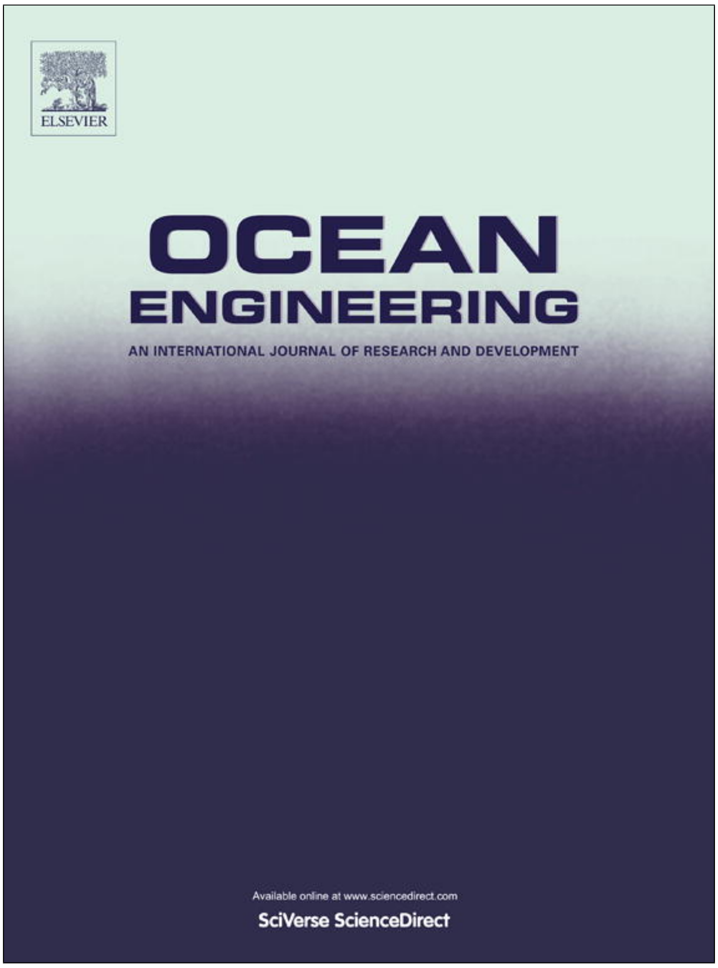
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Short Communication

Classification of hurricanes: Lessons from Katrina, Ike, Irene, Isaac and Sandy

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ABSTRACT

Lessons learned from disastrous hurricanes in recent years, especially Katrina, Ike, Irene, Isaac and Sandy are discussed, and improved ways to inform the public about the potential impact of tropical cyclones are presented. An alternative classification system is shown to be more informative than the Saffir–Simpson scale currently in use, and should prove beneficial to the general public and the coastal engineering community. *The most important lesson is that the size of the hurricane matters, not just its intensity*.

1. Introduction

In a special issue of this journal (Demirbilek, 2010), experts in various fields discussed the lessons learned from the most devastating hurricane in the history of this country, Katrina. They also addressed many issues related to hurricanes, including their anatomy, associated winds and waves, and resulting storm surges. One of the papers in the special issue (Irish and Resio, 2010a) took on the task of better estimation of an index for storm surges generated by land-falling hurricanes, with subsequent improvements by Kantha (2010) and Irish and Resio (2010b). However, the important task of improving the overall classification of hurricanes, with the goal of better informing the public and coastal engineering community, was not addressed.

An article in New York Times (August 29, 2011) by Henry Fountain, immediately after hurricane Irene hit New York city, titled "Hurricane lost steam as experts misjudged structure and next move" is an excellent example of non-experts being confused by the continued use of the Saffir–Simpson hurricane scale (SSHS, see Table 1) by the National Hurricane Center (NHC) to convey the severity of a tropical cyclone to the general public. The article states that "What hurricane specialists had forecast to be a Category 2 or possibly Category 3 storm when it hit eastern North Carolina early Saturday, with maximum sustained winds of 49.2 m/s (110 miles per hour, mph) or higher, roared across the Outer Banks as a Category 1, with winds that were more than 10% slower." If the winds slow down by 10%, the intensity of the hurricane decreases by only about 19%. That is not a significant decrease. The damage sustained in North Carolina was because the "weak" Irene was also enormous in size.

