CHAPTER 33

RESULTS OF OCEAN WAVE-CONTINENTAL SHELF INTERACTION[1]

by

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Abstract

Extensive wave refraction computations and analyses have been made utilizing eleven depth grids on the inner continental shelf along the east coast of the United States. The most important process determining shelf and shoreline wave energy distribution is the interaction of the ocean surface waves with the numerous shelf relief elements. This ocean wave-continental shelf interaction results in a non-uniform wave energy distribution that varies widely with different wave input conditions such as wave approach direction, wave length, and tide level. Techniques are being developed to manipulate and analyze these extensive wave data (encompassing over 500 wave refraction diagrams and associated computations), in order to increase understanding of the complex wave behavior resulting from the ocean wave-continental shelf interaction.

INTRODUCTION

Along the east coast of the United States where the wide, shallow and high relief continental shelf (5) interacts with ocean waves as far as 60 nautical miles from shore, the shoreline wave energy distribution becomes highly irregular and complex. Eleven regional and localized wave refraction computational studies have been made on this shelf and along the shoreline encompassing depth grids with a total of a quarter-million depths and 50,000 wave orthogonals (Figure 1 and Table 1). Along each of these orthogonals 17 different wave parameters were calculated and the values printed out at intervals of approximately 0.5 to 1.0 miles as the waves progress landward from deep water. Computational procedures for these studies have been previously described (3).

Examples of four of the 124 wave refraction diagrams computed for the First Order Virginian Sea Wave Climate Model (7) are presented in Figures 2 through 5, which typify the results obtained for widely varied deep water wave conditions. Attention is focussed upon the variation between low and high tide conditions (Figures 2 and 3) of wave ray

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convergences and divergences (i.e. wave energy concentration and diminution, respectively) along the shoreline, especially at the major resort city of Virginia Beach (located approximately at x = 120). Also of considerable significance are the variations that occur with different wave approach directions (AZ) and wave periods (T) as shown in Figures 3 through 5.

In order to gain a greater understanding of this complex wave behavior, shoreline histograms were constructed of wave energy, wave height (Figure 6), power gradient and shelf contour maps of wave energy, wave height (Figure 7), and maximum values of wave-induced bottom velocities.

Finally, the shoreline wave ray histograms are being subjected to spectral analysis (Figure 8) in an attempt to determine whether the apparent periodicity of wave energy concentrations has a firm statistical basis.

RESULTS AND DISCUSSION

Effects of Shelf Geomorphology

The regional studies of the shelf wave refraction and shoaling effects from Saco Bay, Maine to Cape Hatteras, North Carolina (3,4) indicate a spatial periodicity in shoreline wave energy distribution. This shoreline periodicity results from the interaction of the ocean waves with the numerous relief elements of the continental shelf. These shelf relief elements include the shelf-edge canyons (for 12-second or longer waves) such as Baltimore, Washington and Norfolk Canyons; shelf valleys such as the shelf extension of Hudson, Delaware and Chesapeake Bays; ridge and swale bathymetry, most notably adjacent to southeastern Cape Cod, south shore of Long Island, Barnegat Bay, New Jersey, Delmarva Peninsula and Virginia Beach, Virginia; and shore-connected northeast-oriented ridge systems such as Monomoy Island, Cape Cod; Bethany Beach, Delaware; False Cape, Virginia; and Rodanthe, Cape Hatteras.

Shoreline Wave Energy Distribution

The resultant shoreline wave energy distribution varies with wave approach direction, wave period, stage of the tide and changes in sea level from the inverse barometric effect associated with moderate to severe storms. This spatial variation in shoreline wave energy distribution (i.e. alternate zones of wave energy concentration and diminution) also varies directly with the wave length of the incoming waves. For waves of 6-8 seconds these periodic zones are most prominent at spacings of 1-5 miles in length along the shoreline (Figures 2 through 4) while for waves of 12-14 seconds these zones may be 10-25 miles in length (Figure 5). The variations in the widths of these zones appear related to the distance from shore that the waves begin to interact with the shelf relief elements. This spatial wave energy distribution along the shoreline will affect the morphology and the long-term erosional history of the shoreline (6). Clearly, these trends should be considered in any shoreline planning or management endeavor.

