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An Intensity Scale for Atlantic Coast Northeast Storms

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ABSTRACT

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A new classification of extratropical storms, or northeasters, is developed for the middle Atlantic coast. The classification is analogous to the commonly-used Saffir-Simpson Scale for tropical cyclones. Based upon wave hindcasts for Cape Hatteras, North Carolina, 1,347 storms over a 42-year period are grouped into five classes. The classification variable is an index of storm "power," which is storm's duration times the square of maximum significant wave height. Based upon cluster analysis, the following storm classes are produced: CLASS I (weak, power $\leq$ 771 ft^2hr), CLASS II (moderate, 771 $<$ power $\leqq$ 1,760), CLASS III (significant, 1,760 $<$ power $\leqq$ 10,000), CLASS IV (severe, 10,000 $<$ power $\leqq$ 25,000), and CLASS V (extreme, power $>$ 25,000). The response of the coast (*e.g.*, overwash, erosion, and inlet formation) to the average waves and storm surge in each class range from minor for Class I to extreme in Class V. This classification is a useful tool in comparing the relative strength of coastal storms and may have some potential applications in near real-time assessment of a storm's destructive power.

ADDITIONAL INDEX WORDS: *Storm climatology, coastal storms, storm damage, wave hindcast.*

INTRODUCTION

Over the past century, several great storms have caused hundreds of millions of dollars in damage and scores of deaths along the U.S. Atlantic Coast (Figure 1). The most severe storm of record with respect to widespread destruction was a hurricane in 1933; however, each year less powerful winter storms take their toll on the beaches and structures. From the standpoint of maximum windspeeds, high waves, and storm surge, the Ash Wednesday Storm of 7–9 March, 1962, was among the most severe winter storms of record for the U.S. Atlantic Coast (PODUFALY, 1962; STEWART, 1962; BRETSCHNEIDER, 1964). When high waves and storm duration are coupled, a storm that occurred 7–11 March, 1989, was equally powerful although not as extensive (DOLAN *et al.*, 1989), and preliminary data indicate that the "All Hallows' Eve" storm of 28 October–1 November, 1991 was the most powerful storm in the past 50 years (DAVIS and DOLAN, 1992).

People living along the Atlantic Coast routinely compare the destructive power of these storms. Some claim that the 1991 storm was responsible for more damage and beach erosion than the Ash Wednesday storm, while others maintain that the great 1962 northeaster was more destructive. There are always differences in our perception of a storm's power, with many people judging storm magnitude on the basis of damage caused in their immediate area. This is not an objective way to compare storms in that local damage can increase or decrease due to factors not necessarily related to the storm's atmospheric or oceanographic characteristics.

STORM CLASSIFICATIONS AND STORM CHARACTERISTICS

For the past 20 years, coastal scientists and the general public have used the Saffir-Simpson Scale to compare tropical cyclones (SIMPSON, 1971; SAFFIR, 1979). This scale ranks hurricanes into classes from 1 to 5, in which Class 1 (minor) hurricanes have winds from 74 to 95 mph (32 to 42 m/sec) and Class 5 (major) hurricanes possess windspeeds $>$ 155 mph (79 m/sec) (Table 1). Although the rank of a hurricane on the Saffir-Simpson Scale does not necessarily relate directly to the damage it may cause, there is an assumed relative relationship. HALSEY (1986) recently suggested a ranking of Atlantic Coast extratropical storms into five classes based primarily on a damage potential index (Table 1). In this classification, she also takes into consideration the occurrence of the storms with respect to the tidal cycle and the number of tidal cycles (duration) that the storms bracket.

Saffir-Simpson and Halsey both have 5 storm

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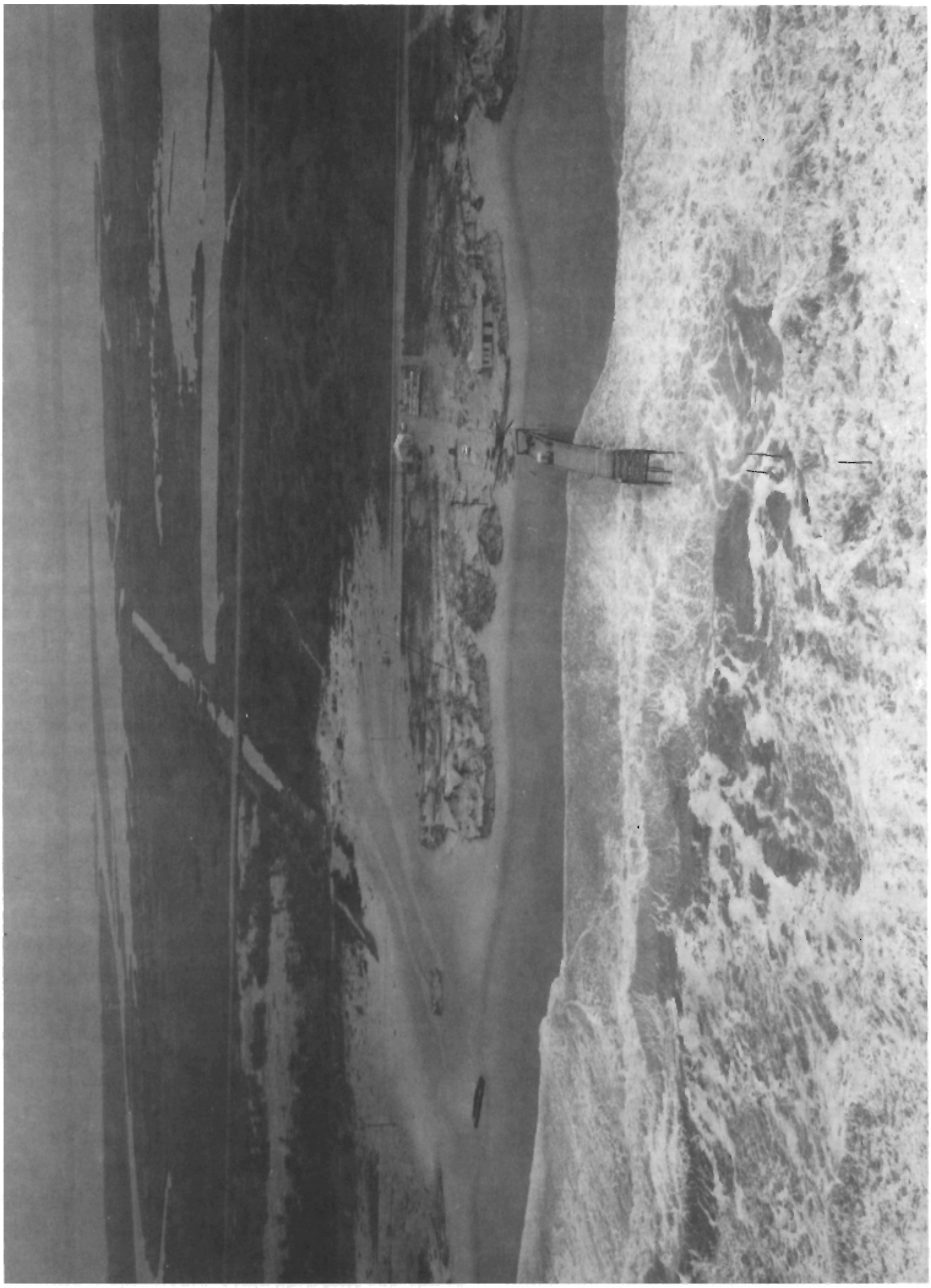