The potential damage due to a hurricane depends not just on its intensity, but also on its size. SSHS does not account for the hurricane size. This brief note is an attempt to bring to the attention of the coastal engineering community, the shortcomings of SSHS, and suggest ways to improve the overall classification of hurricanes.

2. Hurricane classification

Hurricanes, more appropriately tropical cyclones, have the potential to be highly destructive to coastal structures, habitats and communities (see Pielke et al., 2008). Hurricane Irene has once again brought to the forefront the shortcomings of SSHS in extensive use since the 1970s. Improved measures of hurricane intensity and damage potential (e.g. Kantha, 2008, Irish and Resio, 2010a, b) are therefore needed. For more details, the reader is referred to Kantha (2012) and the references cited therein.

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Table 1
Saffir–Simpson hurricane scale (SSHS).

Type	p_c (mb)	V_{max} in m/s (mph)	Surge in m (ft)
TD	1007	< 17 (< 39)	
TS	< 1000	17–33 (39–73)	
Cat 1	980	33–42 (74–95)	1.2–1.5 (4–5)
Cat 2	979–965	43–49 (96–110)	1.8–2.4 (6–8)
Cat 3	964–945	50–58 (111–130)	2.7–3.7 (9–12)
Cat 4	944–920	59–69 (131–155)	4.0–5.5 (13–18)
Cat 5	< 920	> 70 (> 156)	> 5.5 (> 19)

SSHS was originally designed by Herebert Saffir to be an index of the potential *intensity* of wind damage. Thus it is neither an indication of the true *intensity* of the hurricane nor the potential *extent* of wind damage. The then director of NHC, Mr. Simpson added rough estimates of potential storm surge and the resulting SSHS has been used by NHC until recently. In 2009, after Katrina demonstrated unequivocally that storm surge potential based simply on SSHS is misleading, NHC removed the storm surge estimates from SSHS. But the basic scale is still retained.

A peculiar aspect of the SSHS is that, unlike the Richter earthquake scale, the resulting values are quantized. Each category hurricane has a range of properties assigned to it. This means that a change of just a m/s (few mph) in maximum speed near the transition value can make a unit change in the category, which can be highly misleading to the general public (see Table 1). On this scale, if the maximum sustained wind speed is between 49.6 and 58.1 m/s (111 and 130 mph), the hurricane is classified as Category 3; if between 42.9 and 49.2 m/s (96 and 110 mph), as Category 2, and if between 33.1 and 42.5 m/s (74 and 95 mph), as Category 1. If the maximum speed falls to or below 32.6 m/s (73 mph), it becomes just a tropical storm. Irene was initially designated as a Category 3 hurricane, but was downgraded to Category 2 as it neared North Carolina because the maximum wind speeds had dropped a mere 5 mph from 51.4 m/s (115 mph) to 49.2 m/s (110 mph). However, the intensity of the hurricane, which depends on the square of the wind speed, had decreased by only 8.6%. The hurricane was later downgraded to Category 1. These incorrect and ill-advised downgrades dictated by the inherent discrete nature of SSHS are not just confusing to the public and the decision-makers such as local public officials, but might lead to complacency among some and increase public risk.

SSHS also saturates at its higher end because no matter how much higher the maximum speed goes above 69.7 m/s (156 mph), the hurricane is characterized as Category 5. Granted that once the hurricane reaches Category 5, it is sufficiently destructive that further increases may not make much difference, it is still desirable to devise a scale that does not saturate at the higher end, especially since global warming could very likely spawn much stronger hurricanes in the coming decades. Because of ongoing climate change, it is quite possible that some cyclones in the future could exceed Category 5. As clearly demonstrated by hurricanes Katrina, Wilma and Ike, the SSHS is also a grossly misleading index of the *extent* of hurricane impact to be expected. One needs to know not just the hurricane intensity and hence the *intensity* of expected damage in localized domains but also the *extent* of expected damage so that adequate relief measures can be organized.

