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A METHOD FOR ESTIMATING WAVES AT A NEARSHORE BUOY LOCATION OFF THE DELWARE-NEW JERSEY COAST

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1. INTRODUCTION

In October 1975, the National Oceanic and Atmospheric Administration began measuring and recording meteorological and oceanographic data at a location about 70 n mi east of Lewes, Del. (see Fig. 1). These data were measured and recorded with sensors aboard Buoy 44001 which was moored in 35 fathoms of water. With the deployment of Buoy 44004 in October 1977, meteorological and oceanographic data also became available at a location approximately 170 n mi east of Buoy 44001 (see Fig. 1). This offshore buoy, Buoy 44004, is anchored in 1500 fathoms of water.

Unfortunately, the nearshore buoy, Buoy 44001, was removed in November 1979. Nevertheless, for a 3-month period (October through December 1977), measured data at 6-h intervals (0000, 0600, 1200, and 1800 GMT) were recorded at both buoys. We have used this sample of data to develop a method for estimating waves at the nearshore buoy location. Before we discuss this method, we will present a brief statistical summary of the measurements at the two buoys. Also included are findings from our investigation of the relationships of waves to wind direction, water depth, and persistence.

2. STATISTICAL SUMMARY

Both buoys were equipped to measure wind speed and direction, air temperature, barometric pressure, wave spectra, and sea-surface temperature. Richardson (1983) discusses the accuracy of buoy measurements and gives a brief explanation of wave spectra and how they are used to compute wave height and period.

Measured wind speeds at the nearshore buoy varied from 1 to 30 knots. The average wind speed was approximately 14 knots. The average wave height was nearly 4 half-meters and ranged in value from 1 to 14 half-meters. Wave period, which varied from 5 to 11 seconds, averaged 6 seconds. The average air and sea-surface temperatures, which were measured to the nearest tenth of a degree, were 10.9° and 12.8°C respectively.

At the offshore buoy, Buoy 44004, wind speeds were higher than those measured at the nearshore buoy. Wind speeds at the offshore buoy averaged 19 knots and varied from calm to 45 knots. Wave heights were also higher, averaging 5 half-meters, compared to nearly 4 half-meters at the nearshore buoy. However, the range of the wave heights at the two buoys was identical (1 to 14 half-meters). The average wave period of 7 seconds at the offshore buoy was 1 second larger than the average period measured at the nearshore buoy. Average air and sea-surface temperatures were 3° and 6°C warmer, respectively, at the offshore buoy. The warmer temperatures are due to the warm waters of the Gulf Stream, which flows near the offshore buoy (see Fig. 1).

3. RELATIONSHIP OF WAVES TO FETCH, WATER DEPTH, AND PERSISTENCE

Wave height and period are determined by fetch (distance over water that wind has essentially constant direction and speed), wind speed, and duration (length of time the wind has blown over the fetch). Depth of water may be a consideration at the nearshore buoy since this buoy was moored in only 35 fathoms of water. Relationships based on wind speed and duration were not examined because we wanted to see if deepwater waves could be modified by fetch and water depth to give reasonable estimates of waves in nearshore waters.

We tried to capture the effects of fetch, water depth, and persistence by investigating the following:

(1) wind direction (nearest 10 degrees) measured 10 meters above the water surface,
(2) water depth, and
(3) wave height and period measured at earlier times (persistence).

Stability, defined by air-sea temperature difference, was not investigated because Richardson (1983) found that this predictor added little information to his Oregon-Washington coast buoy wave study.

A. Wind Direction

Data at the nearshore buoy were stratified into two categories on the basis of fetch (limited and unlimited fetch) as determined by the measured wind direction at the offshore buoy. Measured winds at the nearshore location were not used because these measurements would not be available to a method for estimating nearshore waves after November 1979. A fetch length criterion was decided upon after inspecting the deepwater wave forecasting curves developed by Bretschneider (U.S. Army Coastal Engineering Research Center, 1973) and after some experimenting. The Bretschneider curves showed that wave growth associated with 14-kt winds with 18-h durations (the average wind condition at the nearshore buoy) is limited by fetch lengths less than 100 n mi. However, our experiments with various fetch lengths showed that a 120 n mi fetch length gave the best results at the nearshore buoy. The Bretschneider curves limit wave growth for fetch lengths less than 120 n mi when 19-kt winds have durations of 18 hours. This is the average wind speed and duration of winds measured at the offshore buoy. We have used a 120 n mi fetch length to stratify buoy data and derive a method for estimating waves at the nearshore buoy location.

