NEARSHORE WAVE SPECTRA MEASURED DURING HURRICANE DAVID

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ABSTRACT

This paper presents the results of an analysis carried out on wave spectra measured at three nearshore sites along the United States Florida coast when Hurricane DAVID passed these sites in 1979. Included are (a) the variability of the shapes of wave spectra during the stages of growth and decay of the hurricane-generated seas, (b) the presentation of spectra according to various spectral formulations, and (c) a comparison between spectra measured at the coastal sites and those measured in deep water for the same severity (significant wave height) of hurricane-generated seas.

INTRODUCTION

For the design of onshore, nearshore, and coastal structures, it is highly desirable and, from a safety viewpoint, extremely important to have a precise description of nearshore sea severity. In particular, for structures along coasts, wave data measured during hurricanes provide a vital source of information for establishing design criteria.

Although many observations and measurements have been made on wind-generated waves associated with hurricanes over deep water, we have as yet little information as to hurricane-generated sea severity in coastal waters.

This paper presents the results of analysis carried out on wave spectra measured at three locations in shallow water when a hurricane passed through these sites. That is, on September 3rd, 1979, Hurricane DAVID approached the Florida east coast from the eastern Carribbean with a moving speed of about 10 knots. During this period, wave recorders installed by the University of Florida at Miami Beach, West Palm Beach, and Vero Beach successfully recorded the waves throughout the duration of the storm at each site.

In order to obtain an accurate representation of wave spectra associated with sea conditions arising from hurricanes, the variability of the shapes of wave spectra during the stages of growth and decay of

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Hurricane DAVID is examined. The wave spectra are represented by various mathematical formulations to provide information for further analysis of coastal waves. Furthermore, comparisons are made between the shapes of wave spectra obtained at the coastal sites and those obtained in deep water for the same severity (significant wave height) of hurricane-generated seas.

WAVE DATA DURING HURRICANE DAVID

Hurricane DAVID (August 26 - September 6, 1979) approached the east coast of Florida from the Carribbean, and its eye passed over several Florida coastal cities as shown in Figure 1. During this period of moving almost due north at about 10 knots (5.1 m/sec), the hurricane moved inland just north of Palm Beach, then later it again

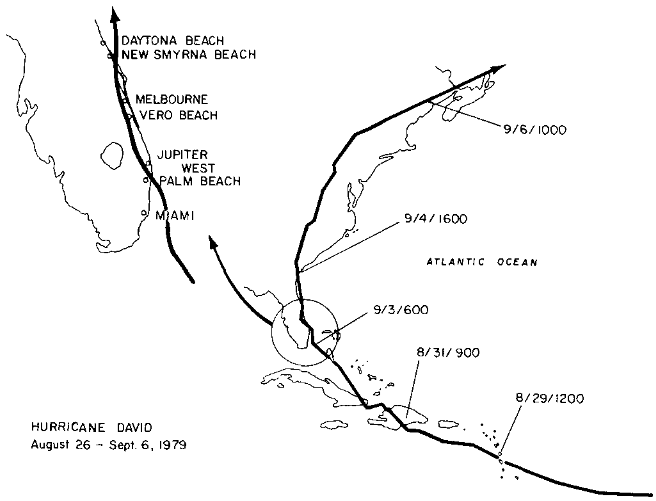


Figure 1 Hurricane DAVID track

moved offshore. The eye diameter was 20 to 30 nautical miles (37 to 56 km) while it was passing over the Florida area, and the highest winds experienced were gusts up to 75 knots (39 m/sec).

The data used in this study were recorded from three measurement sites which are chosen at nearly equally spaced intervals along the Florida east coast. These sites are located at Miami Beach, West Palm Beach and Vero Beach respectively, and are about one kilometer offshore. They are part of the Florida Coastal Data Network system (Howell 1980) which collects long-term diary wave data as well as storm wave data.

The geographic features of these sites and the measured maximum significant wave heights are tabulated in Table 1.

Table 1 Geographic features and measured maximum significant wave heights at three sites

SITE	MIAMI BEACH	WEST PALM BEACH	VERO BEACH
GEOGRAPHIC LOCATION	25°46'06"N 80°07'23"W	26°42'07" 80°01'42"	27°40'20" 80°21'07"
DISTANCE FROM SHORE (km)	0.91	0.61	0.90
WATER DEPTH (m)	6.1	8.5	7.6
SHORTEST DISTANCE TO HURRICANE EYE (km)	70.5	25.0	14.1
MAX. SIG. WAVE HEIGHT (m)	2.65	5.10	3.51

Pressure transducers located about one-half meter above the seabed were used to take data. They were bottom mounted on a completely self-contained electronic cylinder which contains a microcomputer controlled data acquisition system. From surface pressure signals, the pressure energy spectra were computed, and then converted to surface wave spectra by assuming the pressure-wave profile-relation to be linear.

