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# Delineation of a wave climate for Dam Neck, Virginia Beach, Virginia

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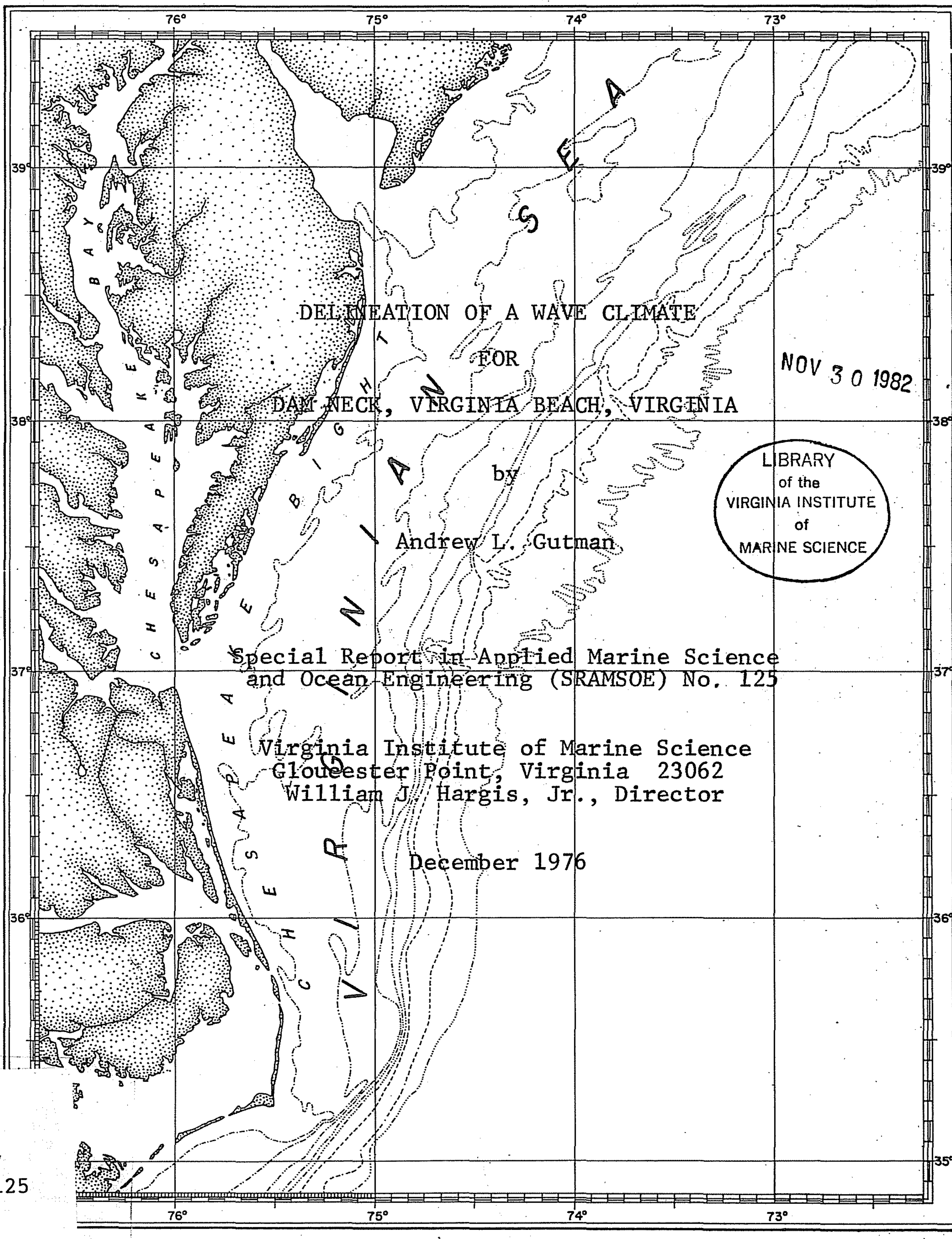


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Special Report in Applied Marine Science
and Ocean Engineering (SRAMSOE) No. 125