Figure 1. The Outer Banks of North Carolina during the peak of the Ash Wednesday storm of 7 March 1962. Note the large overwash areas, dune erosion, and destruction to the fishing pier. This storm ranks among the top 10 most powerful northeasters (Class V) on the Dolan/Davis scale.

classes, but there are significant differences in the bases for the classifications. As shown on Table 1, the Saffir-Simpson Scale incorporates windspeed, central pressure, and storm surge. These attributes are measures that are standardized in the data collection programs of the National Weather Service, the National Hurricane Center, NOAA, and the Corps of Engineers. Northeasters, on the other hand, are not as clearly defined or as tightly structured (PIELKE, 1990); therefore, the attributes that coastal scientists most often use to compare the magnitude of winter storms is the height of the waves, the size of the storm surge they produce, and their duration. Unlike the Saffir-Simpson Scale for hurricanes, windspeed is a less important consideration with northeast storms due to their more diffuse physical characteristics (PIELKE, 1990) and because their peak windspeeds seldom approach those of even minimal hurricanes. Winter storm sustained windspeeds range from 20 to 50 mph (10 to 25 m/sec), whereas hurricane force winds begin at 74 mph (32 m/sec). However, extratropical storms are much more frequent, are usually larger than hurricanes, and generally move slower. Atlantic Coast northeasters routinely span several days (DOLAN *et al.*, 1988) and thus produce wave heights that can match those of their tropical counterparts.

THE DOLAN/DAVIS NORTHEASTER CLASSIFICATION

The classification of Atlantic Coast winter storms that we offer is based on measurements of storm locations, tracks, fetches, durations, and wave heights. Our data consists of 1,347 northeast storms that produced at least a significant deep-water wave height of 5.0 feet (1.5 m) at Cape Hatteras, North Carolina. We used this threshold for our definition of a northeast storm and to calculate its duration based on confirmed field evidence that a 5 foot (1.5 m) deep-water wave will result in measurable beach face erosion along the North Carolina coast. The data span the period 1942 to 1984 (BOSSERMAN and DOLAN, 1968; DOLAN *et al.*, 1988). Whenever possible, we verified our wave height and duration data through comparisons with measured wave records obtained from NOAA buoys and ship observations positioned in the fetch areas.

We classified the 1,347 storms in terms of significant wave heights ($H_{1/3}$) and durations; together these data can be used as an estimate of the relative storm power, which we define as $H_{1/3}^2$ times duration. One could develop a more exacting calculation of wave power; however, we generally do not obtain wave period data in our hindcasting.

Table 1. *The Saffir-Simpson Scale for Hurricanes and Halsey's Scale for Northeasters.*

Saffir/Simpson Hurricane Scale

Scale Number (category)	Central Pressure (millibars)	Winds miles/hour (meters/second)	Surge feet (meters)	Damage
1	≤980	74–95 (32–42)	4–5 (1.32)	Minimal
2	965–979	96–110 (42–49)	6–8 (2.13)	Moderate
3	945–964	111–130 (50–57)	9–12 (3.20)	Extensive
4	920–944	131–155 (58–68)	13–18 (4.57)	Extreme
5	>920	>155 (>69)	>18 (>5.49)	Catastrophic

Northeast Storm Scale (Halsey)

Class 1: (up to 1 tide) Beach erosion and dunes sustain some scarping.

Class 2: (up to 2 tides) Besides heavy beach erosion, dunes moderately to significantly scarped; overwash in weak areas, especially down street ends; sections of unprotected boardwalks popped or lifted off; flooding begins.

Class 3: (2 to 3 tides) Serious beach erosion: dunes not only scarped, but some areas flattened by overwash; flooding serious; widespread boardwalk damage.

Class 4: (3 to 4 tides): Erosion reaching to marsh "basement" in some areas; most manmade dunes flattened; significant overwash; fans coalescing; deeper flooding widespread; breaching in natural dunes increasing.

Class 5: (4 to 5 tides) Surge platforms and incipient inlets present; washover sands completely clog low-lying islands and roads, natural dunes heavily eroded.

Classification Procedures

Our storm classification is developed using a two-stage cluster analysis based upon the relative power of each of the 1,347 storms. Attempts at performing this classification using both wave height and duration were unsuccessful, since the overlap between short-lived storms with high wave heights and longer duration storms with lower heights would limit potential applicability. Thus, these two important factors were combined into one classification variable, relative wave power.

The most commonly used clustering methods are hierarchical agglomerative techniques, in which

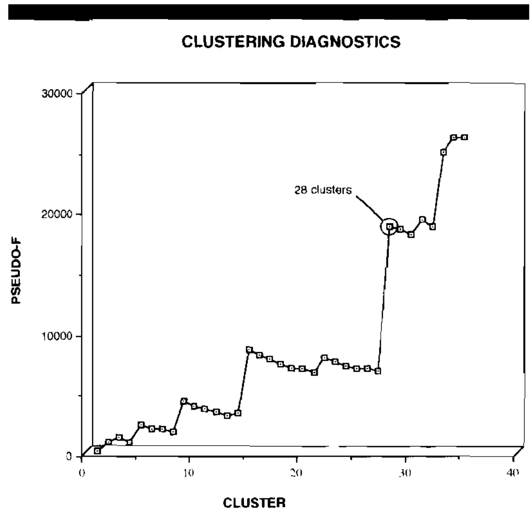

Figure 2. Variation in the pseudo-F statistic (the ratio of between-cluster variance to within-cluster variance) with number of clusters. A 28-cluster solution was selected.