RESULTS OF ANALYSIS

Significant wave height, denoted by H_s, was evaluated from the measured spectra by using the formulation given by $H_s = 4\sqrt{m_0}$, where m_0 is the area under the spectrum. The temporal variation of significant wave height and radial distance from the hurricane center measured at sites are shown in Figures 2(a) through 2(c). It can be seen in these figures that the significant wave height decreases rapidly in the decaying stage in comparison with the increase of its intensity in the growing stage.

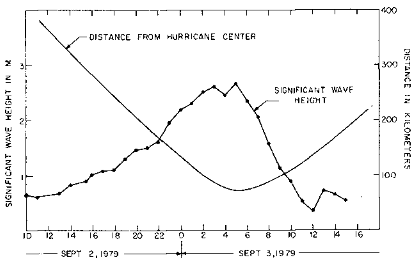


Figure 2 Temporal variations of significant wave height and radial distance (a) Miami Beach

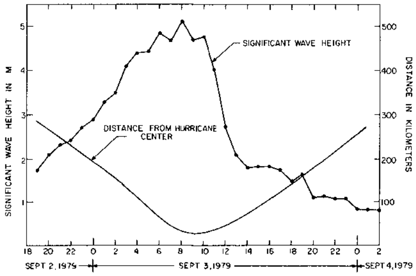
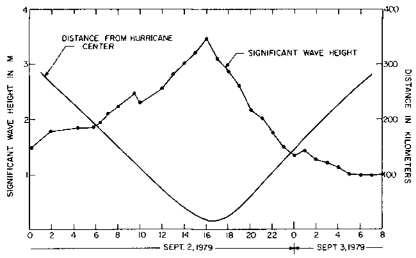


Figure 2 Temporal variations of significant wave height and radial distance
(b) West Palm Beach



(c) Vero Beach

In order to present the overall picture of the growth and decay status of hurricane-generated seas, contour lines of spectral energy densities are constructed from the entire series of spectra, and are shown in Figures 3(a) through 3(c). Each contour in the figure represents spectral density of a certain level (2.0 m^2-sec, 4.0 m^2-sec, etc.) and the inner portions of the enclosed contours correspond to higher spectral densities. The highest spectral density at the innermost portion of the contour lines corresponds to the severest sea state in which the highest significant wave height was obtained.

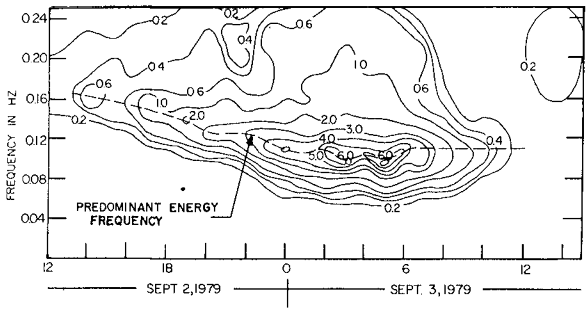
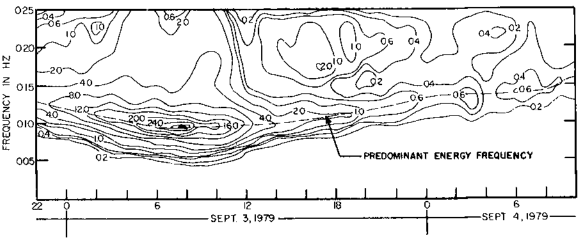
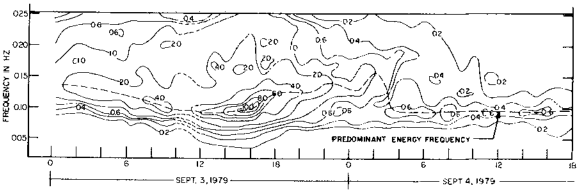


Figure 3 Contours of spectral densities constructed from wave spectra (a) Miami Beach



(b) West Palm Beach



(c) Vero Beach

Figure 3 Contours of spectral densities constructed from wave spectra

The severest sea states at the three sites occurred at 5 am, 8 am, and 4 pm, September 3rd, respectively, and the corresponding spectra had approximately the same peak frequency, 0.094 Hz.

