Hurricane Severity Index: A New Way of Estimating a Tropical Cyclone's 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 to believe that Katrina was "only a Category 3 hurricane." In 2008, Category 2 hurricane Ike caused over $20 billion in damage to the upper Texas coast and southwest Louisiana. Clearly, the Saffir-Simpson hurricane scale is not adequate to measure a hurricane's true destructive potential.

There is a need for a new hurricane intensity and strength scale which takes into account not only a tropical cyclone's maximum sustained winds but also its 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 a tropical cyclone's intensity and 25 points are contributed by the size of its wind field.

2. Historical Data

The source of historical tropical cyclone intensity and wind field data is the National Hurricane Center's extended best-track database, including all tropical cyclones from 1988-2005. Maximum sustained wind and the 34, 50 and 64kt wind radii were recorded for every tropical cyclone in the database at each track point. Data from tropical storms were included, as the Hurricane Severity Index is designed for tropical storms as well as hurricanes.

3. Ranking Tropical Cyclone Intensity

A 25-point scale was created, which assigns points based on a tropical cyclone's maximum sustained wind between 30 and 150kts. See **Figure 1**. Note that a 30kt tropical depression receives 1 intensity point and a 150kt hurricane receives the maximum of 25 intensity points. 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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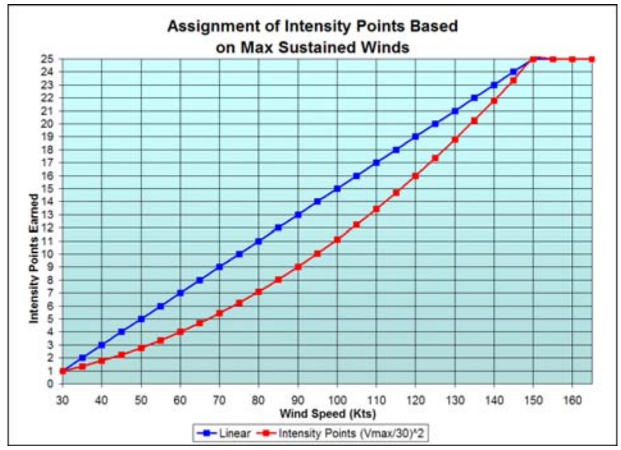

Figure 1

The intensity points were assigned based on the following formula:

- If Vmax < 30, HSI intensity pts = 0
- If 30 ≤ Vmax ≤ 150,

  HSI intensity pts = $\left(\frac{V\max}{30}\right)^2$
- If Vmax > 150, HSI intensity pts = 25

4. Ranking Tropical Cyclone Size

Determining how to assign points based on wind field size was a more difficult problem than assigning intensity points. The first step was to conduct a thorough study of past tropical cyclones. The National Hurricane Center's extended best-track dataset of all named storms from 1988-2005 was utilized, removing all extratropical cyclones, tropical lows and tropical waves. From the dataset, the 34, 50 and 64kt wind radii for nearly 3800 data points were recorded. In addition to the three standard wind radii, an 87kt (100mph) wind radius was also included. ImpactWeather meteorologists have been forecasting the 100mph wind radius for the past 10 years to better define the core of a strong hurricane in their day-to-day site-specific forecasts of wind impact for our clients. The 100mph radius provides a good estimate of the size of a hurricane's core of intense winds, an area where extreme structural damage is prevalent.

Since 87kt wind radii were not part of the NHC extended best-track database, those radii were measured from the detailed H*Wind Hurricane Research Division post-storm analyses for the 2001-2005 seasons. From these measurements, a formula was generated to estimate the 87kt wind radii for any hurricane based on the known 64kt wind radii and the maximum sustained winds using the following multiple linear regression equation.