Judging by the economic cost, the Category 3 hurricane Katrina of the 2005 hurricane season did far more damage (even ignoring the damage done to the city of New Orleans by widely-predicted but unanticipated levee breaks and concentrating merely on the physical damage in Louisiana, Mississippi and Alabama) than the Category 5 Hurricane Andrew did in 1992. For details, see Demirbilek (2010) and fourteen papers included in that Special Issue dedicated to the Hurricane Katrina. This anomaly can be explained by noting that Katrina was almost three times the size of Andrew, with hurricane winds extending to 217 km (135 miles) in radius. The result was that the damage extended along a larger stretch of the coastline. The enormous size of Irene (with hurricane-strength winds extending 140 to 205 km (87 to 128 miles) from the center and tropical-strength winds extending roughly three times as much) is one reason for the extensive wind damage in North Carolina, and of course the wide-spread rainfall and flooding in the northeast US. Storm size matters as much as storm intensity.

Table 2 (adapted from Kantha (2010)) shows prominent Atlantic cyclones that have made landfall in the US. R_{33} is the radius of the hurricane winds (in km), p_c is the central pressure (in mb), L_{30} is the distance to 30 m isobath (in km), SSHS is the Saffir–Simpson scale, SS is the Irish and Resio (2010a, 2010b) surge index, and $Y_{2\ m}$ is the lateral extent of inundation over 2 m (in km). Maximum velocity (V_{max} in m/s) values are from NHC database and so are values of the forward speed at landfall (V_{sp} in m/s). HII and HHI are hurricane intensity, and wind impact indices from Kantha (2006, 2008). Surge index SSI and surge impact index HSI are from Table 1 of Kantha (2010), but values have been corrected for a mistake that made the values slightly higher than the correct values shown in Fig. 1 of Kantha (2010). Note that hurricanes Irene, Isaac and Sandy have been added to the table.

The three catastrophic tropical cyclones in recent years (Katrina in 2005, Ike in 2008 and Sandy in 2012) have demonstrated conclusively that the damage inflicted by a land-falling tropical cyclone does not depend merely on its category on the Saffir–Simpson hurricane scale. Katrina, only a Category 3 hurricane at landfall, caused more physical surge and wind damage than the Category 5 hurricane Camille did in 1969, along the same US Gulf coast. A similar situation occurred again in 2008, when the weak Category 2 hurricane Ike hit the Texas coast and caused extensive storm surge damage there and surprisingly, along the distant southeast Louisiana coast as well. This naturally raises the question in people's minds: how is it that relatively weak hurricanes can wreak so much havoc? The answer to this question necessarily involves the storm size. The relatively large sizes of both Katrina and Ike indicate that the impact potential of a tropical cyclone is also a function of its size. The larger the hurricane, the higher its impact potential, even if its intensity is the same. Since only the SSHS is widely disseminated, the lay public (and local officials not privy to sophisticated models and other data at the federal level) is generally unaware of the true destructive potential of a tropical cyclone. Consequently, there was widespread puzzlement in 2008 as to how a mere Category 2 hurricane Ike could cause so much devastation. Based on the fact that Katrina was *only* a Category 3 at landfall, many people on the Gulf Coast expected it to be far less destructive than the 1969 Category 5 hurricane Camille, and this might have led to complacency among some and compounded the Katrina tragedy.

3. Alternative indices

Alternative indices have been proposed recently to overcome the above-mentioned deficiencies but have not been adopted by NHC. The delineations of hurricane intensity in the SSHS are not based on flow dynamics. The basic tenet of fluid dynamics is that the forces exerted by the fluid must be proportional to the dynamic pressure, the product of the fluid density and the square of the fluid velocity. Whether it is a hurricane, a tornado, a winter storm or a katabatic wind *does not matter*. The storm strength must be proportional to the square of the maximum wind speed,

Table 2
(from Kantha (2010)). Hurricane statistics from Irish and Resio (2010a, 2010b) rearranged in chronological order, and supplemented by other data.