It is of interest to compare the shapes of wave spectra obtained in seas of approximately the same significant wave height but under different conditions; one in the growing stage, the other in the decaying stage of the hurricane. As an example, Figure 4(a) shows a comparison of spectra measured at West Palm Beach in a mild sea state of significant wave height of 2.07 m. As can be seen in the figure, the frequency where the spectrum peaks (modal frequency) in the decaying stage is lower than that in the growing stage. This trend holds throughout the storm as can be seen in Figures 4(b) and 4(c). The same trend was also observed for spectra measured in Miami Beach. However, this general trend is reversed when the hurricane passes inland or shoreward of the point of measurements. As Hurricane DAVID

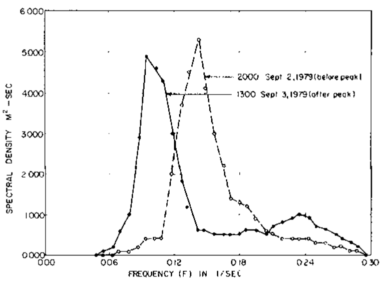


Figure 4 Comparison of wave spectra obtained in the growing and decaying stages of the hurricane, West Palm Beach
(a) Significant height 2.07 m

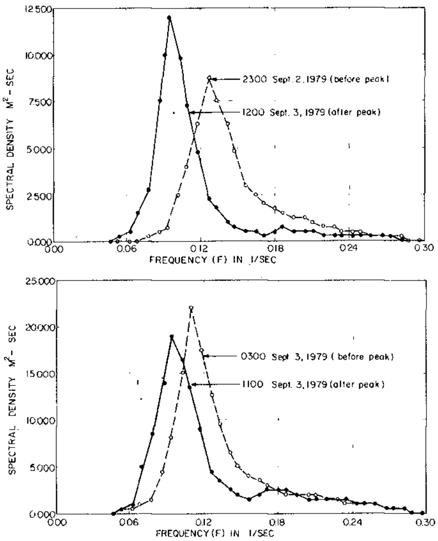


Figure 4 Comparison of wave spectra obtained in the growing and decaying stages of the hurricane, West Palm Beach
(b) Significant height 2.72 m

(c) Significant height 3.99 m

passed Miami Beach and West Palm Beach, its path was offshore. After it passed West Palm Beach, it moved inland, then later moved offshore again. The hurricane's path was inland throughout the period when severe seas were observed at Vero Beach. This may account for the modal frequency in the growing stage being lower than that in the decaying stage for the Vero Beach data as shown in the example in Figure 5.

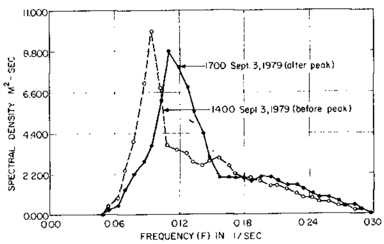


Figure 5 Comparison of wave spectra obtained in the growing and decaying stages of the hurricane, Vero Beach, Significant height 3.08 m

The measured spectra are fitted by various spectral formulations to see how well hurricane-generated nearshore wave spectra can be represented by currently available formulations which have been developed for seas in deep water. These include the one-parameter (Pierson-Moskowitz 1964), and the two-parameter (Bretschneider 1959), three and six-parameter (Ochi and Hubble 1976), and JONSWAP (Hasselmann et al. 1959) spectral formulations. The JONSWAP spectrum used in the comparison is not the mean JONSWAP spectrum; instead it is obtained

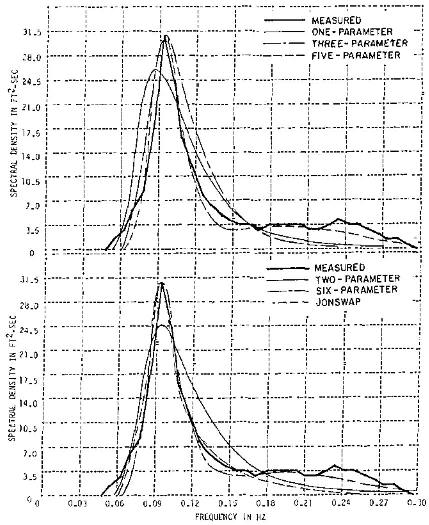


Figure 6 Comparison between measured and mathematical spectra. West Palm Beach, significant height 5.1 m.