Continental Shelf Wave Energy Distribution

In addition to the shoreline effects, this ocean wave-shelf interaction results in offshore areas of "confused seas" which should be identified and noted in the planning for offshore port siting proposed for this region. Note the strong "straight caustic" along the seaward rim of the Delaware canyon (top of Figure 5). Though most apparent for AZ = 157.5° and T = 12 sec, because of the canyon orientation and the abrupt change in depth, such an area of presumed surface disturbance will also occur under other conditions in which the waves travel into abruptly deeper water (2). Two of the computed wave parameters, the maximum horizontal components of the wave-induced bottom velocity and acceleration, can also be applied to shelf sediment transport studies. These two parameters are needed in wave force calculations for proposed offshore structures. The effects of these wave parameters will also vary with different wave approach conditions. As a result of these refraction computations, a library of wave information is available for analyses of regional studies of ocean wave-continental shelf interaction, resulting shoreline and shelf effects, and for delineation of areas favorable to the placement of coastal structures.

Historical Shoreline Changes

Wave refraction computations were made offshore from Wachapreague, Virginia (Figure 1) using both 1852 and 1934 bathymetry (6). Comparison of the bathymetric surveys of 1852 and 1934 indicates that, during this 82-year time interval, these barrier islands have become substantially offset (up to 1 km) seaward on the downdrift side of the inlets. The inlets have migrated southward while the ebb-tidal deltas remained stationary. The offshore bathymetry has undergone concomitant changes within the same 82-year interval, most notably in the ridge and swale bathymetry, which has deepened in the troughs and built upward on the crests.

Using standard computational wave refraction techniques (3) and the older bathymetry it was determined that in 1852 the shorter wavelength northeast waves (T = 4-6 secs) tended to concentrate wave energy at the south ends of these islands, whereas longer northeast waves (T = 12 secs) tended to concentrate wave energy at the north ends of the islands (Figure 9). Moreover, the longer waves approached the shore with their wave orthogonals more perpendicularly to the shoreline than the shorter waves. Thus the more accretional waves built up the shoreline on the downdrift sides of the inlets; while the shorter erosional waves eroded the shoreline on the updrift sides. This effect was amplified by a feed-back mechanism--the more the inlet offset the greater the refraction of the longer waves, which resulted in more buildup and a decrease in littoral drift, especially to the north. However, a tendency since 1852 for the shoreline wave energy distribution to become more uniform along any one of these barrier islands suggests that when the wave energy distribution reaches equilibrium the growth of the inlet offsets will cease, and the inlets will become more stable.

Spectral Analysis of Shoreline Energy Distributions

The spatial periodicity of wave energy concentrations suggested by histograms such as Figure 6 prompts further inquiry. Using standard spectral analysis procedures (1), the initial results of such inquiry are typified by Figure 8. Some support is provided for an assumption of spatial periodicity with spectral peaks being indicated for shoreline intervals of 5.3 and 12.0 nautical miles for the wave conditions AZ = 45° and T = 14 sec. However, limitations of the "data" preclude the formation of any firm conclusions at this point.

CONCLUSIONS

The intimate relationship of inner continental shelf relief and shoreline wave conditions has been demonstrated by wave refraction computations for several locations on the U.S. east coast. The results serve as a guide to interpretation of coastal processes for engineering purposes as well as scientific inquiry.

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WAVE REFRACTION COMPUTATION DEPTH GRIDS

Northern and Middle Atlantic Coastal Shelf of the United States

Name	Corner Coordinates (North latitude/West longitude)				Grid Density (nm)
	NE	SE	SW	NW	
1. Saco Bay, Maine	43° 32′/70° 16′	43° 25′/70° 16′	43° 25′/73° 23.5′	43° 32′/70° 23.5′	0.1
2. Wells Beach, Maine	43° 21′/70° 23′	43° 12′/70° 23′	43° 12′/70° 35′	43° 21′/70° 35′	0.1
3. Monomoy-Nauset, Cape Cod First Order	41° 45′/69° 40′	41° 25′/69° 40′	41° 25′/70° 00′	41° 45′/70° 00′	0.2
4. Monomoy-Nauset, Cape Cod (Nauset Beach, Cape Cod) Second Order	41° 44′/69° 53′	41° 38′/69° 53′	41° 38′/69° 58′	41° 44′/69° 58′	0.1
5. Cedar-Gilgo, Long Island First Order	40° 40′/72° 45′	39° 55′/72° 45′	39° 55′/73° 44′	40° 40′/73° 44′	0.2
6. Cedar-Gilgo Beach, Long Island; Second Order	40° 38.5′/73° 15′	40° 30′/73° 15′	40° 30′/73° 28′	40° 38.5′/73° 28′	0.1
7. Virginian Sea; First Order	38° 50′/74° 00′	35° 15′/74° 00′	35° 15′/76° 00′	38° 50′/76° 00′	0.5
8,9. Virginian Sea; Second Order Wachapreague (1852 & 1934)	37° 45′/75° 10′	37° 20′/75° 10′	37° 20′/75° 43′	37° 45′/75° 43′	0.25
10. Virginian Sea; Second Order (southeast Virginia)	37° 00′/75° 30′	36° 30′/75° 30′	36° 30′/76° 00′	37° 00′/76° 00′	0.25
11. Virginian Sea; Third Order	37° 00′/75° 50′	36° 45′/75° 50′	36° 45′/76° 00′	37° 00′/76° 00′	0.1