At the nearshore buoy, winds with directions between 235° and 354° are associated with limited fetch lengths (less than 120 n mi). Fetch lengths, as functions of wind direction, are shown for the nearshore buoy in Fig. 2.

Results of the fetch stratification are summarized in Table 1. There is little difference between average wind speeds for limited and unlimited fetch conditions. However, the wave height associated with unlimited fetch conditions is a half-meter larger (30 percent larger) than the average wave height associated with an unlimited fetch.

B. Water Depth

In an attempt to capture the effects of water depth (shoaling and wave refraction) on wave height modification, we stratified our sample on the basis of wave period. However, we were unable to isolate the effects of shoaling and refraction so we conclude that the water depth (35 fathoms) at the nearshore buoy was too deep to allow 5- to 10-s waves to be modified by the continental shelf.

C. Persistence

The best predictor of wave height and period at both buoys was persistence. Correlation coefficients associated with wave height at the nearshore buoy varied from 0.86 for persistence at 6 hours to 0.28 for persistence at 24 hours. For wave period, persistence at 6 and 24 hours gave correlations of 0.77 and 0.43 respectively.

At the offshore buoy, correlation coefficients associated with wave height varied from 0.84 for 6-h persistence to 0.19 for persistence at 24 hours. Wave period had correlations coefficients of 0.66 and 0.22 for 6- and 12-h persistence respectively.

4. A METHOD FOR ESTIMATING NEARSHORE WAVES

Wave heights measured simultaneously at the two buoys had a correlation of 0.73. In about 40 percent of the cases, wave heights measured at the nearshore buoy were equal to the heights measured at the deepwater buoy. Wave periods were identical about 55 percent of the time; however, the correlation was lower (0.47). We found that when we modified the offshore wave heights by a fraction of the associated fetch length, the modified offshore wave heights were a very good estimate of the wave heights measured at the nearshore buoy.

The fetch-length modification was determined in the following manner. The fetch lengths and corresponding wind directions shown in Fig. 2 were used to construct a predictor. We constructed this predictor by multiplying the wave height at the offshore buoy by the fetch length which corresponded to the wind direction at the offshore buoy. A linear relationship between the measured wave height at the nearshore buoy and the constructed predictor was determined. We forced the additive constant term in this linear relationship to be zero. The derived relationship after forcing is:

$$HT(NS)_t = 0.008\ FETCH_t\ HT(OS)_t, \qquad (1)$$

where $HT(NS)_t$ is the nearshore wave height in half-meters at time t, $FETCH_t$ is the fetch length in n mi based upon the wind direction at time t at the offshore buoy (see Fig. 2), and $HT(OS)_t$ is the wave height in half-meters at the offshore buoy at time t. The coefficient 0.008 has units $(n\ mi)^{-1}$.

Notice that 0.008 (1/125) is approximately the reciprocal of the fetch length associated with unlimited fetches. Waves associated with unlimited fetches are modified very little.

When (1) is used to compute the wave heights at the nearshore buoy location, the correlation between these computed heights and the heights measured at the location is 0.84. In more than 65 percent of the cases, the height (to the nearest half-meter) computed by (1) is equal to the height measured at the nearshore buoy. The number of waves, by categories of height for waves measured at the nearshore and offshore buoys, are shown in Table 2. The number in parentheses is the number of waves after the fetch modification with (1). If the modification were perfect, all off-diagonal terms in parentheses would be zero. The results of the modification are very encouraging, especially for the higher wave heights.

The Bretschneider wave forecasting curves showed that wave height and period are related to fetch length in a similar manner. Because of this relationship, we calculated wave period with (1). These calculations were made by substituting wave period (to the nearest second), in place of wave height in (1). As with wave height, in about 65 percent of the cases, the period (to the nearest second) computed by (1) is equal to the period measured at the nearshore buoy. The associated correlation coefficient is 0.63. Table 3 shows the number of waves by categories of period for waves measured at the nearshore and offshore buoys. The number in parentheses is the number of waves after the fetch modification. For short-period waves, the fetch-length modification gave good estimates of period.

To aid the marine forecaster in estimating waves at the nearshore buoy location, we have included Tables 4 and 5. Table 4 gives an estimate of the nearshore wave height in feet for wind direction and wave height in feet at the offshore buoy. Since wave height forecasts are issued in feet, heights were converted from half-meters to feet.