If $V_{max} \geq 87$ kt and Re_{87} is unknown,

$$\mathrm{Re}_{87estimated} = 0.5683\,\mathrm{Re}_{65} + 0.0792V_{max} - 9.5383$$

Note that this equation estimates the effective radius of the 87kt wind field based on the known effective radius of the 64kt wind field and the maximum sustained winds of the hurricane. Once all wind radii were either measured or estimated, the average coverage of the 34, 50, 64 and 87kt winds in every storm from 1988-2005 was calculated. 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 a historical range of tropical cyclones
- 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 64 and 87kt wind radii based upon this relationship. **Table 1**, below shows how the 25 size points are awarded:

Wind Radii	Size Point Range
34 kts	1-3
50 kts	1-4
64 kts	1-8
87 kts	1-10

Table 1

A tropical cyclone's wind field can be highly asymmetrical, making it difficult to compare wind field coverage between tropical cyclones. To standardize the wind radii of all tropical cyclones in the dataset, an effective radius (R*e*) for each wind threshold was computed. The effective radius is defined as follows:

$$Re = Effective\ Radius = 0.5\sqrt{(RNE^2 + RSE^2 + RSW^2 + RNW^2)}$$

The effective radius defines the radius of a circle that has the same areal coverage as the tropical cyclone's wind field. For example, a hurricane may have a 64kt wind field that extends 30 nautical miles (nm) only in the northeast and southeast quadrants. Winds in the southwest and northwest quadrants are below 64kts. Using the equation above would yield an effective radius of 21.2 nm. That is, a circle with a radius of 21.2 nm would have the same areal coverage of 64kt winds as a hurricane with 64 kt winds extending out 30nm from the center in the northeast and southeast quadrants. Effective radius provides an easier way to compare one tropical cyclone's size characteristics to another.

To calculate how many size points a tropical cyclone would receive for each of the four wind radii described earlier, all of the effective wind radii values for each of the four wind fields were computed. The top 5 percent of the wind radii were then removed, as there were clearly a few outliers with very large wind fields that would have skewed the results toward high ranges. Similarly, the lower 5 percent of the wind radii were removed to eliminate any unusually small tropical cyclones. With the upper and lower 5 percent of wind radii removed, a realistic range for each of the four wind radii was derived. These ranges were divided equally according to the number of size points possible in **Table 1**. The 34kt wind radius range was divided into three equal ranges, the 50kt into four equal ranges, the 64kt into eight equal ranges, and the 87kt radii were divided into ten equal ranges. These values may be found in **Figure 2**.

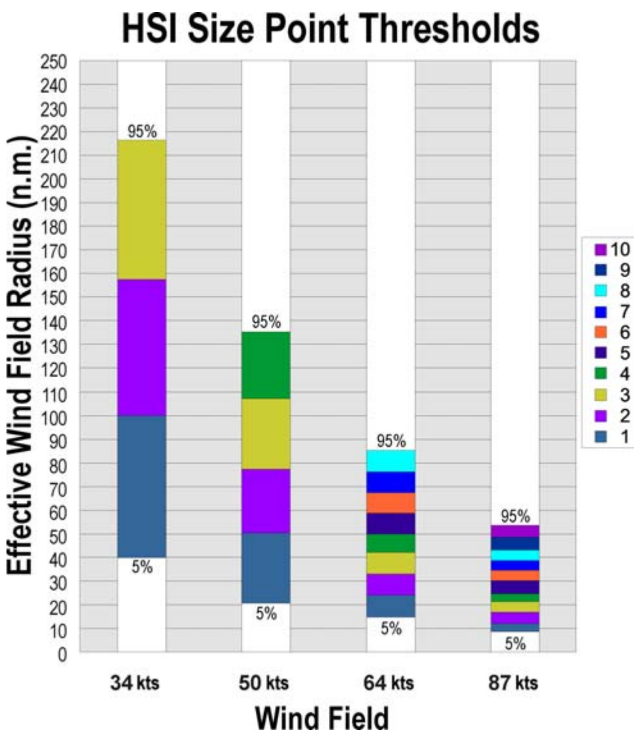

Figure 2

Points are awarded for each of the four wind radii depending on the extent of each wind field. For example, if a hurricane with 100kt winds has a 34kt effective wind radius that is in the top 1/3 of the 34kt range, it would get three points for its 34kt wind field. If its 50kt effective wind radius is in the lower ¼ of the 50kt range, then it gets an additional one point. If its 64kt effective wind radius is in the second 1/8 of the 64kt range, then it gets an additional two points. Finally, if its 87kt effective wind radius is in the third 1/10 of the 87kt range, then it is assigned an additional three points. This 100kt 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 Category 5 hurricane is shown in **Table 2**.