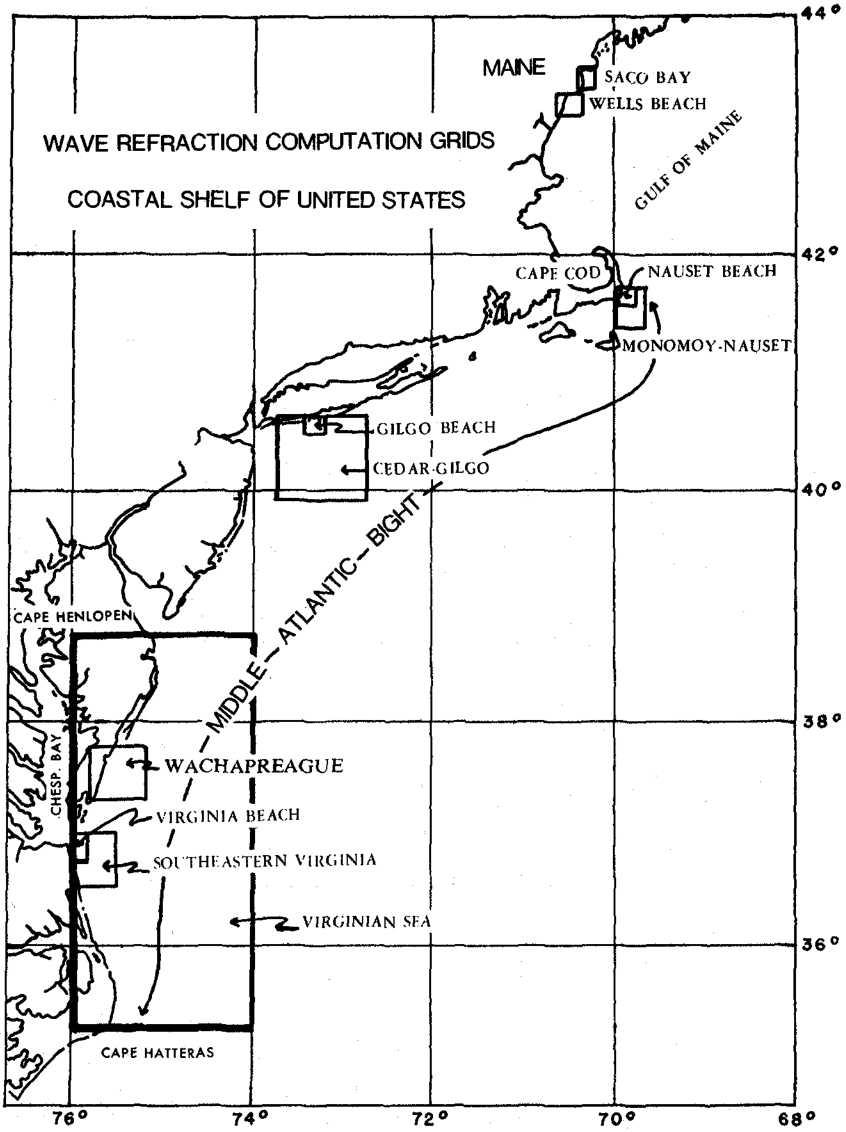

Figure 1. Wave refraction computation grids on the northeast and middle Atlantic continental shelf of the United States.