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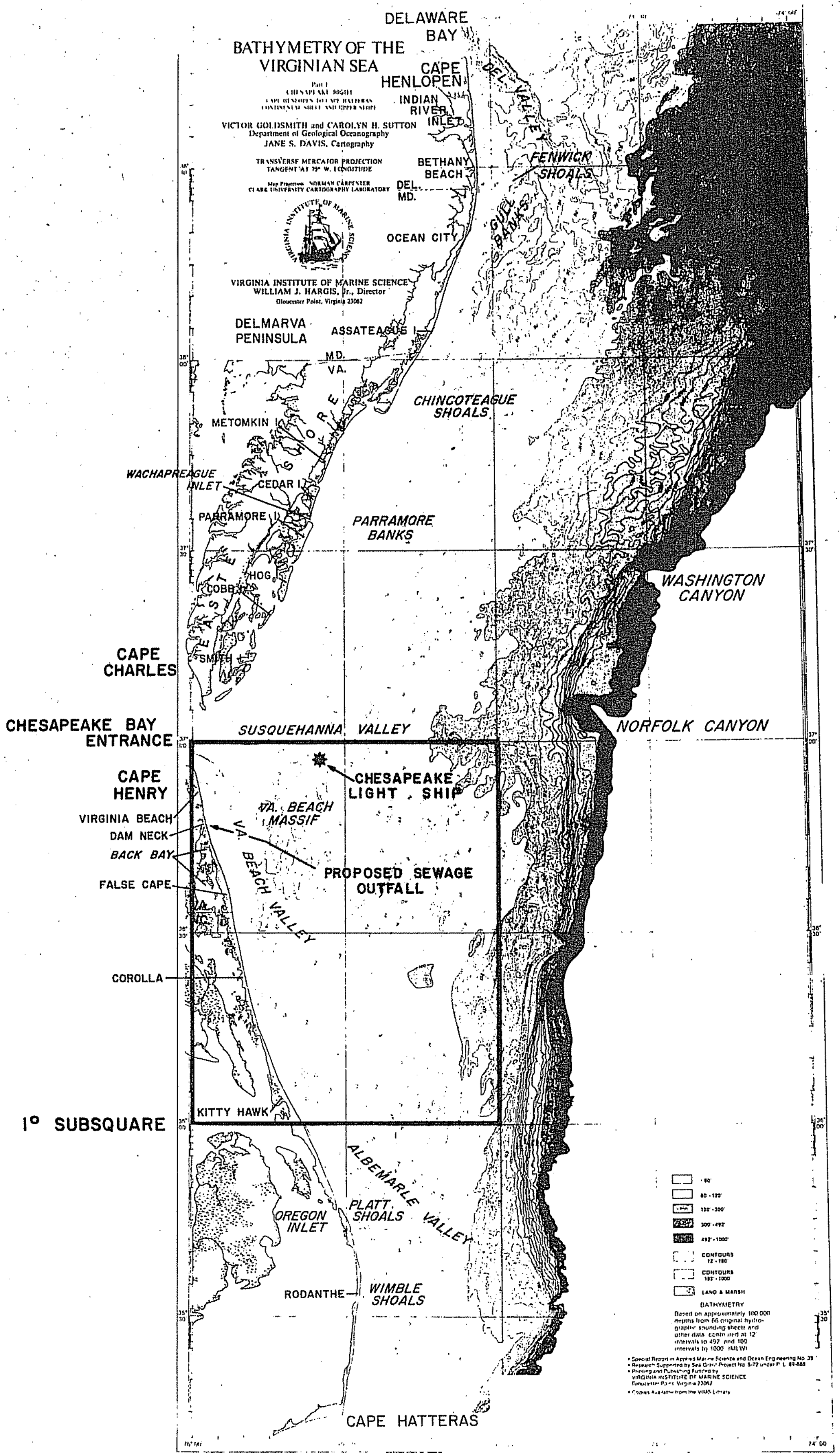


Figure 1a. Location Map

SUMMARY

A total of 78,449 wave observations from six sources, which vary widely in format duration, biases, and quality are compiled in this report (Figs. 1 and 2):

a) Shipboard wave observations for a 1° Marsden Square 116-subsquare 65 (14,580 observations during 12/48-12/73).

b) Chesapeake Lightship wave observations (3977 observations during 1/70-12/72).

c) Coastal Engineering Research Center-Coast Guard Cooperative Surf Observation Program (25,338 observations during 4/54-12/65).

d) Virginia Beach wave gage (6,354 observations during 4/64-10/69).

e) Virginia Institute of Marine Science-Coastal Engineering Research Center Voluntary Wave Observer Program (1882 observations during 6/74-8/76).

f) Hindcasted wave (SMB by Saville, 1954) for Chesapeake Light (26,260 wave computations during 1/48-12/50).

The principal descriptor of wave height used here is the "significant wave height", which is defined as the average height of the highest 33% of the waves occurring during a particular sampling period.

Conclusions resulting from the thorough synthesis and comparison of these wave data are:

1) After evaluation of the limitations and biases of all the above listed data sources, the Virginia Beach wave gage data is determined to be the most reliable, useful and representative source for delineating the nearshore wave climatology for the proposed Dam Neck Ocean Outfall.

2) Only a slight seasonality of wave height and direction is indicated by the six data sources:

a) The mean wave heights during the summer (April-August) are lower than waves during the winter. (September-March) by about 0.1 to 1.5 feet depending on the source.

b) The dominant direction of wave approach is from the Southeast and East during the summer and from the Northeast and East during the winter.

3) Wave periods are unreliable for all sources but the gage, because all the observed wave period data show large apparent biases towards lower wave periods and lack any apparent trends.

4) The mean wave heights of the six data sources show a landward decrease, which would be expected for waves traveling across the shelf, lending credence to the data and this synthesis.

5) The extreme wave climate constructed from the Virginia Beach gage data (located at a depth of 20 feet) is:

a) 68% of all significant wave heights ($H_s$) were less than 4.2 feet and 99.7% were less than 9.5 feet.

b) The highest significant height measured at the gage during the period of record was $H_s$ = 11.5 feet.

c) The highest significant wave height likely to occur in the Virginia Beach, Dam Neck area, in 27 years, extrapolated from a frequency of occurrence curve, was determined to be $H_s$ = 13.5 feet.

6) From previous wave refraction data, comparisons of nearshore and offshore wave data sources, previous storm occurrences, and gage characteristics, it is determined that the data recorded at the Virginia Beach wave gage is representative of wave events which are likely to occur adjacent to Dam Neck in 30 feet of water. Thus, monthly summaries of these data are presented in the Appendix, as a further aid to the engineer.