Table 2. *Original 28-cluster solution, including the number of storms in each cluster and the average deep-water significant wave height, duration, and relative power (significant wave height^2 × duration).*

Cluster	No. Storms	Height (ft)	Duration (hrs)	Power (ft^{2}hr)
1	670	7	8	347
2	340	8	18	1,154
3	65	11	31	3,347
4	123	10	26	2,200
5	24	12	37	5,126
6	34	12	34	4,267
7	18	12	45	6,041
8	24	12	59	7,431
9	5	13	66	9,550
10	5	12	58	8,698
11	9	16	55	12,351
12	4	15	65	13,253
13	3	19	50	15,887
14	2	18	68	19,281
15	3	16	96	23,169
16	2	16	77	16,750
17	3	17	38	10,852
18	2	17	59	17,659
19	2	19	64	22,085
20	1	13	131	21,129
21	1	25	62	37,216
22	1	24	64	35,948
23	1	16	55	14,434
24	1	30	44	39,150
25	1	18	150	50,784
26	1	23	89	47,081
27	1	17	95	28,105
28	1	25	170	104,249

individual entities (*i.e.* storms) are grouped in a step-by-step fashion based upon some similarity measure, typically Euclidian distance. Thus, those objects closest together at each clustering step are merged until all observations are combined into one large cluster. Obviously, the researcher must select some optimum number of clusters based upon the cohesiveness of the resulting clusters or other methodological considerations. The goal of any clustering exercise is to identify an optimal grouping of objects in which both the within-cluster similarities and the between-group differences are maximized.

Hierarchical techniques are primarily distinguished by the way in which similarity is computed between clusters containing more than one member. *Single linkage* (SNEATH, 1957), for example, is based on the distance between the nearest observations in each cluster, while in *complete linkage* (LANCE and WILLIAMS, 1967) the similarity statistic is the distance between the most distant observations. Because of these differences, different clustering methods can produce different results when applied to the same data set. Single linkage procedures have a tendency toward "chaining", in which long strands or elongated clusters are detected rather than compact, spherical clusters. Conversely, complete linkage tends to be very sensitive to outliers and subsequently develops clusters with similar diameters (ROMESBURG, 1984; KALKSTEIN *et al.*, 1987).

We used *average linkage* clustering to develop our storm classification. In this method, cluster similarity is the average distance between all pairs of observations between two clusters (SOKAL and MICHENER, 1958; HAWKINS *et al.*, 1982). Average linkage is biased toward producing clusters with small variances and is good at recovering compact, spherical groups. In studies comparing different clustering methods, average linkage has been shown to be superior to most other hierarchical, agglomerative techniques (MILLIGAN, 1980) and has proven useful in climatological analysis (KALKSTEIN *et al.*, 1987). However, average linkage tends to produce a large number of very small clusters.

Using relative wave power as the defining variable, our individual storms are grouped into 28 clusters (Figure 2). A 28-cluster solution is chosen since the merging of clusters at step 27 results in a large drop in the total variance explained, indicating that fairly dissimilar clusters are merged. A 15-cluster solution was also investigated, but

Table 3. *Characteristics of the five storm classes in the Dolan/Davis Scale. Power is defined as the maximum deep-water significant wave height squared times the storm duration. The mean, standard deviation, and sample size are represented by $\bar{x}$, s, and N, respectively.*

	Frequency		Significant Wave Height (m)		Duration (hr)	
Storm Class	N	%	$\bar{x}$	s	$\bar{x}$	s
1 Weak	670	49.7	2.0	0.3	8	4.3
2 Moderate	340	25.2	2.5	0.5	18	7.0
3 Significant	298	22.1	3.3	0.7	34	17
4 Severe	32	2.4	5.0	0.9	63	26
5 Extreme	7	0.1	7.0	1.3	96	47

	Power (m^2hr)			
Storm Class	$\bar{x}$	s	Range (m^2hr)	Range (ft^2hr)
1 Weak	32	20	power ≤ 71.63	power ≤ 771
2 Moderate	107	25	71.63 < power ≤ 163.51	771 ≤ power ≤ 1760
3 Significant	353	178	163.51 < power ≤ 929.03	1,760 < power ≤ 10,000
4 Severe	1,455	378	929.03 < power ≤ 2,322.58	10,000 < power ≤ 25,000
5 Extreme	4,548	2,370	power > 2322.58	power > 25,000

the 28-cluster result produced a better classification.

Of the 28 clusters, 17 contain less than five storms (Table 2). However, the procedure adequately divided the storms possessing weak or moderate power. Obviously, a classification containing 28 groups has little practical utility, and the fine subdivision of the most powerful storms is largely a function of the clustering method selected. Since the primary goals of this research are to produce a storm classification which has both scientific merit and practical value and is analogous to the Saffir-Simpson Scale, we manually grouped the 28 clusters into five classes. Thus, we used average linkage analysis to provide the first filtering of the data and we then organized the clusters into five classes.

The manual classification, though subjective, is based upon the following rationale. Average linkage clusters 1 and 2, with 670 and 340 members, respectively, became Classes I and II (Table 2). Clusters 3 through 10 are combined into Class III based upon an increase in both the mean wave height and duration as compared with Class II. Class IV storms have power values between 10,000–25,000 ft^{2}hr and include clusters 11–20 and 23. These differ from Class III storms largely on the basis of wave height, since the durations of the weaker Class IV storms are similar to some Class IIIs. The top seven storms, with power values greater than 25,000, are grouped into Class V. These extreme northeasters have either unusually long durations, very high wave heights, or both. Though it is likely that another person would have developed five groups with slightly different membership, our classification is justifiable based upon the average linkage output, and the relative frequencies of storms within each of the five classes highlights the rarity of severe and extreme (Class IV and V) northeasters.

DESCRIPTION OF OUR FIVE STORM CLASSES

The wave height, duration, relative wave power, and the transition values of power for each storm

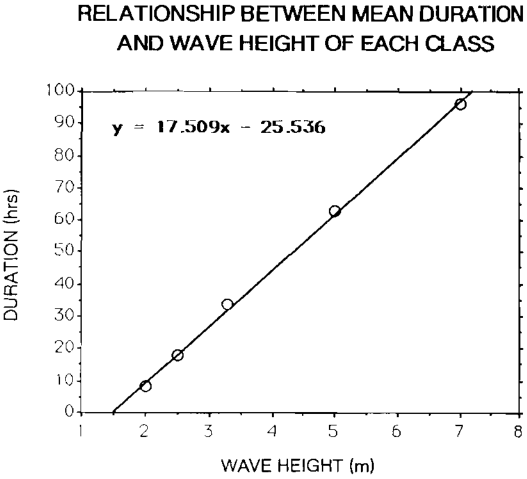

Figure 3. Relationship between the mean duration and the mean significant deep-water wave height of the five storm classes.