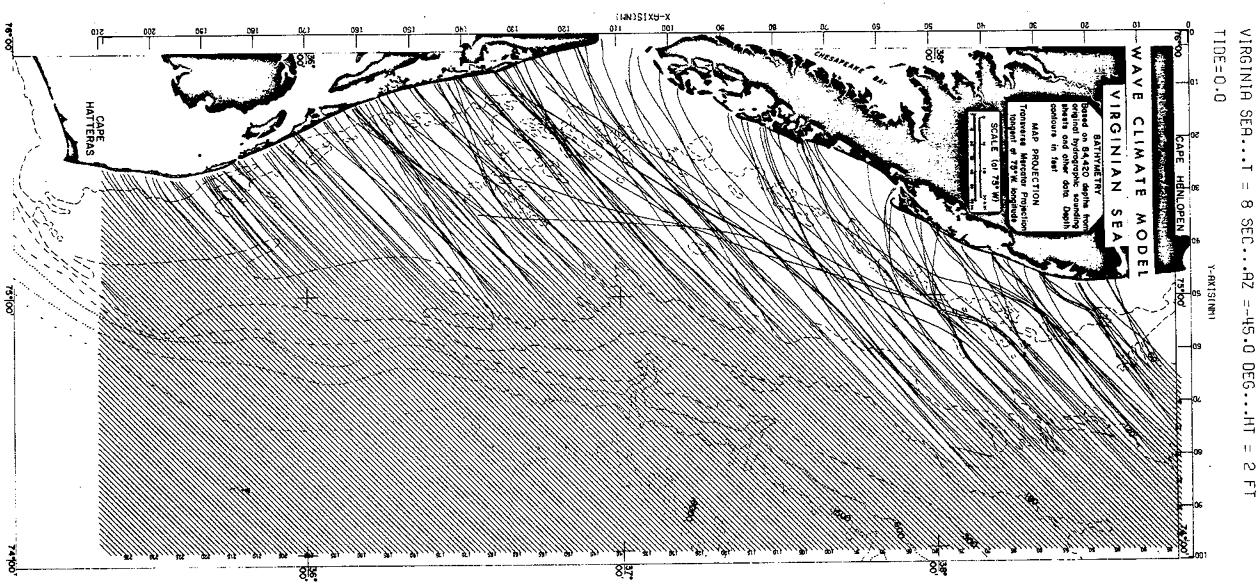

Figure 2. Wave refraction diagram of the wide, shallow and high relief U.S. continental shelf from Cape Henlopen, Delaware, to Cape Hatteras, North Carolina, with waves from the northeast with a period of 8 seconds, deep water height of 2 feet, and low tide conditions. Note the alternate shoreline zones of wave energy concentration and diminution as indicated by convergence and divergence of the wave orthogonals. Also computed were values of 17 different wave parameters at approximately one-mile intervals along each orthogonal.

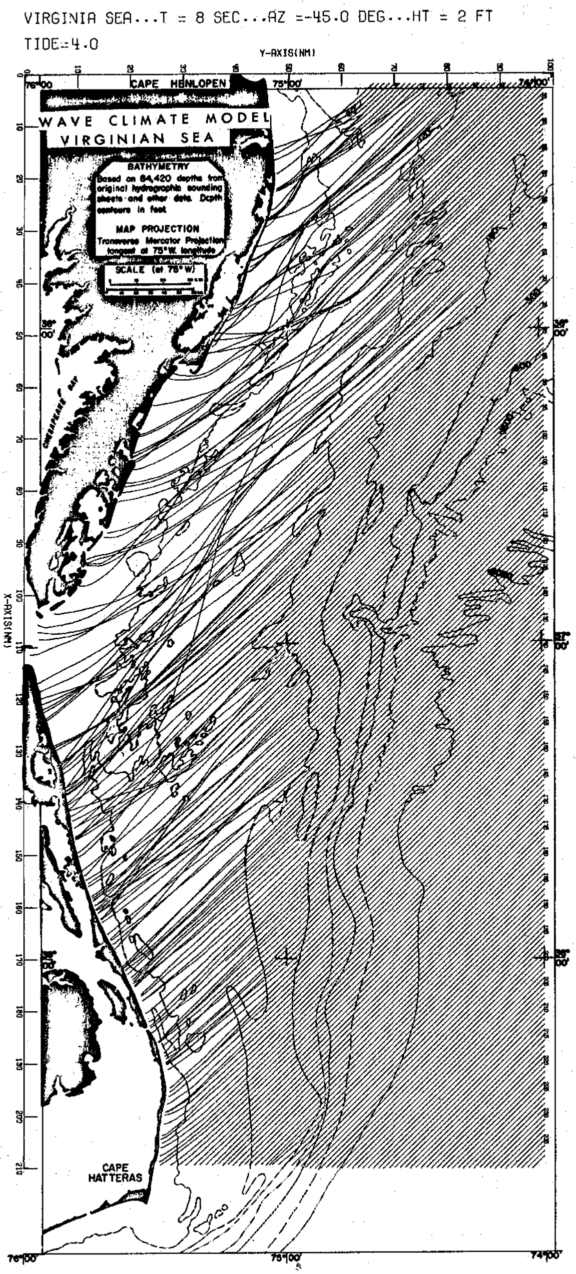

Figure 3. First order computation grid of the Virginian Sea Wave Climate Model for AZ=45.°, T=8 sec., Ht=2 ft., and Tide=+4 ft.