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B. VIMS-CERC Sample Wave Observer Form

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# DELINEATION OF A WAVE CLIMATE

# FOR

# DAM NECK, VIRGINIA BEACH, VIRGINIA

by

Andrew L. Gutman

December 1976

## PREFACE

This report has been prepared at VIMS under contract with Malcolm Pirnie Engineers, Inc., Newport News, Virginia, by Andrew L. Gutman under the supervision of Dr. Victor Goldsmith and Dr. Robert J. Byrne, in response to a request for detailed wave information to be used by others in planning a proposed sewage ocean outfall pipeline and diffuser to be located off Dam Neck, Virginia. These wave data will be useful for the design of the outfall structure, as well as optimal utilization of construction vessels during the emplacement of the outfall pipe.

The data and results presented in this report are derived from information supplied by several sources:

1) N.O.A.A. Environmental Data Service provided shipboard and Chesapeake Lightship wave data.

2) The U.S. Army Corps of Engineers Coastal Engineering Research Center provided the wave data from the Virginia Beach Gage, the Cooperative Surf Observation Program, and the VIMS-CERC Voluntary Surf Observer Program.

3) The SMB Hindcast wave data comes from the Beach Erosion Board (now C.E.R.C.) T.M. #55 by Thorndike Saville Jr., (1954).

4) Storm data was provided by W.S. Richardson of the Techniques Development Lab., U.S. Weather Service (N.O.A.A.) and the Norfolk Station National Weather Service office.

A.E. DeWall and E. Thompson of CERC were particularly helpful in supplying wave data.

Robert Gregory assisted in the computations.

DATA SOURCES AND METHODS

## DESCRIPTION OF WAVES

If an observer is given the task of visually describing the wave height and/or wave period on the ocean surface or at the shoreline, the difficulties of estimation soon become apparent. The reason the exact specification of the wave height and period is difficult is that the sea surface, at any given time or place, is composed of many different wave "trains" with different heights and periods. Furthermore, each of these component waves is moving at a different speed so that the faster components move through the slower ones. The result is that the sea surface is always confused. The problem the observer faces is to characterize the confusion in some meaningful and internally consistent fashion.

Research on ocean waves indicates that the distribution of wave heights passing a point do conform, more or less, with known statistical distributions. As a result it has been possible to estimate various characteristics of these distributions. A schematic representation of a frequency distribution of wave heights passing an observation point over some short time interval is shown in Figure 1d. Also shown is some of the parameters useful in engineering work. In particular we will make use of $H_{1/3}$ and $H_{1/10}$. $H_{1/3}$ $(=H_s)$ is called the "significant wave height" and it is defined as the average of the waves in the upper 33% of the distribution.

In addition to these parameters the significant wave period, $T_s$, is considered. This is generally a semi-subjective average period of the most prominent waves.

Of the data sources previously listed only the recording wave gage data can be formally treated to obtain $H_s$ and $T_s$. The other data sources gives visually estimated values of $H_s$. Experience has shown that an observer at sea, when estimating wave heights, estimates a value close to $H_s$. These parameters are discussed further in later sections.

COOPERATIVE SURF OBSERVATION PROGRAM

25,338 wave observations were accumulated between 4/54-12/65 at Virginia Beach in this Coast Guard-Coastal Engineering Research Center Project. In this program $T_s$ was estimated by counting the time of passage of eleven wave crests (10 complete breakers) and then dividing by ten. Significant wave height ($H_s$) was estimated by recording the average height of the highest third of the breakers. Wave direction was recorded as the direction from which the most prominent waves were coming just before they broke. Observations were taken every four hours, recorded on coded forms and then sent to CERC. A sample form complete with instructions for the wave observer is included in the appendix to this report.

Table 1 outlines the many problems associated with such an observation program. It is concluded that this data should be only applied in the Virginia Beach area and the data should not be used to determine structural design. However, the data is useful in that it represents an unusually long period of record and can be used in conjunction with other, more seaward, data.

## VIRGINIA INSTITUTE OF MARINE SCIENCE-COASTAL ENGINEERING RESEARCH CENTER VOLUNTARY WAVE OBSERVER PROGRAM

Some 1,882 wave observations along the coast from Virginia Beach, Virginia to Currituck Light, North Carolina were gathered between January, 1975 and August, 1976 at ten locations (Fig. 1). Estimates of significant wave height and period were determined as described for the COSOP Program (above). However, observations were not taken every four hours but on a daily basis, usually five days/week Monday through Friday. In addition, data was derived along the coast at 10 separate locations at highly sporadic intervals, as opposed to one location for the COSOP Program (Figure 2).

As indicated in Table 1, these data are of little use in delineating a wave climate of use for engineering design and planning. It does, however, provide some estimate of the long shore variation of wave energy along the coast.

A sample form complete with instructions for the wave observer is included in the appendix to this report.

## SHIP WAVE OBSERVATIONS

Wave information stored on magnetic tape by N.O.A.A. Environmental Data Service for Marsden one degree subsquare

SS-65 within Marsden 1° degree square 116 (Fig. 1) adjacent to the study area consisted of 14,580 observations accumulated during 12/48-12/73.

Shipboard wave observers (NOAA, 1964) are instructed to select a patch of foam or similar floating material, and divide the elapsed time of passage of ten or fifteen wave crests through the foam by the number of crests, to estimate a wave period. Wave height is determined by comparison to a known object on the ship. It is assumed that these estimates represent significant wave height and period. Shipboard wave observers are generally untrained and often rely on experience rather than actual time or height measurements to estimate the wave parameters.

Thompson and Harris (1972) have discussed errors involved with shipboard wave observations (see Table 1). As with all observer programs, much error and bias must be assumed when interpreting the data. Nevertheless, shipboard wave observations fill a gap by providing a deepwater wave climatology. As will be shown here, when compared with measured waves, these observations appear to be quite reasonable.