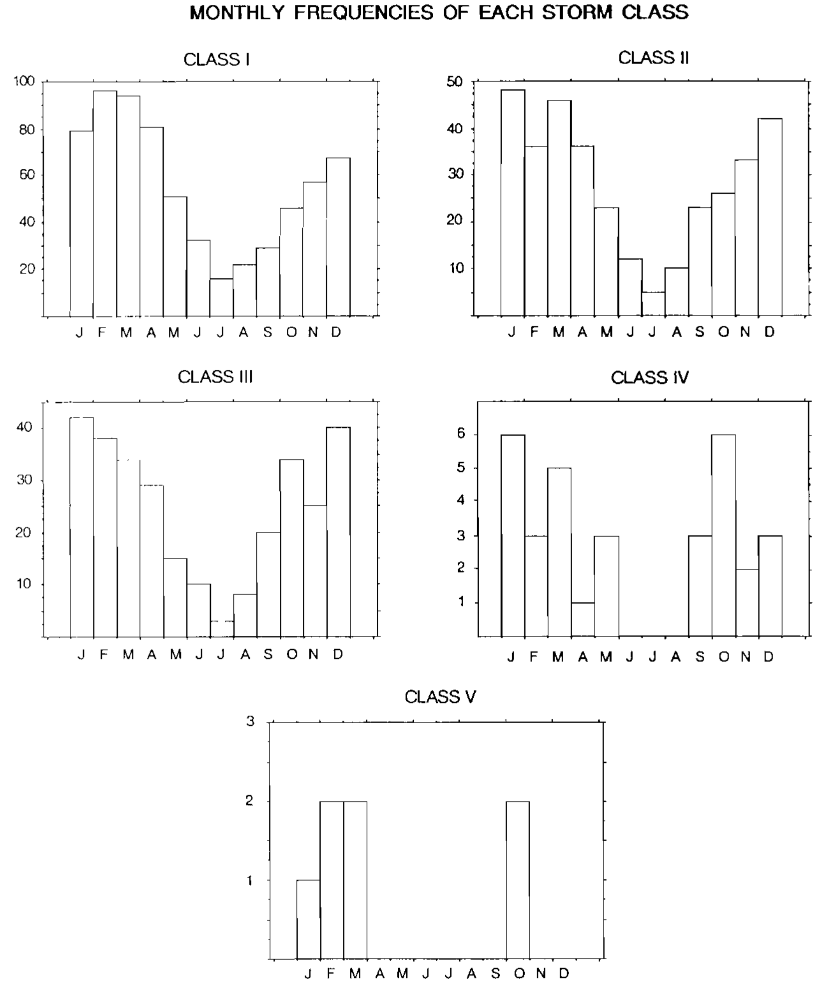

Figure 4. Monthly frequency of each storm class.

class are summarized in Table 3. Class I (weak) storms account for almost 50% of the storms included in our data set. These weak systems generate significant wave heights that average 2.0 m and have an average duration of 8 hours. The storms in our Class II (moderate) category have average significant wave heights of 2.5 m and durations of 18 hours. Class III (significant) storms have an average significant wave height of 3.3 m and an average duration of 34 hours. Class III storms and higher can cause extensive damage to coastal structures and serious beach erosion. Of the remaining 2.4% are Class IV, or severe northeasters. These storms have longer durations, averaging 63 hours, and generate average significant wave heights of 5 m. The average duration of the Class IV storms also insures that their high waves will bracket several tidal cycles. Finally, our Class V storms, or extreme northeasters, are very powerful and rare. Over the 42-year period of data used in this study, only 7 of the storms reached Class V intensity. Their deep-water significant wave height averaged 7.0 m and their average duration is 96 hours.

Figure 3, a scatter plot of our mean hindcasted wave height data and mean storm durations, confirms the expected strong relationship between the hindcasted significant mean wave heights, ex-