No.	Name	Year	R_{33} (km)	p_c (mb)	L_{30} (km)	Surge (m-m)		SSHS	SS	Y_{2m} (km)	V_{sp} (m/s)	V_{max} (m/s)	HII	HHI	SSI	HSI
1	September	1938	233	936	10	2.3	3.5	2	0.2	179	16	51	2.4	11.2	0.6	0.6
2	October	1941	143	970	40	3.2	3.2	2	0.4	136	9	49	2.2	6.1	1.2	0.8
3	October	1944	179	960	53	2.3	3.4	3	0.7	132	7	54	2.7	10.2	2.3	1.9
4	Audrey	1957	164	946	118	3.4	3.8	4	1.3	181	7	64	3.8	15.5	4.4	3.3
5	Carla	1961	177	936	34	3.3	3.7	4	0.6	188	3	68	4.2	20.1	3.6	3.0
6	Hilda	1964	154	960	88	2.3	3.0	3	1.1	94	3	51	2.4	7.4	3.6	2.6
7	Betsy	1965	195	945	52	4.1	4.8	3	0.8	265	7	54	2.7	11.1	2.4	2.2
8	Beulah	1967	164	950	20	2.4	2.9	3	0.3	100	3	61	3.4	13.5	1.7	1.3
9	Camille	1969	109	910	120	6.4	6.9	5	2.7	189	6	74	5.0	16.0	5.1	2.6
10	Celia	1970	101	944	30	2.7	2.8	3	0.5	68	7	57	3.0	6.8	1.5	0.7
11	Frederic	1979	164	950	48	3.5	3.8	3	0.7	184	6	60	3.3	12.8	3.0	2.3
12	Allen	1980	150	945	21	2.1	3.7	3	0.3	116	2	51	2.4	7.2	1.3	0.9
13	Gloria	1985	229	951	24	1.9	2.7	2	0.3	74	15	44	1.8	7.0	0.7	0.8
14	Hugo	1989	146	934	56	5.7	5.7	4	1.0	235	8	64	3.8	13.8	3.0	2.0
15	Andrew	1992	77	919	67	2.4	2.4	5	1.0	32	8	75	5.2	11.7	2.9	1.1
16	Opal	1995	169	940	21	3.1	3.7	3	0.4	173	9	51	2.4	8.1	1.1	0.8
17	Bret	1999	108	953	22	0.9	1.5	3	0.3	–	3	51	2.4	5.2	1.3	0.6
18	Lili	2002	133	966	84	3.2	3.6	1	0.9	136	6	42	1.6	3.6	1.2	0.8
19	Isabel	2003	214	957	25	1.8	2.0	2	0.3	–	3	45	1.9	7.0	1.2	1.2
20	Frances	2004	139	960	15	1.8	2.4	2	0.2	16	3	47	2.0	5.2	0.8	0.5
21	Charley	2004	40	950	57	2.1	2.1	4	0.6	5	9	67	4.1	4.3	1.0	0.2
22	Ivan	2004	128	955	31	3.0	3.1	3	0.4	109	6	54	2.7	7.3	1.6	1.0
23	Dennis	2005	33	952	24	1.7	2.5	3	0.3	4	6	54	2.7	1.9	0.6	0.1
24	Katrina	2005	217	919	140	7.5	8.5	3	3.1	404	3	57	3.0	14.5	7.2	7.3
25	Rita	2005	174	946	119	3.0	4.6	3	1.9	270	4	51	2.4	8.3	3.7	3.0
26	Wilma	2005	179	951	118	1.8	2.4	3	1.7	–	7	52	2.5	9.1	2.6	2.2
27	Dolly	2008	35	967	21	1.5	2.4	2	0.2	–	9	39	1.4	0.8	0.2	0.0
28	Gustav	2008	110	957	81	4.5	4.5	2	1.1	151	3	49	2.2	4.7	2.6	1.3
29	Ike	2008	195	952	92	4.8	5.9	2	1.3	303	4	49	2.2	8.3	3.3	3.0
30	Irene	2011	140	950	–	–	–	1	–	–	6	36	1.2	2.3	–	–
31	Isaac	2012	95	968	140	1.8	2.2	1	–	404	3	36	1.2	1.6	1.7	0.8
32	Sandy	2012	150	–	–	1.0	2.0	–	–	–	–	31	0.9	1.7	–	–