## CHESAPEAKE LIGHTSHIP

Three years (1/70-12/72) and a total of 3917 wave observations are available on magnetic tape from N.O.A.A. Environmental Data Service (Asheville, N.C.) for the Chesapeake Lightship. The lightship is located in forty feet of water off the entrance to the Chesapeake Bay. Data is collected in the same manner as outlined above for the ship observation program and therefore the same limitations and errors associated with this program apply to the Chesapeake Lightship wave data (see Table 1).

The Chesapeake Lightship data is of value because it provides a wave climatology for inner shelf water depths, between the near shore and the deep water wave observation programs.

SMB HINDCAST DATA FOR CHESAPEAKE BAY ENTRANCE

26,260 wave observations for Chespeake Bay Lightship position were hindcasted with the Bretschneider revised Sverdrup-Munk's method using U.S. Weather Bureau maps for the three year period 1948-1950 by Thorndike Saville, Jr., of the Beach Erosion board (Saville, 1954). Fetch and wind speed and direction were determined from North America Surface Synoptic charts at six hour intervals. Significant wave heights and periods were computed using the SMB method and compiled by height, period, and direction on a monthly and yearly basis.

The SMB is a simple empirical model for hindcasting deep water significant waves. Shallow water wave parameters must be determined by using wave refraction across the shelf. Results from such a simple model must be applied with caution (see Table 1). The SMB method is useful to the coastal engineer because wave parameters, especially for extreme wave events, can be determined with a minimum of time and data. However, their results do not always agree with other data (Goldsmith, et al., 1974).

## VIRGINIA BEACH WAVE GAGE

Of all the data presented in this report those from the wave gage should be considered the most reliable. A step resistance gage operated by the Coastal Engineering Research Center (U.S. Army Corps of Engineers) between 1/64-10/69 was located on the 15th street fishing pier in 20 feet of water. Due to repairs, instrument failure, and natural and unnatural destruction some months are missing from the 5½ year record. Summaries for the Virginia Beach Gage which indicate the months the gage was operative, are included in the appendix to this report.

A step resistance gage uses electrical contact points along a staff to sense water surface elevation. It appears (Esteva and Harris, 1970) that the SR gage estimates wave heights 20% greater than other gage types for high waves and about one foot too high for low and moderate wave conditions. Run up inside the H-Beam that supports the gage and biological fouling appear to account for the higher estimates of wave height from a step resistance gage.

During the period of operation for the Virginia Beach gage CERC changed methods for recording and analysis of wave data. Between 1965-1968 pen and ink records were used while since

November, 1968 signals from the wave gage were sent automatically over telephone lines and converted to digital records. Only a brief outline of CERC procedures for analysis of pen and ink and digital wave records follow. A more detailed description can be found in Harris (1970) or Thompson and Harris (1975).

Wave period templates were used to estimate the period of the higher heights and more uniform waves from pen and ink records. By dividing the length of a record by the period, the number of waves in the record can be estimated. From this a semi-objective procedure is used, based on the assumption that wave heights conform to a Rayleigh distribution function, to determine the rank 'n' of a wave which theoretically will have a height equal to the significant wave height. The height of this 'n'th highest wave is measured and constitutes the observation of significant wave height for that six hour period.

After November, 1968, the Virginia Beach gage wave records were recorded digitally and analysed by computer. This analysis procedure uses a wave spectrum to determine the wave parameters. Since a wave record will contain individual waves of varying height and period, a wave spectrum better represents a field of waves. Based on the assumptions that the wave heights can conform to a Rayleigh distribution and that the sea is represented by a narrow band of energy spectrum, the significant wave height has been defined as four times the standard deviation of the record. The significant wave period is defined as the period of maximum energy density for the computed energy spectrum.

A wave climatology determined from the Virginia Beach gage should be reliable within the limitations imposed by the wave gage (see Table 1) for nearshore coastal engineering design and planning; however, wave direction is not measured.

## DATA PRESENTATION AND USAGE BY THE ENGINEER

This wave climate has been prepared from an unusually large and varied data base. Wherever possible the data from all sources is presented in a unified format. However, the following differences in methodology amongst the various programs hinders this effort:

a) Wave heights and periods are often grouped in different intervals and units. For example, COSOP wave heights are recorded in one foot intervals, the wave gage data in ½ foot intervals and the ship observation data is listed in 1½ meter intervals.

b) Periods of sampling differ (Figure 2).

c) Methods of observation differ.

d) Virginia Beach gage lacks wave direction data.

e) Directional data is recorded in both 8 (COSOP) and 12 point (Ship Observations, Chesapeake Lightship, SMB calculations) compass directions.

The reader is advised to keep these differences in mind while reviewing the data presented in the following figures and tables.

### TABLES

Table 1 lists errors and limitations associated with each data source.

Tables 2-5 are summaries for each directional data source of significant wave height and direction expressed as percent of observations for the entire length of record. Direction refers to the compass points from which the waves approach. Height and direction intervals vary among the tables.

Table 6 is a summary of significant wave height and period for forty-five months of Virginia Beach wave gage data expressed as percent of total observations. This compilation represents a summary of both pen and ink and digital (see methods section) data. No calm conditions (CERC procedure) are included in this summary.