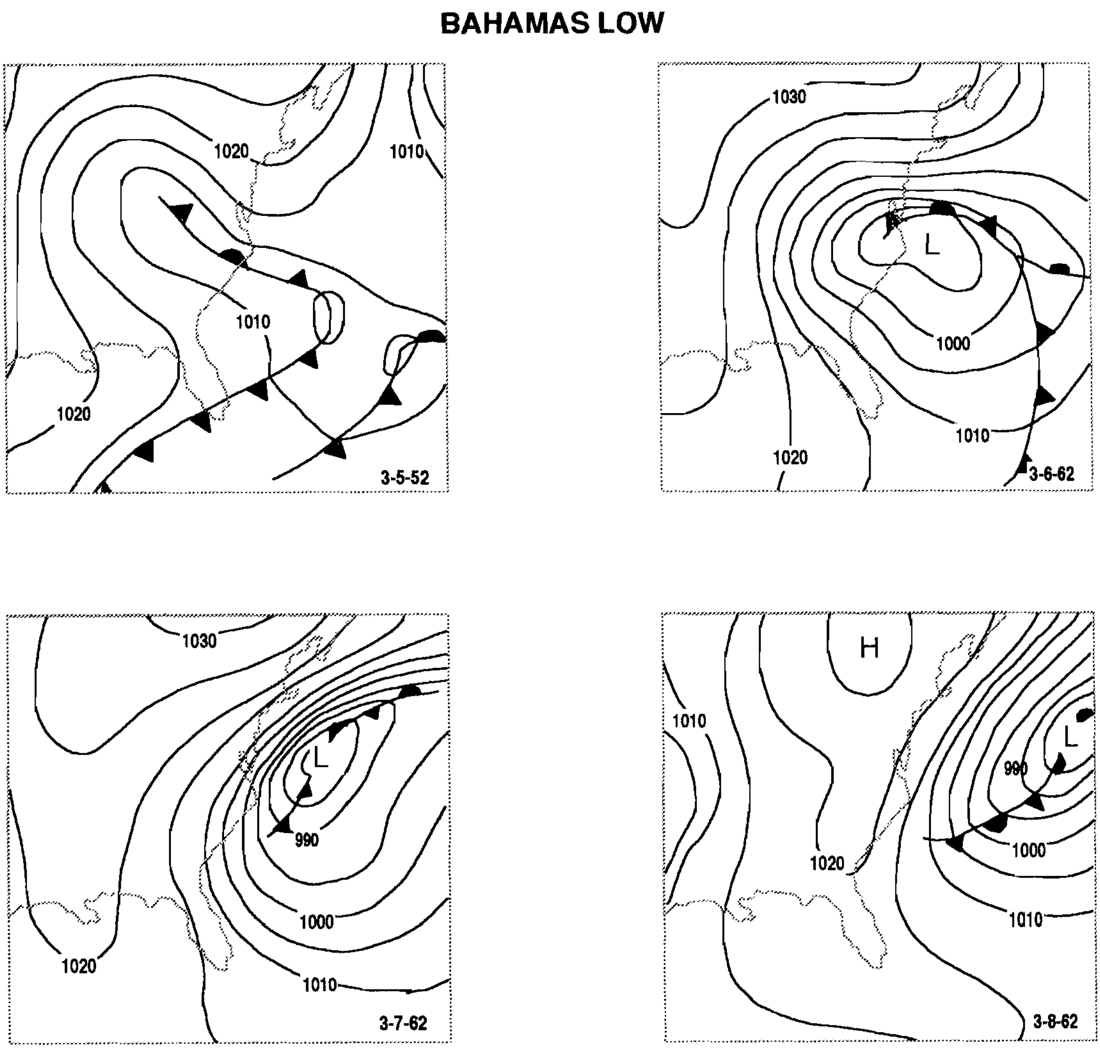

Figure 5. An example of a strong northeaster that forms near the Bahamas (a "Bahamas Low"). The northward progression of the cyclone is blocked by an anticyclone over the northeastern United States, and a tight pressure gradient develops between the center of the cyclone and the anticyclone over land. The surface isobar interval is 5 millibars.

pressed in terms of statistical aggregates (classes) and the durations of the storms for each of the five wave classes.

Seasonality

Monthly storm frequencies clearly indicate that a maximum number of extratropical storms occur between December and April and the fewest occur between June and August (Figure 4). This is consistent with the seasonal migration of the polar front, the feature associated with mid-latitude cyclone formation and tracking. The seasonality of the Class I, II, and III storms spans most of these months; however, Class IV storms occur mostly in October and January (6 storms each) with a secondary maximum in March (5 cases). Of the seven Class V storms, five occurred during the months January, February, and March and the remaining two formed in October. Of the stronger coastal storms (Classes IV and V), one common type ("Bahamas Low") forms north of Cuba, tracks slowly northward, and intensifies over the open ocean (Figure 5). This storm track is related to a maximum in cyclone frequencies near the Bahamas in October (KLEIN, 1957). A second track commonly associated with strong northeasters ("Florida Low") develops near the Florida peninsula and travels north-northeast (Figure 6). These systems are common in March, coincident with an early spring extratropical cyclone maximum (KLEIN, 1957). We have discussed the relationship between storm tracks and intensities more completely in DAVIS *et al.* (1992).

LONG TERM TRENDS IN STORM FREQUENCY

Secular variations in North American cyclone frequencies have been analyzed in some detail (REITAN, 1979; ZISHKA and SMITH, 1980). Specifically with regard to coastal storms, HAYDEN (1981) noted a minimum in coastal storms through the late 1920's, with a steady increase and a concurrent decrease in continental cyclones through the early 1960's and a subsequent decrease in maritime cyclones into the early 1970's. Although our data set begins in 1942, it includes an additional 5 years not available to Hayden. The five-year moving average of annual Class I storm frequencies (Figure 7) mirrors the decline in the number of coastal storms from the early 1960's to the early 1970's; however, an increase is clearly evident over the last decade. This correlation is anticipated, since Class I northeasters account for 50% of all coastal storms. Class II storms exhibit a similar overall trend but are more variable from year to year, while Class III northeasters became somewhat more prevalent in the 1960's than over the previous 15 years. The Class IV and V storm data must be viewed with caution owing to the small number of storms, but it is clear that a maximum occurred in the late 1960's and early 1970's. From 1963 through 1973, at least one Class IV storm occurred in the Atlantic each year (except for 1966), and two Class IV northeasters occurred in 1970, 1971, and 1972. This is supported by HAYDEN (1975) who demonstrated an increase in the number of storms which produced at least 3.5 m deep-water waves from 1965–1974. Of the seven Class V storms, six occurred since 1960 (Table 4).

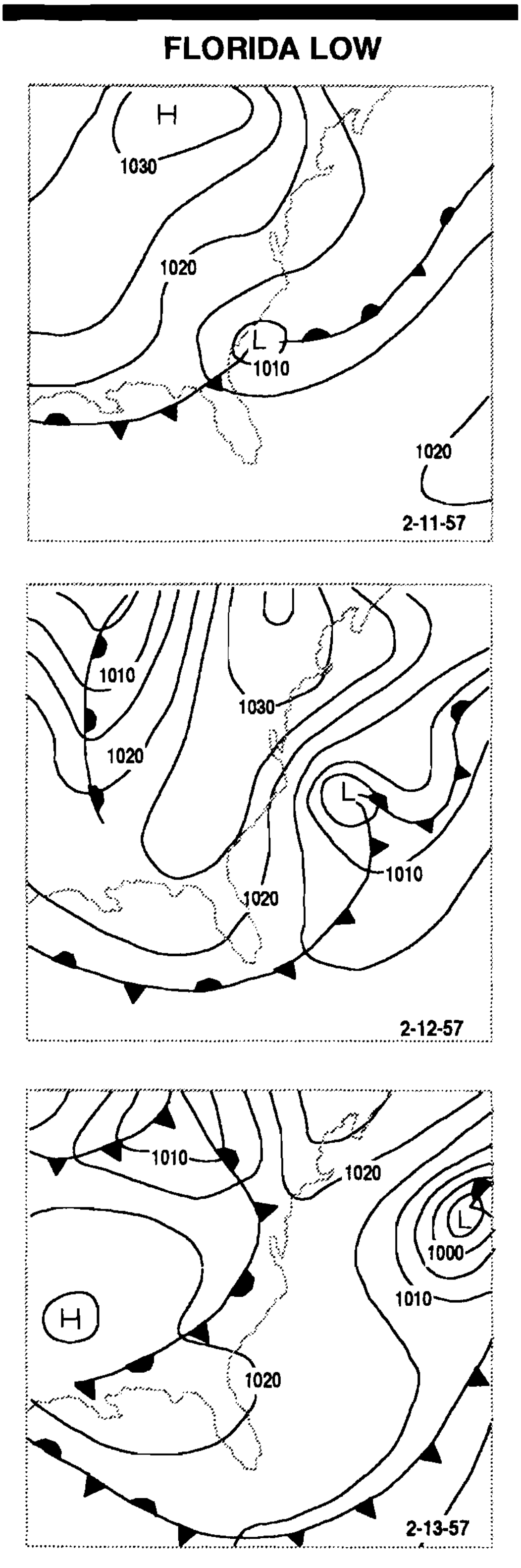

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Figure 6. An example of a strong northeaster that forms over the Florida peninsula (a "Florida Low"). The surface isobar interval is 5 millibars.