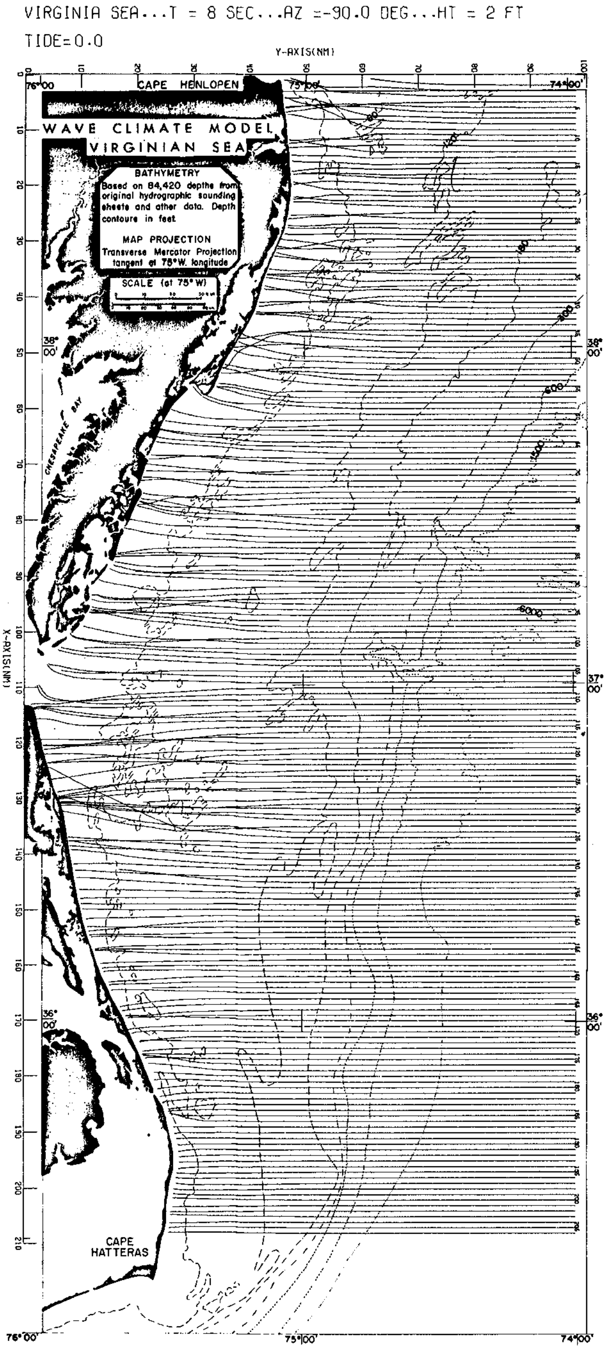

Figure 4. First order computation grid of the Virginian Sea Wave Climate Model for AZ=90°, T=8 sec., Ht=2 ft., and Tide=0.