Tables 7 and 8 list the average ($\Sigma x/n$) seasonal significant wave heights (meters) and periods (seconds) for each season. Winter is considered December-March; Spring is considered April-May; Summer is June-September; and Fall is October-November. N.O.A.A. Environmental Data Service (which provided most of the data) uses this particular grouping; therefore, in an effort to standardize format of presentation, all data has been grouped this way. As discussed later in the section on seasonality, this may not be the best possible format for this area.

The ± standard deviation of each average $H_s$ and $T_s$, a measure of the dispersion of individual observations about the mean value is presented as

$$\sigma = \sqrt{\frac{\Sigma x^2 - (\Sigma x)^2/n}{n-1}}.$$

Tables 9-12 list seasonal average percentages of wave height by direction expressed as percent of total observations. The last row for each season lists the percent of waves from each direction greater than, or equal to, either five feet (SMB and COSOP data) or three meters (ship observations and Chesapeake Light). This value is simply the sum of each direction column for waves above three meters or five feet.

Table 13 lists the duration in hours of waves in the entire Virginia Beach gage record which exceeded a significant wave height of nine feet. Only the months during which these highest waves occurred are listed. For each of the three significant wave heights (9.5′, 10.5′, and 11.5′), there are listed the computations corresponding to $H_{1/10}$ (the average of the highest 10% waves), and $H_{max}$ (the highest anticipated wave height). Most wave records are expressed in significant wave height. Therefore, parameters such as $H_{1/10}$ and $H_{max}$ must be calculated based on the assumption that wave heights conform to the Rayleigh distribution. $H_{1/10}$ and $H_{max}$ are calculated according to the relations; $H_{1/10} = 1.28\ H_s$ and $H_{max} = 1.77\ H_s$, after Longuet-Higgins (1952).

For the Virginia Beach gage, each of the measurements are made every six hours and is considered statistically representative of a duration of six hours. In order to determine the duration in hours for each listed wave height, the percent of observations for the given height was multiplied by six and by the total number of observations.

Table 14 lists the tropical and extratropical storms which occurred during the period of record for the Virginia Beach gage. The term storm (extratropical) was defined by Richardson (personal communication) as having a storm surge of two feet or greater at a tidal gage, which in this area, was at Hampton Roads, Virginia. The Virginia Beach wave gage record is missing during only two of these storms, one of which occurred five days following another storm which had destroyed the gage. Wind speeds and directions are from the Norfolk Weather Station located at the Norfolk Regional Airport. The speed associated with each storm represents the highest wind (m.p.h.) that lasted for over one minute, during the storm. The wave heights associated with each storm from the Virginia Beach gage are then listed. Again as in Table 13, $H_{1/10}$ and $H_{max}$ are calculated values (after Longuet-Higgins, 1952).

Tropical storm data is compiled identically as for extratropical storms except that storm names are also listed.

Table 15 is a compilation of wave refraction data available from the VIMS-VSWCM (Virginia Sea Wave Climate Model) data bank (Goldsmith, et al., 1974). The data summarizes changes in deep water waves ($H_o$ = 6 feet) as they cross the shelf between 30 and 20 feet of water for eight and ten second waves from the Northeast, East, and Southeast. Wave height for six to ten wave rays (see Figures 14-20) refracting into shore between Dam Neck and Virginia Beach were averaged* in about 20 and 30 feet of water.

In general, Dam Neck is an area of relatively low wave energy from the northeast waves (due to extensive refraction by the Virginia Beach Massif), and is an area of wave energy concentration for southeast, and to a lesser extent east, waves (see discussion in Goldsmith, et al., 1974, p. 37).

Table 16 represents a compilation of the daily VIMS-CERC volunteer wave observer data organized according to location (between Virginia Beach, Virginia and Currituck Beach Light, North Carolina) and by season. It appears that the greatest wave heights occur in the summer months while the longest wave periods seem to occur during the fall. However, the data varies widely between observers (especially wave periods), and the seasonal differences for most observers are probably statistically non-significant. Thus, because of all the problems involved in data from untrained wave observers and irregular data collection, little credence should be given these wave data.

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*An average height is used because the depth grid (0.5 nm) employed in the Virginian Sea Wave Climate Model is too coarse to be site specific for the proposed outfall site, and computations from a single ray could be misleading.

## FIGURES

Figures 1a & 1b & 1c are maps showing the location of data sources and the proposed sewage outfall.

Figure 1d is a diagram which shows the percent of total number of waves in each wave height range and the location of $H_s$ $(H_{1/3})$ and $H_{1/10}$ on the distribution.

Figure 2 compares the lengths and dates of records, and presents the number of observations, measurements or computations for each data source.

Figure 3 is a graphical comparison of the average significant wave heights for each data source, by season, which are listed in Table 7.

Figure 4 is a graphical comparison of the average significant periods for each data source, by season, which are listed in Table 8.

Figure 5 is a representation of monthly and seasonal significant wave heights (see Table 7 and Appendix) for the Virginia Beach gage. An envelope of one standard deviation which represents the dispersion of individual waves about the average monthly significant wave height is also represented in this figure. 68% of all waves for a given month have occurred within an envelope represented by + and - one standard deviation value.

Figure 6 is identical to Figure 5 except that it represents the significant wave period.

Figure 7 represents the frequency (expressed in percent of total observations) with which waves higher than a given height have occurred during the period of record. Cumulative frequencies, with the 100% level set at waves greater than or equal to zero feet, are constructed from Tables 1-6, and then plotted on semi-log paper with these data points clearly shown. In following the curves to extreme heights (low frequencies), it should be remembered that the lines are visually extrapolated and that data exists only for the points indicated.