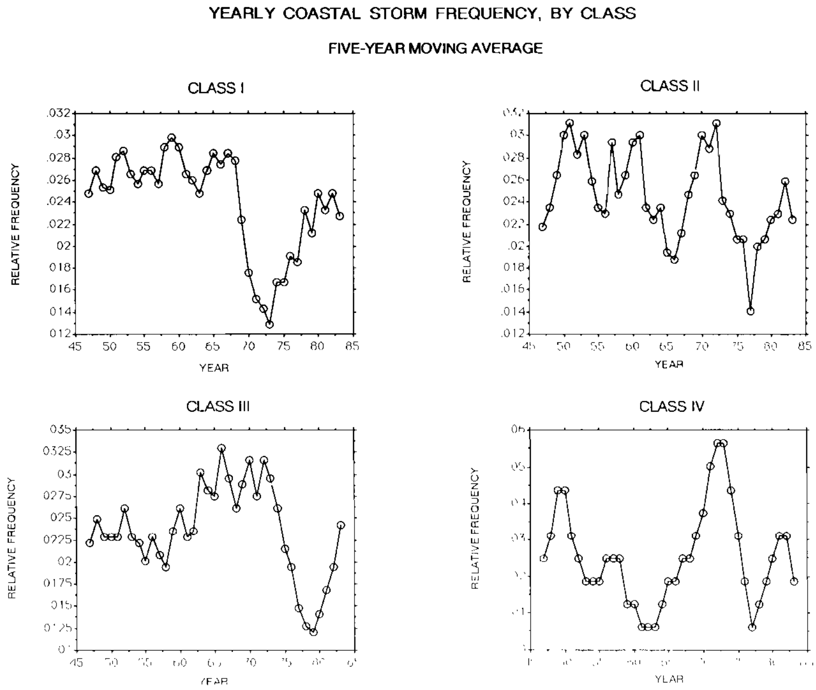

Figure 7. Five-year moving average of the yearly relative frequency for each storm class. Each point plotted is the middle year in the five-year period. Class V storms are not included, since there were only seven storms in this category (in 1951, 1960, 1962, 1969, 1973, 1980, and 1982).

RETURN INTERVALS FOR NORTHEASTERS

We plotted the relative wave power index of each storm versus frequency to develop return intervals for each class (Figure 8). The relationship is linear on a log-log plot and robust (r^2 = 0.86). The average return interval for a storm of Class I is about 3 days, while a strong Class I or a weak Class II storm occurs about once every 12 days. Class II northeasters occur about once per month on the average, while Class III storms have a return interval of one every nine months. The average for our Class IV storms is once every 11.3 years and the return interval for our average Class V northeaster is over 100 years. However, of the 7 storms identified in Class V, six had relative power values below the mean. One storm, in 1969, with a particularly long duration resulted in an extreme power index. Excluding this storm, the average return period for Class V storms is 67 years.

Table 4. *Top 10 Storms (mid-Atlantic) based on the hindcast of significant wave heights.*

Storm Rank	Date	Power Index (m^2 hr)	Peak Wind (kts) [m/s]	Wave Height (m)	Duration (hrs)
1	2/16/69	9,690	35 [18]	7.6	170
2	10/14/51	4,720	32 [16]	5.6	150
3	2/9/73	4,376	40 [20]	7.0	89
4	3/7/62	3,639	40 [20]	9.1	44
5	3/1/80	3,459	40 [20]	7.5	62
6	10/22/82	3,341	37 [19]	7.2	64
7	1/30/60	2,612	33 [17]	5.2	95
8	10/26/70	2,176	29 [15]	5.2	81
9	5/25/72	2,150	30 [15]	5.2	81
10	10/28/69	2,134	28 [10]	4.1	126

APPLICABILITY OF CLASSIFICATION TO OTHER REGIONS

Although our classification of northeasters is specific to Cape Hatteras, we feel that the criteria used to classify each storm into one of five classes is universally applicable. In an attempt to examine the representativeness of the Cape Hatteras site, significant wave heights from a subsample of Class IV and V storms from 1956–1975 were compiled from the Atlantic Coast Wave Information Study (ACWIS) monthly wave records (CORSON *et al.*, 1982). Since the ACWIS data set has only monthly temporal resolution, for months in which a Class IV or Class V Atlantic northeaster occurred, surface weather maps were consulted to determine if any other major storms occurred during the same month and the coastal regions those storms might have impacted. For those months in which it was clear that only one major northeaster occurred, the maximum significant wave heights from the ACWIS data could be attributed to that particular storm event. Results based on 20 storms show that the highest average significant wave heights occurred at Cape Hatteras and Cape Cod, probably because these sites are not sheltered from waves created by storms with differing tracks (Figure 9). Wave heights from these storms are similar from northern Georgia to Cape Cod, except for some minor variations at more sheltered coastal sites.

Thus, at least with regard to major northeasters, there are not substantial variations in significant wave heights along the mid-Atlantic coast. However, the cut-off power values for our five classes were selected specifically for Cape Hatteras. Therefore, one would expect the distribution of storms in each class to vary along the coast. For example, while Class I and Class II storms account for 75% of all northeasters at Cape Hatteras, this frequency may increase at Cape Cod where small and rapidly moving cyclones that travel through New England may create high enough waves to merit classification. The spatial variation in the frequency and magnitude of northeasters along the Atlantic seaboard is a topic that requires additional research.

STORM CLASSES VERSUS COASTAL DAMAGE

Table 5 summarizes our preliminary assessment of the relationship between the wave and the storm surge heights associated with each of our storm classes and the expected coastal response (erosion, overwash, and damage). Naturally, the impact of a given northeaster depends considerably on the coastal area involved. Areas with low relief, for example, overwash frequently, and other areas may have high erosion rates due to factors other than storm frequency. Table 5 was developed based on our own experiences along the mid-Atlantic. We are currently working to

Table 5. *Storm Classes and Coastal Impacts*

Storm Class	Beach Erosion	Beach Recovery	Dune Erosion	Dune Breaching	Overwash	Inlet Formation	Property Damage
Class 1 (weak)	Minor changes	Full and usually immediate	None	No	No	No	No
Class 2 (moderate)	Modest: confined to lower beach	Full	None	No	No	No	Minor, local
Class 3 (significant)	Erosion: extends across entire beach	Usually recovery over considerable period of time (months)	Can be significant	No	On low profile	No	Loss of many structures at local scale
Class 4 (severe)	Severe beach erosion and recession	Recovery seldom total	Severe dune erosion or destruction	Where beach is narrow	On low profile beaches	Occasionally	Losses of structures at community level
Class 5 (extreme)	Extreme beach erosion (up to 50 m in places)	Permanent and clearly noticeable changes	Dunes destroyed over extensive areas	Widespread	Massive in sheets and channels	Common	Extensive regional scale: millions of dollars