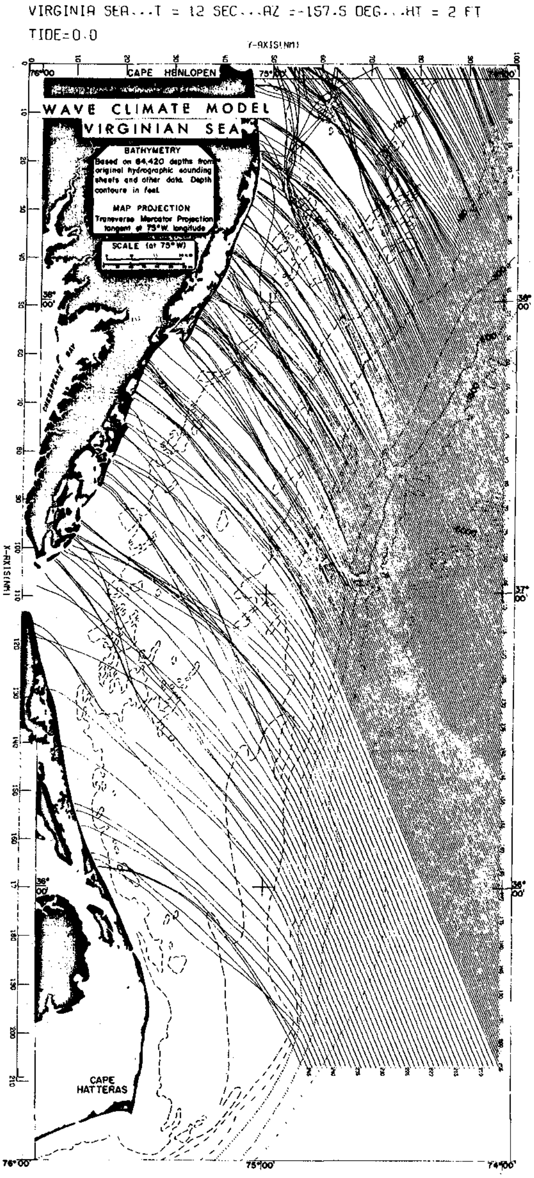

Figure 5. First order computation grid of the Virginian Sea Wave Climate Model for AZ=157.5°, T=12 sec., Ht=2 ft., and Tide=0.

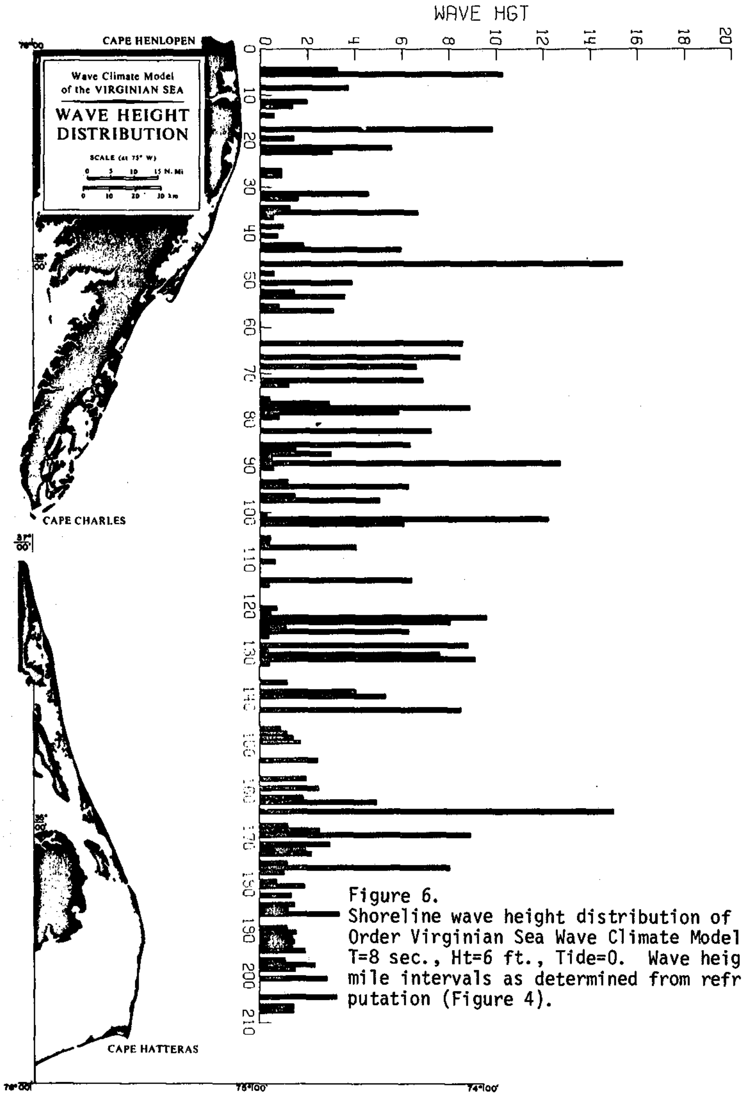

Figure 6.
Shoreline wave height distribution of the First Order Virginian Sea Wave Climate Model for AZ=90°, T=8 sec., Ht=6 ft., Tide=0. Wave heights for one-mile intervals as determined from refraction computation (Figure 4).