From this Figure and Figure 2 the frequency of occurrence in number/year of a particular significant wave height can be estimated. For example, from the COSOP curve it is seen that a wave height of 10 feet or greater occurred only .02% of the time during 4/54-12/65. Therefore, there are only .0002 x 25,338 total observations or five wave observations over a height of ten feet. Since each observation is considered to represent four hours of record there were a total of 4 x 5 or 20 hours of waves over ten feet between 4/54-12/65. Since this is 20/24 of a day and there are (25,338/6) days in the record, then wave heights above ten feet for the COSOP data occurred once in (20/24)/(25,338/6) = .83/4223 days or one day in 14.36 years, or one observation per 2.36 years.

Figure 8 for the Virginia Beach gage is similar to Figure 6 but it also shows a curve calculated for $H_{1/10}$ from $H_s$. An example below demonstrates calculation in number/year of waves with $H_s \geq 11$ feet, or $H_{1/10} \geq 14$ feet.

$$H_s \geq 11 \text{ feet occurs} = .05\%$$

$$\text{Total \# of observations} = 6354$$

$$\text{\# of observations} \geq 11 \text{ feet} = 3.18$$

$$\text{Duration} \geq 11 \text{ feet} = 3.18 \times 6$$

$$= 19.08 \text{ hours}$$

$$\text{Number of days per year} = \left(\frac{19.08}{24}\right) \Big/ \left(\frac{6354.}{4}\right)$$

$$H_s \geq 11 \text{ feet}, H_{1/10} \geq 14 \text{ feet} = 1 \text{ day}/5.4 \text{ years}$$

$$= 3.18 \text{ obs.}/1558 \text{ day}$$

$$= 1 \text{ observation}/1.35 \text{ years}$$

Figures 9-14 are wave roses showing pictorially the percentage occurrence of waves of different height from each direction. The data is listed in Tables 2-5 and 9. Differences in rose format are necessary due to methods and categories of data collection. All waves from between 195°-345° azimuth (0° is north) are neglected because the shoreline of interest in this report is oriented about north-south. The COSOP data is further reduced to seasonal wave roses (Table 9) to evaluate changes in nearshore direction of wave height and approach.

Figure 15-20 (from Goldsmith, et al., 1974) are wave ray diagrams for 6 wave conditions in the VIMS-NASA-LANGLEY Virginia Sea Wave Climate Model. Wave rays approaching the shoreline between Dam Neck and Virginia Beach were selected for the compilation of data in Table 15.

# DISCUSSION

## VARIATIONS ACROSS THE ADJACENT CONTINENTAL SHELF

This wave climate synthesis represents data derived from surf, shallow water, mid-water, and deep water wave conditions. As waves travel across this very wide and high relief shelf into shallow water they are primarily affected by refraction, shoaling and bottom friction. Due to these effects, monitoring stations should detect at least two general changes in wave characteristics for waves traveling from deep to shallow water: 1) The angle of wave approach relative to the shoreline should progressively reduce (wave crests become increasingly parallel to the coast). 2) Wave heights will greatly decrease from friction, and either decrease or increase from refraction. Given all of the variability, unreliability, nonuniform sampling periods, and a large error associated with wave observers, it is completely surprising, but very gratifying to note that comparisons of wave sources which reflect different depths along the shelf actually do indicate these changes in wave characteristics (Tables 7, 8 and Figures 3, 7).

### Wave Height

The following conclusions, regarding changes in wave height distributions across the shelf in the Virginia Beach Area, were arrived at from comparisons of the various data presented in this report.

1) Deep water average significant wave heights are generally about two feet higher (SMB Hindcast, Chesapeake Lightship and Ship Observations) than the averages for shallow water conditions (COSOP and Virginia Beach Gage).

2) The largest average significant wave (see Figure 3) heights are associated with the hindcast data. Note also (see Tables 2-5) that the percent greater than or equal to 10 feet (~ 3 meters) is 6.8 for SMB hindcast while only 2.1% for ship and 1.4% for the Chesapeake Lightship observations. These higher averages would be expected because of the simple assumptions of the SMB computations, the avoidance of extreme conditions by ships, and the evacuation of the lightship during extreme wave events, and the fact that only the SMB hindcasted wave observations are for strictly deep water conditions, since the Ship Wave Observations encompassed within the 1° square contain an unknown amount of wave data taken in depths less than "deep" water for the longer period waves.

3) Ship observations in MS 116, SS-65 do not represent only deep water conditions, but instead a range of depths from deep to shallow. Due to this range, the average wave heights from ship data might be expected to conform to more mid-shelf conditions. The Chesapeake Lightship is anchored in the inner-shelf (40 feet) and it is interesting to note that average significant wave heights for both sources are essentially the same, though winter values are higher and summer values lower for the ship observations.

4) Since larger wave heights are associated with breaking waves (which are monitored by the shoreline COSOP program) than with nonbreaking waves, it is not surprising that average significant wave heights are slightly higher for the COSOP data than the wave gage, even though the gage is located in 20 foot water depths.

5) The frequency of occurrence of waves greater than a given height is, as would be expected, higher on the shelf than in nearshore water (see Figure 7). For example, waves greater than or equal to 10 feet had a frequency occurrence of only .2% in 20 feet of water (Virginia Beach gage), but 2% in 40 feet of water (Chesapeake Lightship) and 7% in deep water (SMB hindcast). The frequency occurrence of waves greater than about five feet is slightly higher for the Virginia Beach gage than COSOP data. This difference is likely due to unequal sampling periods, that is the five years of gage record was unusually stormy compared to the 20 years of COSOP record. In addition, COSOP observations often do not include extreme wave events while the gage does. Also, note the high standard deviations of both data sets in Table 7.