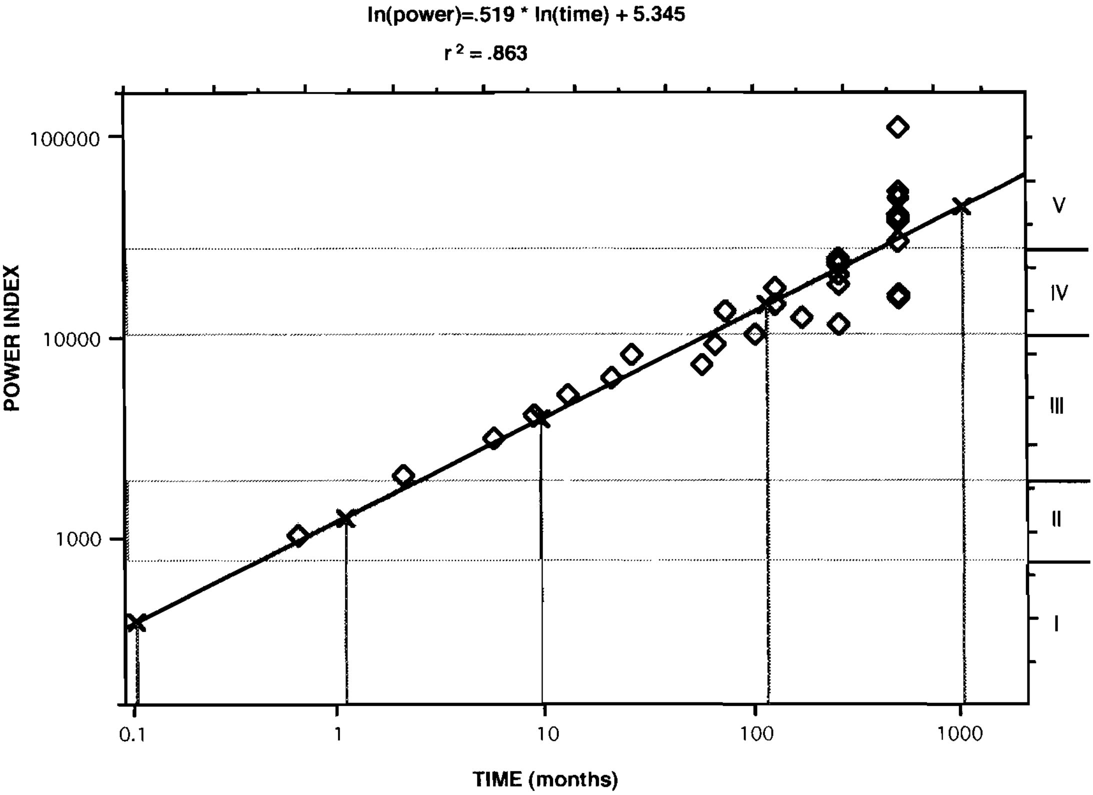

Figure 8. The return interval of Atlantic northeasters as a function of the relative storm "power."

confirm these relationships. The best records are available for the larger Class IV and V storms from the Corps of Engineers storm damage assessments.

The Ash Wednesday Storm of 1962 is clearly the best example of a Class V northeaster. This storm resulted in dozens of new tidal inlets, extensive overwash, extreme beach and dune erosion, and the loss of approximately $300 million in property (Figure 1). HALSEY (1986) stresses in her storm damage classification that a storm's coincidence within the annual and monthly tidal cycles can be critical with respect to its potential damage index. The Ash Wednesday Storm occurred during the perigean spring tides and its duration spanned five semi-diurnal tidal cycles. When this combination occurs, wave attenuation in the shear-zone is significantly reduced during the highest tides, and the potential damage increases accordingly. In terms of damage potential, therefore, a northeaster with Class IV atmospheric and oceanographic attributes can result in impact equal to that of a Class V storm.

PREDICTABILITY OF SEVERE AND EXTREME NORTHEASTERS

Forecasting severe northeasters is as difficult as predicting hurricanes; however, the development of Class IV and V storms has some commonalties. Severe winter storms occur mostly during the months of January, February, and March, and almost all of the Class IV and V storms form in one of two specific areas of cyclogenesis, in the subtropics between Florida and Cuba (Figures 5 and 6). They typically are blocked to the north by a strong high pressure system, thus slowing their northward progress and producing the opportunity for development of a long fetch over the open ocean as well as long durations (DAVIS *et al.*, 1992). Through application of this kind of information, it is possible to identify time periods when strong northeasters are most likely, perhaps with-