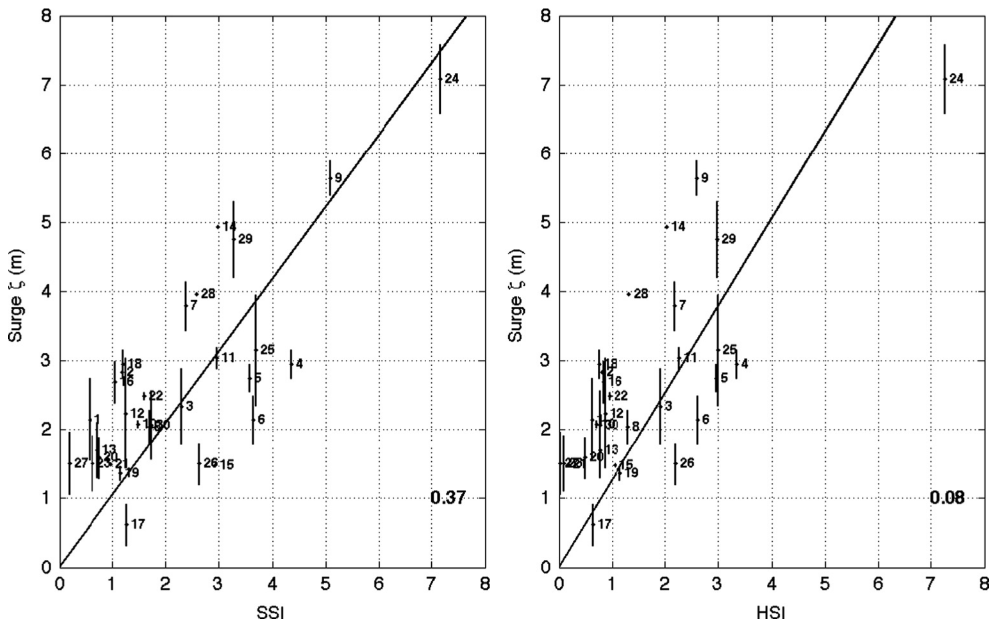

Fig. 1. The observed storm surge plotted against the storm surge index SSI (left hand panel) and the surge impact index HSI (right hand panel) for hurricanes listed in Table 2. The number in the bottom right hand corner indicates the R^2 value of the linear fit. Hurricane numbers correspond to those in Table 2.

and therefore the Hurricane Intensity Index (HII) is best defined as

$$HII = \left(\frac{V_{\max}}{V_{\max}^{ref}}\right)^2 \qquad (1)$$

where the reference speed is 33 m/s (74 mph) corresponding to Category 1.0 hurricane. Such a scale is continuous and does not saturate at its higher end. More importantly, it is based on the laws of physics. Consequently, it is a more accurate indication of the strength of a hurricane than is SSHS. Note that a weak tropical storm would be Category 0.3 on this scale. On this scale, based on NHC advisories at 8:00 AM EDT, Irene was Category 2.4 on August 25th (not Category 3), Category 2.2 on August 26th (NHC downgraded it to Category 2), Category 1.3 at on August 27th (NHC downgraded it to Category 1), and Category 1.0 on August 28th (NHC had it at Category 1). By 11:00 PM EDT on August 28th, the time of the last NHC advisory, Irene was a Category 0.5 tropical storm. Clearly, the decrease in Irene classification from 2.4 to 2.2 to 1.3 and then 1.0 makes more sense than 3 to 2 to 1! NHC should seriously consider adopting such a continuous scale. Transition to such a scale from SSHS would be quite painless and readily understood by the public that is used to dealing with a similarly non-discrete earthquake scale.

It is also quite obvious that a single index such as SSHS (or HII) cannot be expected to accurately represent all important aspects of a tropical cyclone: 1. Storm intensity, 2. Wind impact potential, 3. Storm surge potential and 4. Surge impact potential. The laws of Physics will not allow it. Separate but related indices are needed (Kantha, 2009, 2010 etc).

The wind impact (damage) potential is a function of both the *intensity* and the *size* of the storm (Kantha, 2006, 2008, 2010, 2012). The larger the storm, the higher the *extent* of destruction it brings to the coastal community. The wind impact should also correlate with the work done by the wind (or equivalently the dissipation of wind energy) and hence should be proportional to the cube of the wind velocity, and not the square. Clearly, an index such as SSHS or HII that represents just the storm intensity cannot be used to represent the wind impact potential also. A separate index is needed. Since most of the intense wind damage inflicted by a hurricane is confined to a narrow strip of the coast near the landfall, a Hurricane (wind) Hazard Index (HHI) can therefore defined as

$$HHI = \left(\frac{V_{\max}}{V_{\max}^{ref}}\right)^3 \left(\frac{R_{33}}{R_{33}^{ref}}\right) \tag{2}$$

with a reference radius corresponding to Hurricane Andrew. HHI is 1.0 for a Category 1.0 hurricane with a radius of 77 km (48 miles). On this scale, a hurricane of the same size but Category 5.0 with a speed of 69.7 m/s (156 mph) would have HHI of 9.4. But if the same hurricane had a radius twice as large, HHI would be 18.7. Thus the hurricane size figures prominently in this index.