Wave Period

Analysis of wave period data receives little emphasis in this report because large differences in average wave periods exist between the data sources, differences which are not induced by waves traveling across the shelf but due to differences in methodology and observer errors. For example, over 99% of all observations from the Chesapeake Lightship recorded wave periods of five seconds and less, which probably indicates bias and error due to the observers and recording procedure, and not a dominance of 5 second waves. From Table 8, it is seen that the average significant wave periods range from five to ten seconds with no relation to depth induced changes. The only objective wave period information of use to the coastal engineer is available from wave gage records. This information is supplied in Table 6.

There is, however, one trend apparent in Table 8, which explains the weaknesses in these data. The measured (Virginia Beach Gage) and computed waves (SMB) have the highest wave periods, approximately 8 to 10 seconds, respectively, for all seasons; whereas all other data (observed) is about 5 seconds. This is because when two superimposed wave trains occur, even the trained observer generally sees only the shorter period waves. In this area it is very common to have a local "sea" combined with a longer period swell produced by a distant storm. Evidently, most observers see only the local sea. Thus, only data measured by instruments, and statistically processed, will show the correct percentage of longer period waves.

## Wave Direction

The anticipated changes in direction of approach of waves traveling across the shelf are well documented in this report. The dominant angle of approach relative to the shoreline, decreases for monitoring stations in increasingly shallow water. Comparison of COSOP, Ship, and Chesapeake Lightship Observations show for increasingly nearshore conditions diminishing northerly and southerly components (wave crests perpendicular to shore) and increasing easterly components (wave crests parallel to shore).

## SEASONALITY

Information regarding seasonal changes in wave characteristics is important to coastal engineers trying to most efficiently and safely plan the use of construction vessels. The data presented in this report indicates changes, though small, in seasonal wave characteristics. According to Hayden (1975) annual cycles of wave climate exist along the east coast of the United States. For the Virginia Beach area, Hayden (1975) found a winter to summer transition data of April 10, and a summer to winter transition at August 17, based on the same COSOP data presented in this report.

### Wave Height

Figure 3 examines the seasonality of significant wave height for all wave sources. It is evident that these seasonal height averages are greater during the winter and fall, and lower during the spring and summer. The differences between summer and winter averages range from as little as .1 foot for the COSOP data to 1.4 feet for the ship data. In any case, considering the large standard deviations, (Table 7) most differences are probably not important.

Figure 4 is an analysis of monthly data for the Virginia Beach gage, which is of most use, and the most reliable for nearshore coastal engineering. It is evident that the highest significant average heights occur between September-October and December-March with the lowest between April-August. Given a standard deviation (dashed line) of about 1.5 feet, this average seasonal difference of .4 feet between summer and winter should be regarded as being unimportant. Although there is a slightly higher probability of 4 foot waves during the winter than summer at Virginia Beach, it should be noted that 68% (± 1st deviation) of all waves during all months had significant wave heights less than 4.2 feet ($H_{1/10}$ = 5.1 foot). From Table 13 it is seen that 99.7% of all waves during all months were less than $H_s$ of 9.5 feet ($H_{1/10}$ of 12.2 foot). If $H_s$ = 9.5 feet is of no concern to the coastal engineer, than seasonality should be of no concern. However, twice as many waves over 5 feet occurred between December and March (5.4%) than between April-August (2.2%), though in either case, the total number was small.

Figure 3 also compares seasonal and monthly average significant wave heights. The data clearly shows that the use by NOAA (see discussion of Tables 7 & 8) of seasonal groupings which include September as a summer month is not a good practice for this area. September average significant wave heights are as large as those for the winter months. This conclusion confirms Hayden's data of winter to summer transition during August.

## Wave Direction

The direction of wave approach changes between winter and summer months. Figures 10 & 11, depicting data presented in Table 9, show the predominance of Southeast and Easterly components during the summer, and Northeast and Easterly components during the winter for nearshore wave conditions (COSOP data).

## REPRESENTATIVENESS OF VIRGINIA BEACH GAGE WAVE DATA

For nearshore coastal engineering design and planning, a wave gage supplies the most reliable and objective wave climatology available. However, application of these gage data is limited by two critical issues: 1) The period of record for the gage (4/64-10/69) may not represent typical wave conditions, but instead abnormally calm or stormy periods; 2) The location and depth of the gage may not reflect conditions at the exact location of the proposed structure. These problems are discussed below.

1) As noted in the first section describing the design of the Virginia Beach gage, data from a step resistant gage is a conservative estimate of wave height distributions.

2) Data collected by W.S. Richardson at Techniques Development Lab of the U.S. Weather Service between 1957-1969 indicate that there were an average of three extratropical storms per year. Table 14 lists the occurrence of tropical and extratropical storms during the period of operation of the Virginia Beach gage. There were 16 extratropical storms over

a five year period, or an average of 3 storms/year. There were also a number of intense storms during the same period (e.g., 1/16/65, 11/9/68, 3/1/69).

3) Table 14 also lists tropical storms during the period of record of the gage from data compiled by the Norfolk Weather Station. The storms listed do not represent the most intense hurricanes of the century, but only extratropical events of average intensity.

4) Comparisons such as Figures 3 & 7 demonstrate that the average significant wave heights from the wave gage data fit well into the range of values expected due to waves crossing the shelf.