To familarize you with Table 4, let's go through an example. If a 19- to 21-ft wave is measured at the offshore buoy and the wind direction is 290°, then the estimated wave height at the nearshore buoy location would be 9 to 10 feet. To estimate wave period, refer to Table 5. If the period associated with this 19- to 21-ft wave is 12 to 13 seconds and the offshore wind direction is 290°, then the estimated wave period at the nearshore buoy location would be 6 seconds.

We feel that when wind directions are similar at both buoy locations these tables should give good estimates of waves at the nearshore location. For our development sample, the mean absolute difference between the wind directions at the two locations was 35 degrees.

5. SUMMARY AND FUTURE PLANS

As expected, wind speeds and wave heights were higher and periods were longer at the offshore buoy location. Also for this location, air and sea-surface temperatures were warmer due to the Gulf Stream. A good predictor of wave height and period at both buoy locations is persistence. Wave measurements at the offshore buoy, when modified by fetch length with (1), should provide good estimates of waves at the nearshore buoy location.

We plan to develop wave forecast equations for the offshore buoy location. This development will be patterned after our statistical wave forecast equations for the deepwater buoy location off the Oregon-Washington coast (Richardson, 1983). Wave and wind forecasts at Buoy 44004 could be used in conjunction with Tables 4 and 5 to make wave forecasts for the nearshore buoy location.

6. ACKNOWLEDGMENTS

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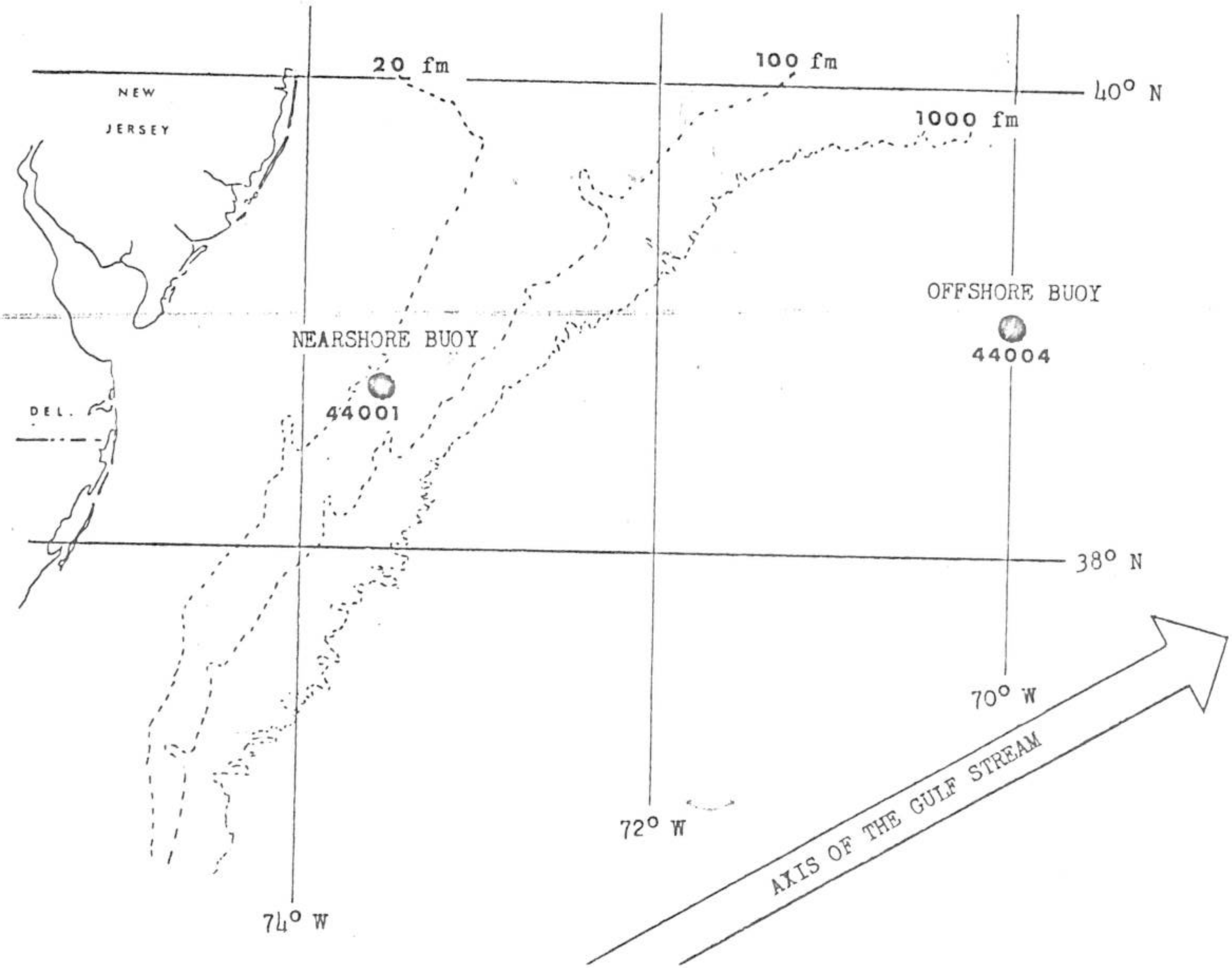