Finally, the storm surge caused by the land-falling hurricane is a major factor in inundation of coastal structures and the resulting damage. Since the storm surge is the result of the dynamic response of the coastal shelf to the wind forcing by hurricane winds, it is hard to quantify without an appropriate model. Nevertheless, a rough index has been devised recently (Irish and Resio, 2010a, 2010b; Kantha, 2010)

$$SSI = \left(\frac{V_{\max}}{V_{\max}^{ref}}\right)^2 \left(\frac{L_{30}}{L_*}\right)\psi_x\left(\frac{R_{33}}{L_{30}}\right)\psi_t\left(\frac{R_{33}}{L_{30}}\frac{V_{\max}}{V_{sp}}\right) \tag{3}$$

is the storm surge index, with L_* chosen to be 40 km to make SSI roughly equal in magnitude to the maximum surge height. The functions ψ_x and ψ_t are taken as: $\psi_x(x) = 1 - e^{-3x}$ and $\psi_t = 1 - e^{-0.04t}$, so that they are within 2% of saturation for $x=1$ and $t=75$, respectively. $V_{\max}^{ref} = 33$ m/s as in Kantha (2006, 2008). L_{30} is the distance from the coast to the 30 m isobath. The potential storm surge impact itself depends on the size of the hurricane and can be characterized by Kantha (2010).

$$HSI = 0.36\left(\frac{R_{33}}{R_{33}^{ref}}\right)SSI \tag{4}$$

3.1. Andrew

Hurricane Andrew with landfall wind speed of 73.8 m/s (165 mph) but a radius of only 77 km (48 miles) had a HHI of 11.1, whereas Katrina with a landfall wind speed of only 55.9 m/s (125 mph) but size of 217 km (135 miles) had a HHI of 13.6! These numbers could have made it clear to the lay public and local officials why the Category 2.9 Katrina was likely to be almost as destructive as the Category 5.0 Andrew. HHI would have provided a more accurate estimate of the extent of destruction to be expected from hurricane winds than SSHS. Note that HHI is indicative of the damage *potential*, not the *actual* damage, since the latter would be a function of the nature of the real estate traversed by the hurricane. While it must be supplemented by data such as the population density and real estate values to estimate potential losses accurately, it does provide a rough idea of the potential impact and is therefore of some societal utility.

Table 3
Six-hourly hurricane statistics from NHC advisories for Irene and Sandy.

Date	Time (EDT)	Location (Lat, Lon)	V_{max} (mph)	R_{33} (km)	V_{sp} (mph)	p_c (mb)	SSHS	HII	HHI	
Aug 25	05:00	24.6N, 76.2 W	115	110	12	950	3	2.4	5.4	Irene (2011)
	11:00	25.9N, 76.8W	115	110	13	951	3	2.4	5.4	
	17:00	27.0N, 77.3W	115	130	14	950	3	2.4	6.4	
	23:00	28.3N, 77.3W	115	130	14	942	3	2.4	6.4	
Aug 26	05:00	29.3N, 77.2W	110	150	14	942	3	2.2	6.4	
	11:00	30.7N, 77.3W	105	150	14	946	2	2.0	5.6	
	17:00	31.7N, 77.4W	100	150	14	951	2	1.8	4.8	
	23:00	32.6N, 76.9W	100	150	13	951	2	1.8	4.8	
Aug 27	05:00	34.1N, 76.5W	90	150	14	952	1	1.5	3.5	
	11:00	35.2N, 76.4W	85	150	15	952	1	1.3	3.0	
	17:00	36.2N, 76.0W	80	140	13	950	1	1.2	2.3	< Landfall
	23:00	37.3N, 75.4W	80	205	16	954	1	1.2	3.4	
Aug 28	05:00	39.2N, 74.5W	75	205	18	958	1	1.0	2.8	
	11:00	41.4N, 73.7W	60	–	26	966	–	0.7	–	
	17:00	42.7N, 72.8W	50	–	26	975	–	0.5	–	
	23:00	45.3N, 71.3W	50	–	26	980	–	0.5	–	
Oct 28	05:00	31.9N, 73.3 W	75	165	13	960	1	1.0	2.2	Sandy (2012)
	11:00	32.5N, 72.6W	75	280	14	951	1	1.0	3.8	
	17:00	33.4N, 71.3W	75	280	15	952	1	1.0	3.8	
	23:00	34.5N, 70.5W	75	280	14	950	1	1.0	3.8	
Oct 29	05:00	35.9N, 70.5W	85	280	15	946	1	1.3	5.6	
	11:00	37.5N, 71.5W	90	280	18	943	1	1.5	6.6	
	17:00	38.8N, 74.4W	90	280	28	940	1	1.5	6.6	
	23:00	39.8N, 75.4W	75	150	18	952	1	1.0	2.0	
Oct 30	05:00	–	70	150	–	–	–	0.9	1.7	< Landfall