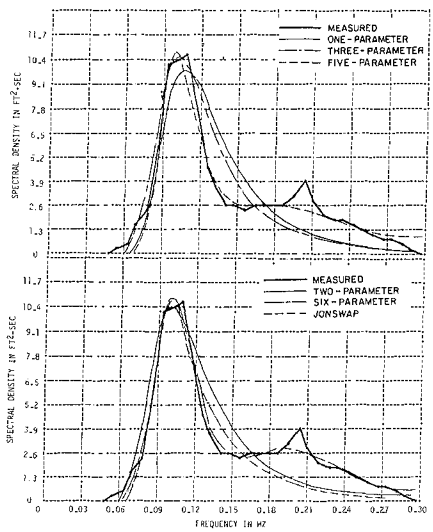


Figure 7 Comparison between measured and mathematical spectra. Vero Beach, significant height 3.5 m

by fitting the measured spectrum through least-square fitting techniques. Included also in the comparison is the five-parameter spectrum which is a combination of a three-parameter formulation representing the lower-frequency range of the spectrum and a two parameter formulation representing the higher frequencies.

The results of the comparison between measured and mathematical spectra show that the five and six-parameter spectra appear to best represent the measured spectra in shallow water areas throughout the various stages of the hurricane. Also, the JONSWAP spectral formulation yields a good fit to the shape of the measured spectra, in general, with the exception of those with a secondary peak or an extended plateau in the high-frequency region. As an example, Figures 6 and 7 show a comparison made for the severest sea state observed at West Palm Beach and Vero Beach, respectively, during the hurricane.

The shapes of hurricane-generated wave spectra obtained at the coastal sites and those obtained during hurricanes in deep water are compared. If the shapes of deep and shallow water hurricane-generated wave spectra are alike under certain conditions, then the results of analysis made on the shapes of deep-water hurricane spectra may be used for those of shallow water. In the comparison of Hurricane DAVID (shallow water) wave spectra with spectra measured in deep water, the results obtained during Hurricane ELOISE in the Gulf of Mexico (Withee and Johnson, 1977) are used, and comparisons are made between spectra having the same significant wave height and the same modal frequency.

As an example, Figure 8(a) shows a comparison between deep and shallow water (8.5 m water depth) wave spectra of significant wave height of 4.8 m with the same modal frequency of 0.098 Hz. Other examples of comparison made in less severe sea states are shown in Figures 8(b) and (c). Although the shapes of hurricane-generated wave spectra measured in deep and shallow water of 7-10 m water depth are significantly different in mild sea conditions (significant wave heights less than 2 meters), the shapes of spectra with the same significant wave height and the same modal frequency appear to be very similar in relatively severe seas as shown in Figure 8.

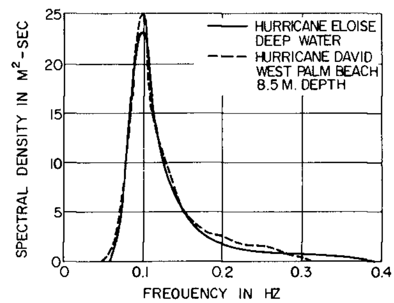
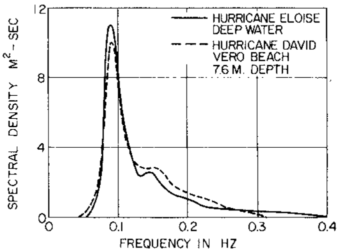
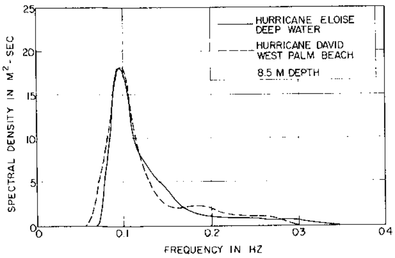


Figure 8 Comparison of hurricane wave spectra measured in coastal and deep waters.
(a) Significant height 4.8 m



(b) Significant height 3.D m



(c) Significant height 3.9 m

CDNCLUSIONS

This paper presents the results of analysis carried out on wave spectra measured at three nearshore sites along the United States Florida coast when Hurricane DAVID passed through these sites. It is found from the results of the analysis that the peak frequencies of the spectra in the decaying stage of the hurricane-generated coastal waves are, in general, lower than those in the growing stage. This implies that the wave energy in longer wave lengths is dominant in the decaying stage.

The shapes of the measured wave spectra can best be represented by the five and six-parameter spectral formulations throughout various stages of the hurricane. The JONSWAP spectral formulation also yields a good fit to the shapes of the measured spectra, in general, with the exception of those with a secondary peak or an extended plateau in the high-frequency region.

The shapes of the hurricane-generated wave spectra with the same significant wave height and the same modal frequency obtained in coastal and deep water are very similar in relatively severe seas.

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