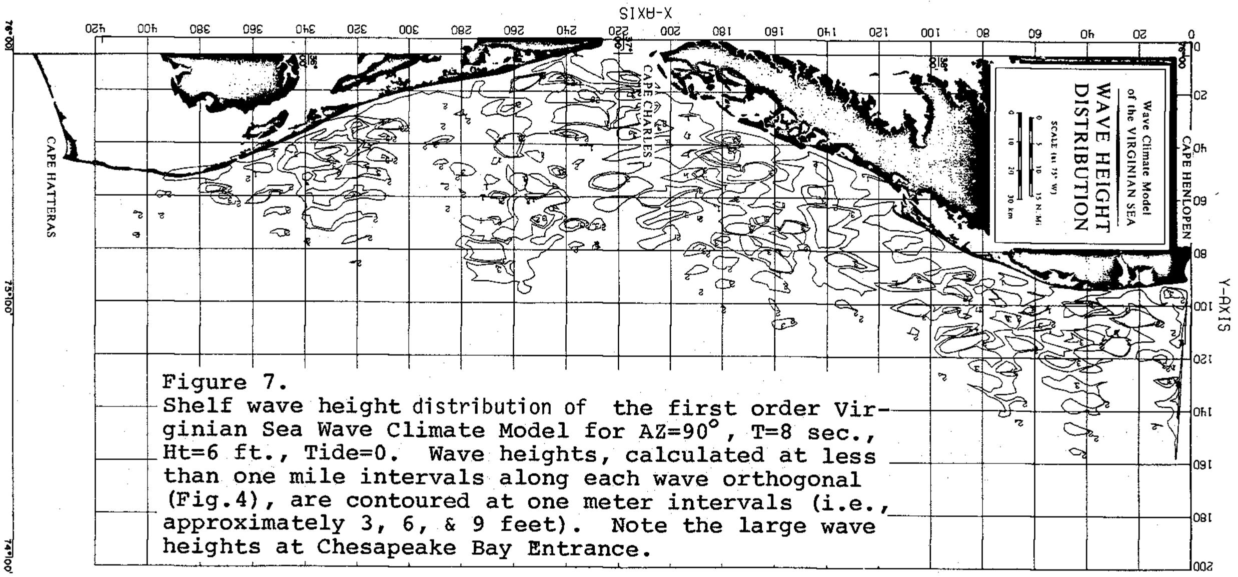

Figure 7.
Shelf wave height distribution of the first order Virginian Sea Wave Climate Model for AZ=90°, T=8 sec., Ht=6 ft., Tide=0. Wave heights, calculated at less than one mile intervals along each wave orthogonal (Fig.4), are contoured at one meter intervals (i.e., approximately 3, 6, & 9 feet). Note the large wave heights at Chesapeake Bay Entrance.