3.2. Irene

Based on NHC advisory data at 5:00 AM EDT (see Table 3), Irene's HHI was 5.4 on August 25th [hurricane winds extending 110 km (68 miles) from the center], 6.4 on August 26th [hurricane winds extending 150 km (93 miles) from the center], decreasing drastically to 3.5 on August 27th [hurricane winds still extending 150 km (93 miles) from the center] but remaining at 2.8 on August 28th [hurricane winds extending 205 km (127 miles) from the center]. These numbers correlate much better with the actual damage caused by winds (not inundation by surge or flooding) in North Carolina, New Jersey and New York City. Note the large HHI values as Irene nears landfall in North Carolina (Table 3)!

As noted elsewhere by many, a peculiar aspect of Irene is that the central pressure remained around 950–952 hPa (appropriate to a Category 3 hurricane in the open ocean), even as she was downgraded from Category 3 to category 1 (the same is true for Sandy, see below). Only on August 28th had the central pressure increased to 963 hPa (mb). Fortunately for East Coast residents, Irene never lived up to her full potential. New Yorkers also lucked out by Irene lingering too long near Cape Hatteras, ingesting drier continental air masses and getting slowed down by land over her western half so that when she reemerged to hit New Jersey, New York City and New England, she had weakened considerably, transforming herself to merely a tropical storm but a prodigious rain maker!

3.3. Isaac

The same holds for Isaac in August 2012. Isaac took almost the same track as Katrina and made landfall ironically on the Seventh anniversary of Katrina. However, like Irene, Isaac did not intensify and remained a diffuse system when he hit New Orleans as Category 1.2 hurricane. He also nearly stalled after landfall and the resulting slow motion caused over 20″ of rain in some places. This led to additional problems related to flooding in many places but the levees held in New Orleans. Thus like Irene, Isaac turned out to be a prodigious rainmaker. The storm surge was a modest 2 m, with a SSI of only 1.7 (compared to Katrina's 7.2) and even lower HSI of 0.8 (Katrina was 7.3).

3.4. Sandy

The late season hurricane Sandy in 2012 turned out to be very destructive, second only to hurricane Katrina in 2005. It made landfall as a post-tropical cyclone and NHC stopped issuing advisories because it was no longer a tropical cyclone. But while it remained a borderline Category 1 on the SSHS near landfall, its size remained large with hurricane force winds extending to 280 km (see Table 3). This enormous size of Sandy was principally responsible for the extensive storm surge on the New Jersey and New York coastlines, causing property damages exceeding $50 billion, as well as significant loss of lives. Note that surge indices are not shown in Table 3 for Irene and Sandy, but these indices are expected to be large because of the enormous sizes of these cyclones.

Table 2 includes the values of HII, HHI, SSI and HSI for various hurricanes. Fig. 1 shows a plot of the observed storm surge plotted against SSI and HSI. Katrina (#24) occupies a unique position among the Atlantic hurricanes over nearly 75 years of record keeping.

4. Conclusions

As Katrina and Sandy have demonstrated, tropical cyclones can be very destructive. More importantly, minimization of loss of lives requires *prompt reaction* of the public to pre-storm decisions by the authorities. A better and less-confusing classification of hurricanes using a continuous intensity scale based on the laws of physics should help. As far as the coastal engineering community is concerned, a better intensity index accompanied by a potential damage index and a meaningful storm surge index should be useful in making crucial decisions, both pre-storm and post-storm. HII is an improved estimate of the hurricane *intensity*, HHI is an indication of the potential *extent* of wind damage, SSI is indicative of the storm *surge* to be expected, and finally, HSI is indicative of the potential *surge impact*. It is time to acknowledge that the size is just as important as the intensity in estimating the tropical cyclone wind and surge damage potential.

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