Saffir-Simpson Hurricane Scale vs. HSI						
Saffir-Simpson 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 rank. **Table 3** lists the HSI values for past hurricanes as they made landfall on the U.S. Coast. Reliable wind radii data are only available as of 1988. Radii for hurricanes prior to 1988 were derived from the current SLOSH dataset and should be considered rough estimates. 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.). Therefore, 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 1995	100 – Cat 3	11	**25**	36
Miami 1926*	115 – Cat 3	15	19	34
Audrey 1957	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
Ike 2008	95 – Cat 2	10	17	27
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
Bob 1991	90 – Cat 2	9	4	13

* Wind radii derived from SLOSH database

Table 3

In **Table 3**, compare Hurricanes Katrina and Camille. Both made landfall in the same area, but Katrina caused significantly more damage from storm surge and resulting loss of life than did Camille. Notice that each hurricane had an 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 when predicting the potential impact of a land-falling tropical cyclone.

A good example of how the Hurricane Severity Index can be used as a tool for estimating the destructive potential of a land-falling tropical cyclone would be a comparison of Hurricane Dennis and Hurricane Ivan. Both hurricanes struck the same area of the Gulf Coast. Each was a Saffir-Simpson Category 3 hurricane with 105kt sustained winds at landfall. However, the resemblance ends there. **Figure 3** demonstrates the differences between the two hurricanes as they neared landfall.

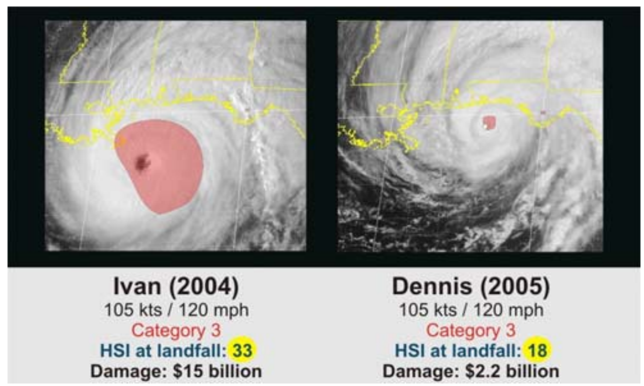

Figure 3

The shaded area in **Figure 3** represents the extent of the 64kt wind fields in Hurricane Ivan on the left and Hurricane Dennis on the right. Even though Hurricane Ivan had weakened considerably by the time it neared the Mississippi Delta, its wind field was considerably larger than that of Hurricane Dennis. Hurricane Ivan's size point total (21) was 3.5 times that of Hurricane Dennis (6). This difference in the size of the wind fields of the two hurricanes resulted in vastly different effects both offshore and at landfall.

Hurricane Ivan produced significant wave heights of 50-55 feet across and maximum wave heights approaching 100 feet in the offshore lease areas south of the mouth of the Mississippi River. Hurricane Dennis produced significant wave heights closer to 30-35 feet and maximum wave heights of 40-45 feet. Hurricane Ivan's storm surge approached 15 feet in Escambia Bay just east of Pensacola, FL. Hurricane Dennis produced a storm surge of between 5-7 feet just east of where the center made landfall between Pensacola and Panama City, FL. Hurricane Ivan produced damage totaling nearly $15 billion dollars in insured and uninsured losses. The losses from Hurricane Dennis were estimated to be near $2.2 billion dollars. From a comparison of the damage produced by these two hurricanes with identical maximum sustained winds, it is clear that the Saffir-Simpson Hurricane Scale is deficient in that it does not differentiate between two hurricanes of identical intensity but vastly different wind field size.