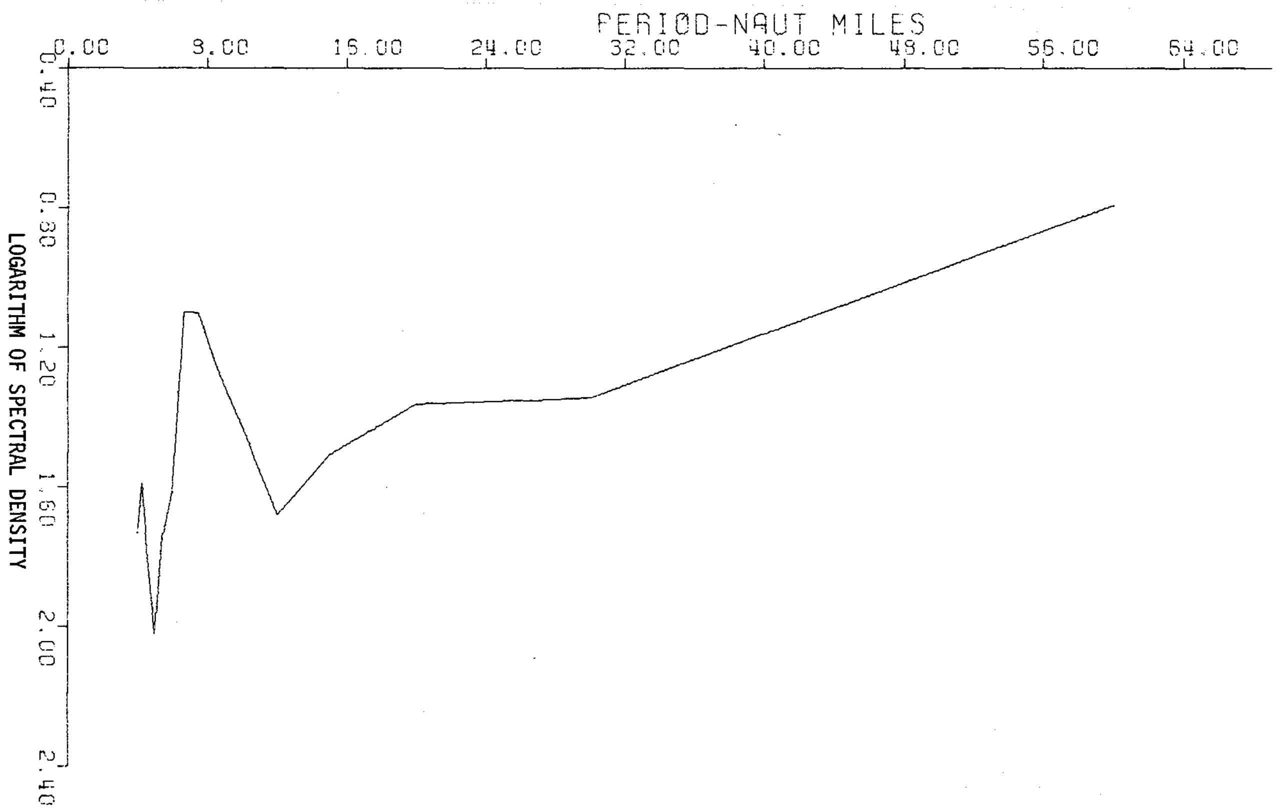

Figure 8. Spectral analysis of shoreline wave height distribution for AZ=45°, T=14 sec., Ht=6 ft., and Tide=0 (Figure 6). From the First Order Virginian Sea computation grid. Note the strong peaks at shoreline intervals of 5.3 and 12. nautical miles.

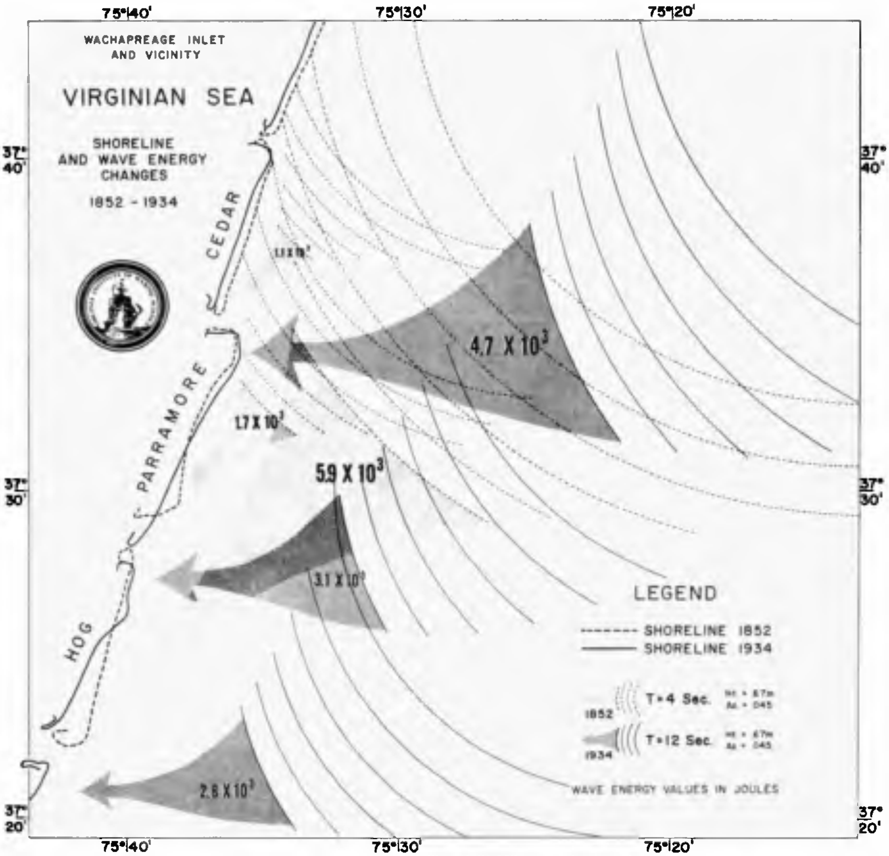

Figure 9. Schematic illustrating the close relationships between historical shoreline changes along the eastern shore of Virginia between 1852 and 1934 and the wave refraction computations using 1852 and 1934 bathymetry (Wachapreague computation grids in Fig. 1 and Table 1).