Figure 1. Locations of buoys 44001 and 44004. The 20-, 100- and 1000-fathom (fm) contours are shown as broken lines. Also shown is the axis of the Gulf Stream.

Wind Direction	Fetch Length (nearest 10 n mi)
355° - 234°	120 (unlimited fetch)
235° - 244°	110
245° - 254°	80
255° - 274°	70
275° - 284°	80
285° - 334°	60
335° - 344°	80
345° - 354°	110

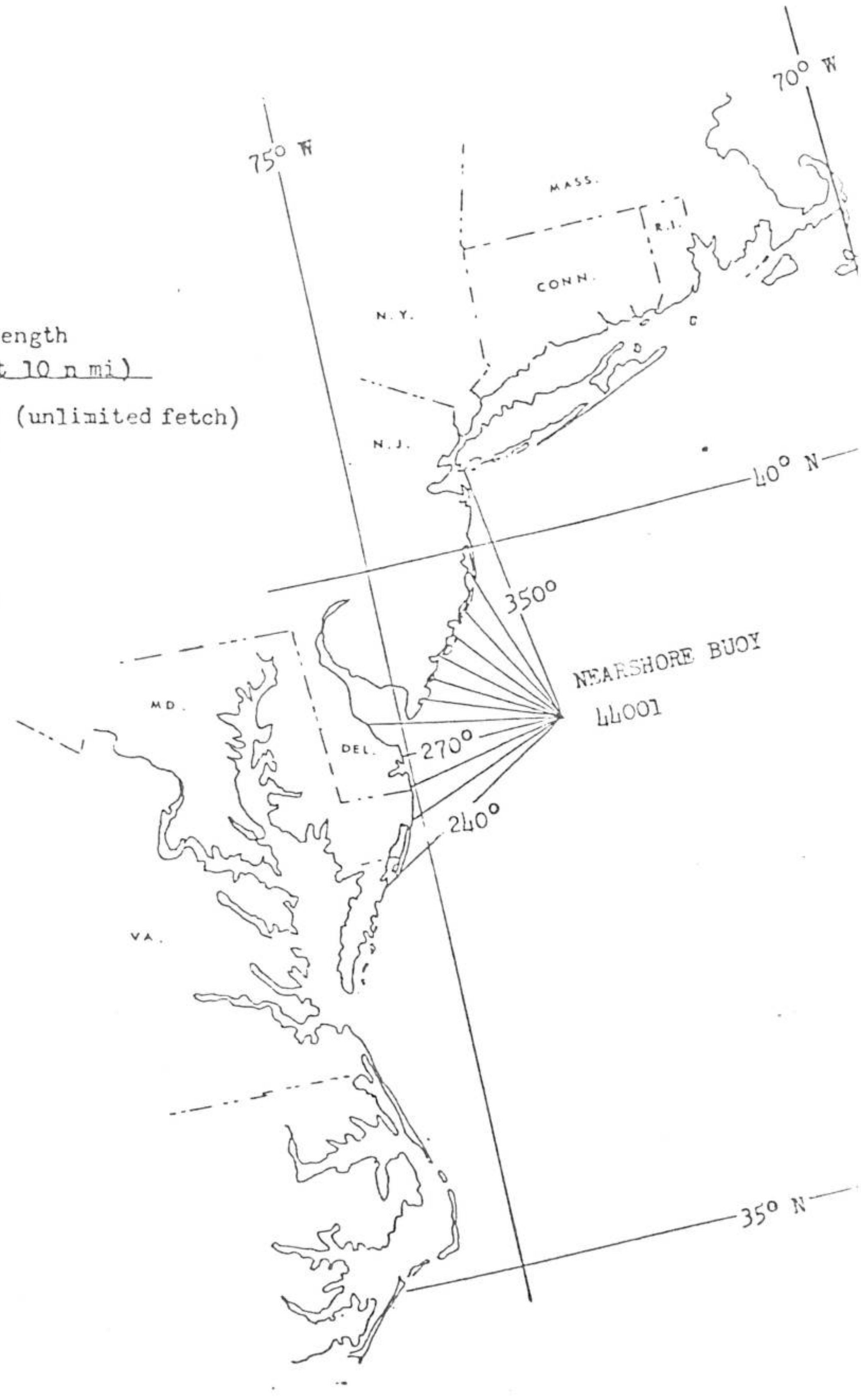

Figure 2. Fetch lengths in n mi as functions of wind direction at the nearshore buoy.