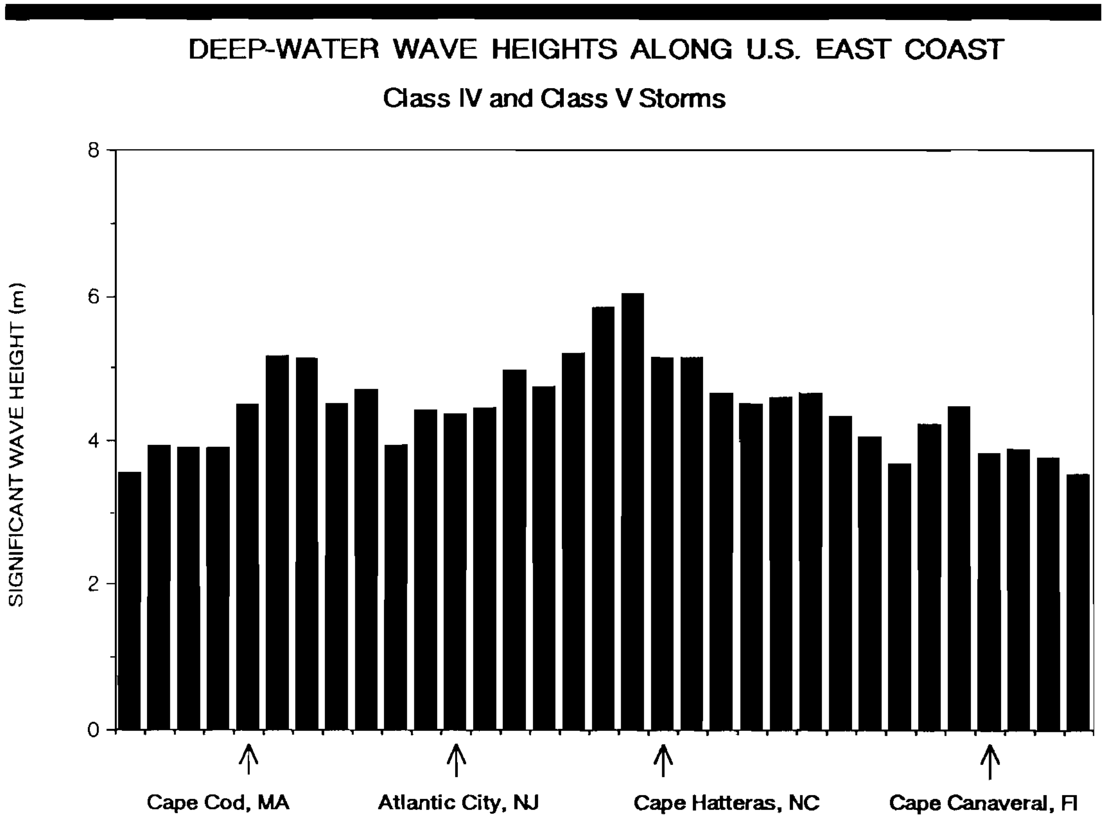

Figure 9. Average significant deep-water wave heights for Class IV and Class V storms along the eastern coast of the United States. These data are compiled from the ACWIS (Phase II) wave data set (CORSON *et al.*, 1982) for coastal storms from 1956–1975.

in a Bayesian statistical framework. In addition, numerical weather forecast models currently predict the location and intensity of storms with some accuracy up to five days in advance. Thus, a coastal storm watch/warning system could be developed based upon these forecasts and other climatological information, but the lack of permanent and reliable weather observations over the Atlantic produces significant errors in model forecasts of coastal storms.

CONCLUSIONS

We believe this new storm classification has practical value. Based on regular wave height observations, it is simple to compute the relative power of a given storm system simply by keeping track of the number of hours with waves above 5 ft (1.5 m). To some degree, the categorization of a storm can take place on a real-time basis, similar to the Saffir-Simpson hurricane intensity scale. This information would be useful to coastal residents and emergency managers, who would benefit from some lead time before severe or extreme northeasters approach.

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□ RÉSUMÉ □

On propose pour la côte Atlantique moyenne, une nouvelle classification des tempêtes extratropicales ou Northeasters (NE). La classification est analogue à celle des cyclones tropicaux de Saffir-Simpson. Basée sur le spectre de houle du Cap Hatteras (Caroline du Nord), on a groupé en cinq classes, 1,347 tempêtes sur une période de 42 ans. La classification est représentée par un indice d'"énergie" de la tempête, fonction de la durée et du carré de la hauteur de la houle significative maximale. Par analyse de groupement, les classes suivantes ont été définies: Classe 1: faible (énergie $e < 771$ ft^2 h), Classe 2: modérée ($771 < e < 1760$), Classe 3: significative ($1,760 < e < 10,000$), Classe 4: vigoureuse ($10,000 < e < 25,000$) et Classe 4: extrême ($e > 25,000$ ft^2 h). Les réponses sur le littoral aux houles moyennes et aux tempêtes (lessivage, érosion, formation de goulets) se classent entre mineures pour la classe 1 jusqu'à extrêmes pour la classe 5. Cette classification est un outil commode pour comparer la force relative des tempêtes et peut avoir quelques applications en temps réel pour en estimer le pouvoir destructeur.—*Catherine Bousquet-Bressolier, Géomorphologie E.P.H.E., Montrouge, France.*

□ ZUSAMMENFASSUNG □

Für die zentrale Atlantikküste der USA wird eine neue Klassifikation außertropischer Stürme, der sog. Northeasters, entwickelt. Sie entspricht der gebräuchlichen Saffir-Simpson-Skala für tropische Zyklonen. Basierend auf der Auswertung entsprechender Aufzeichnungen von Cape Hatteras, North Carolina, wurden 1,347 Stürme eines Zeitraums von 42 Jahren fünf Klassen zugeordnet. Als Kriterium für die Zuordnung gilt der Sturmstärkenindex (= SI), definiert als Produkt aus der Dauer des Sturms und dem Quadrat der maximalen signifikanten Wellenhöhe. Mit Hilfe einer Clusteranalyse wurden folgende Klassen festgelegt: Klasse I (gering, $SI \leqq 771$ ft^2 h), Klasse II (mäßig, $771 < SI \leqq 1,760$ ft^2 h), Klasse III (bedeutend, $1760 < SI < 10,000$ ft^2 h), Klasse IV (stark, $10,000 < SI \leqq 25,000$ ft^2 h) und Klasse V (extrem, $SI < 25,000$ ft^2 h).

Die jeweiligen Auswirkungen der durchschnittlichen Wellen und Sturmfluten dieser einzelnen Klassen auf die Küste (z.B. durch Überflutung, Erosion und Bildung von Seegats) reichen von 'gering' in Klasse I bis 'extrem' in Klasse V. Diese Klassifikation eignet sich zum Vergleich der Stärke von Küstenstürmen. Ein potentielles Anwendungsgebiet stellt die Einschätzung der zerstörerischen Kraft eines Sturmes dar.—*Jürgen Wunderlich, Department of Geography, University of Marburg, Germany.*

□ RESUMEN □

Se ha desarrollado para la costa Atlántica media una nueva clasificación de tormentas extratropicales. La clasificación es análoga a la Escala de Saffir-Simpson comunmente utilizada para ciclones tropicales. Se basa en los cálculos de olas para Cabo Hatteras, Carolina del Norte, de 1,347 tormentas ocurridas durante un período de 42 años y que fueron agrupadas en cinco clases. Esta clasificación variable es un índice de la "potencia" de la tormenta, siendo igual al tiempo de duración de la tormenta por el cuadrado de la máxima altura significativa de la ola. Basándose en un análisis de grupo, se obtuvieron las siguientes clases de tormentas: Clase I (débil, potencia $\leqq$ 771 ft^2 hr), Clase II (moderada, 771 $<$ potencia $\leqq$ 1,760), Clase III (significativa, 1,760 $<$ potencia $\leqq$ 10,000), Clase IV (severa, 10,000 $<$ potencia $\leqq$ 25,000), y Clase V (extrema, potencia $>$ 25,000).

La costa respondió a las olas y a las ondas de tormenta promedio en cada una de las clases, desde las menores (Clase I) a las extremas (Clase V). Estas clasificaciones son un medio útil para comparar la fuerza relativa de las tormentas costeras y pueden poseer algunas aplicaciones potenciales al establecer en tiempo real la potencia destructiva de una onda de tormenta.—*Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.*