Of all the tropical cyclones in the dataset, the highest-ranking hurricane to hit the U.S. Coast so far has been 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 hurricane with the lowest central pressure ever recorded in the Atlantic Basin, ranks. Wilma's intensity was well over 150 kts, giving it the maximum of 25 points for intensity. But look at Wilma's size points at its peak intensity – only 5. Wilma had one of the smallest 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

One can also compare the HSI values of well-known tropical cyclones graphically, as in **Figure 4:**

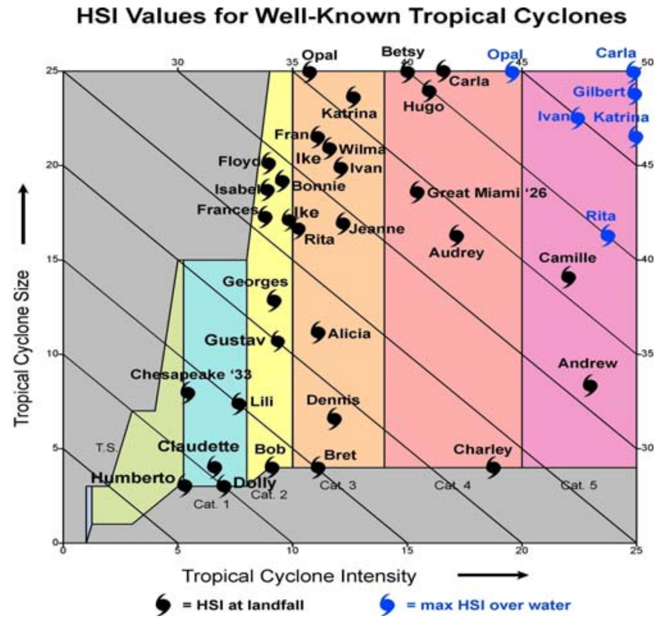

Figure 4

Figure 4 is a graphical representation of the data in **Table 3** and **Table 4**. The horizontal scale represents a tropical cyclone's intensity points, ranging from a 30kt 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. 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 some 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. When a tropical cyclone is active, the current and past intensities and wind field sizes are known from the current and past advisories. Using the current 120-hr forecast of intensity and wind field size, one can project HSI values out to 120 hours as in **Figure 5**.

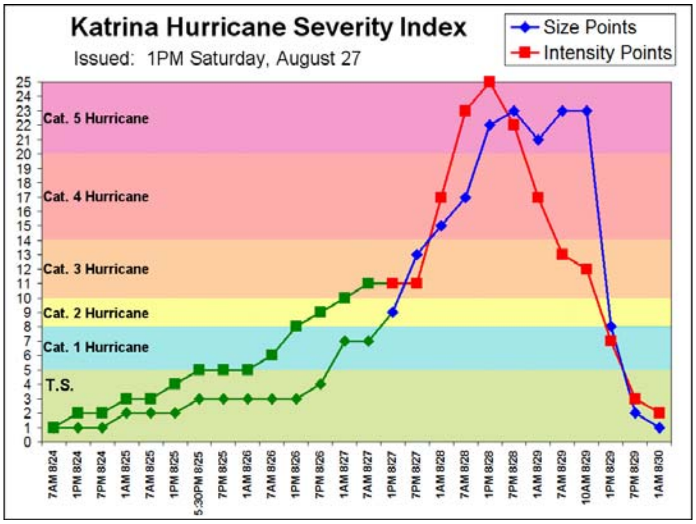

Figure 5

Figure 5 is a plot of Hurricane Katrina's two HSI components 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 intense 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 is 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, this 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 by emergency managers as a tool to aid in the decision to escalate a phased hurricane action plan.

The Hurricane Severity Index is being incorporated into a damage prediction model, which is currently in development. The model employs a multiple polynomial regression technique using four explanatory variables; the size and intensity components of HSI, maximum storm surge and a wealth index. The damage prediction model leverages the relationships that exist between the explanatory variables and normalized damage to provide insight into a likely range of future damage associated with landfalling hurricanes.

Future work will involve further refinements to the HSI calculations, incorporating each hurricane season into the dataset. Other work will involve the quantification of the HSI size component with the potential generation of wind waves as well as the size and extent of the projected storm surge. We will also be compiling a searchable database of past HSI values for comparison purposes.

6. References

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