Table 1. Average wind speed, wave height, and wave period at the nearshore buoy. Categories of fetch are based on measured wind directions at the offshore buoy.

Fetch	Wind Speed		Wave Height		Wave Period	
	Average (knots)	No. of Observations	Average (half-meters)	No. of Observations	Average (seconds)	No. of Observations
Unlimited (355° - 234°)	13.5	152	4.1	154	6.5	154
Limited (235° - 354°)	14.1	114	3.1	115	5.8	115

Table 2. Number of waves by categories of height at the two buoys. The number in parentheses is the number of waves after the fetch modification was applied to offshore wave heights.

Nearshore Buoy Heights (half-meters)	Offshore Buoy Heights (half-meters)							Total
	1-2	3-4	5-6	7-8	9-10	11-12	13-14	
1-2	14 (38)	41 (20)	3 (0)					58
3-4	2 (6)	40 (66)	35 (10)	4 (1)	2 (0)			83
5-6	0 (2)	12 (17)	27 (29)	15 (10)	3 (2)	2 (0)	1 (0)	60
7-8		1 (1)	3 (4)	5 (9)	3 (1)	5 (2)		17
9-10			1 (1)	1 (1)	1 (1)			3
11-12						1 (1)		1
13-14							1 (1)	1
Total	16 (46)	94 (104)	69 (44)	25 (21)	9 (4)	8 (3)	2 (1)	223

Table 3. Number of waves by categories of wave period at the two buoys. The number in parentheses is the number of waves after the fetch modification was applied to offshore wave periods.

Nearshore Buoy Periods (seconds)	Offshore Buoy Periods (seconds)				Total
	≤5	6-7	8-9	10-11	
≤5	36 (78)	54 (15)	3 (0)		93
6-7	10 (39)	75 (59)	19 (6)		104
8-9		14 (16)	11 (9)		25
10-11			1 (1)		1
Total	46 (117)	143 (90)	34 (16)		223

Table 4. Estimated wave heights (feet) at the nearshore buoy location (38.7 N, 73.6 W) as a function of wind direction and wave height (feet) at the offshore buoy (39.0 N, 70.0 W).

Wind Direction at Offshore Buoy	Offshore Buoy Height (feet)							
	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24
355° - 234° (Unlimited fetch)	1-3	4-6	7-9	10-12	12-14	15-17	18-20	21-23
235° - 244°	1-3	4-5	6-8	9-11	11-13	14-16	17-18	19-21
245° - 254°	1-2	3-4	4-6	6-8	8-10	10-12	12-13	14-15
255° - 374°	1-2	2-3	4-5	6-7	7-8	9-10	11-12	12-13
275° - 284°	1-2	3-4	4-6	6-8	8-10	10-12	12-13	14-15
285° - 334°	1	2-3	3-4	5-6	6-7	8-9	9-10	11-12
335° - 344°	1-2	3-4	4-6	6-8	8-10	10-12	12-13	14-15
345° - 354°	1-3	4-5	6-8	9-11	12-13	14-16	17-18	19-21

Table 5. Estimated wave period (seconds) at the nearshore buoy location (38.7 N, 73.6 W) as a function of wind direction and wave period (seconds) at the offshore buoy (39.0 N, 70.0 W).

Wind Direction at Offshore Buoy	Offshore Buoy Period (seconds)				
	≤5	6-7	8-9	10-11	12-13
355° - 234° (Unlimited fetch)	≤5	6-7	8-9	10-11	12
235° - 244°	≤5	6	7-8	9-10	11
245° - 254°	≤5	≤5	6	6-7	8
255° - 274°	≤5	≤5	≤5	6	7
275° - 284°	≤5	≤5	6	6-7	8
285° - 334°	≤5	≤5	≤5	≤5	6.
335° - 344°	≤5	≤5	6	6-7	8
345° - 354°	≤5	6	7-8	9-10	11