's true destructive potential both at sea and at landfall. The Hurricane Severity Index can be used as a tool used in the escalation of a phased hurricane action plan by emergency managers.

In the future, we will be adding the tropical cyclones of the 2006 and 2007 (and future) hurricane seasons and updating making adjustments to the wind field size ranges based upon the new data. The 2006 and 2007 hurricane seasons were relatively quiet for most of our clients, but we plan to work with our clients in incorporating HSI forecasts into their hurricane action plans.

6. References

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SLOSH program used to estimate radii for significant historical storms before 1988.