5) a. Table 15 summarizes the data available in the VIMS Virginian Sea Wave Climate Model Data Bank (Goldsmith, et al., 1974) of the changes in wave height due to refraction, shoaling and friction between deep water and depths of 30 to 20 feet for a variety of wave directions and periods. The data presented is for an average of 6 to 10 rays reaching the Virginia Beach to Dam Neck area. From Table 15 it is seen that these wave heights change an average of only .1 foot between a depth of 20 and 30 feet while passing over this shelf area.

b. The alongshore variation in wave heights between 6 to 10 wave rays is negligible.

6) Except for a very limited number of waves the gage located in 20 feet of water measures only nonbreaking waves (see following section).

From the above discussion it can be concluded that forty-five months of data recorded by a gage located in 20 feet of water at Virginia Beach is directly applicable to conditions at Dam Neck in 30 feet of water at the proposed depth of the diffuser section, subject to detailed wave refraction studies.

## EXTREME WAVE CLIMATE

The magnitude and frequency of occurrence of extreme wave events determine the design of many marine structures. Near-shore wave gages provide the most reliable recorded data for construction of extreme wave climates. Tables 13 & 14, and Figure 7 & 8 summarize the most pertinent extreme wave data.

The highest significant wave height ($H_s$) which occurred during the entire period of record of the Virginia Beach was 11.5 feet. However, given the definition of $H_s$ we know that waves above 11.5 feet occurred. During the 19 hours of measured $H_s$ = 11.5 feet a number of waves up to 14.7 feet ($H_{1/10}$) and a very small number of waves up to 20.4 feet ($H_{max}$) could be expected. During the entire record of the gage the highest wave likely to have occurred was 20.4 feet, but only very few (less than ten) isolated waves would reach this height.

It is of interest to the coastal engineer whether or not waves will be breaking over the proposed structure. Munk (1949) established the relation:

$$\frac{D_b}{H_b} = 1.28$$

where $D_b$ = water depth at breaking

where $H_b$ = water height at breaking

This relation provides a rough idea of the limiting height or depth of breaking waves. No recorded $H_s$ or $H_{1/10}$ would have broken at the gage while the $H_{max}$ recorded was probably just beginning to break. A storm condition with 20 foot waves might be expected to be accompanied by a storm surge of several feet which at high tide could increase the water depth at the gage to 26 feet. Thus, the rare $H_{max}$ of 20.4 feet would just break at this 26 foot depth. Therefore, the Virginia Beach gage recorded exclusively nonbreaking waves, with only a few exceptions (less than 10).

On the other hand in 30 feet of water, the depth of the proposed diffuser, (or 36 feet in a severe storm) no waves which were recorded by the Virginia Beach gage would have been breaking waves.

The extreme wave climate presented in this report is limited by the length of record. Between 1964 and 1969 no waves of $H_s$ over 11.5 feet were observed. This does not necessarily mean that no waves with higher significant wave heights will occur at the proposed site. For example, a significant wave height greater than 11.5 feet might have occurred during the 1962 Ash Wednesday storm, the 100 year storm. Anticipated wave heights for such a storm could be estimated using wave hindcasting and refraction techniques.

However, extrapolation of Figure 8 to low frequencies of occurrence seems justifiable from the comparison of the Virginia Beach gage curve with longer record curves such as the ship data. Extrapolated to the .01 percent level, a wave height $H_s$ = 13.5, $H_{1/10}$ = 17.28 and a $H_{max}$ = 23.9 feet might be expected to occur one day in 27 years. Therefore this extrapolated wave height distribution might be a better estimate of the extreme wave height that is likely to occur in the Virginia Beach Dam Neck area than the shorter period measured waves. The fact that the gage design itself promotes conservative height estimates supports this conclusion.

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TABLE 1.

| WAVE SOURCES | ERRORS & LIMITATIONS |
|---|---|
| COAST GUARD-CERC COOPERATIVE SURF OBSERVATION PROGRAM at Virginia Beach C. G. Station | 1) Surf zone conditions only<br>2) Waves fully affected by:<br>a. Refraction<br>b. Bottom friction<br>c. Wave breaking<br>3) Site specific with respect to longshore variations of wave energy<br>4) Data often lacking for extreme events (CERC, 1973)<br>5) Observer bias and errors<br>6) Observations at unknown tidal stage<br>APPLICATION SITE SPECIFIC AND SHOULD NOT BE USED FOR SPECIFIC STRUCTURAL DESIGN |
| VIMS-CERC VOLUNTARY WAVE OBSERVER PROGRAM at 10 Locations along the Coast | 1) Surf zone conditions only<br>2) Waves fully affected by:<br>a. Refraction<br>b. Bottom friction<br>c. Wave breaking<br>3) Data usually lacking for extreme events<br>4) Observer bias and errors<br>5) Short duration of record<br>6) One observation per day and 5/week<br>7) Untrained observers<br>8) Many sites along coast<br>9) Observations at unknown tidal stage<br>APPLICATION ONLY TO ESTIMATE LONGSHORE VARIATION OF WAVE ENERGY |
| VIRGINIA BEACH WAVE GAGE | 1) Nearshore conditions<br>2) Wave affected by:<br>a. Refraction<br>b. Bottom friction<br>3) Non-directional record<br>4) Overestimate of height due to gage type<br>5) Incomplete record<br>6) Two methods of recording and analyses<br>7) Site specific<br>MOST RELIABLE AND PRECISE INFORMATION SEAWARD OF BREAKERS UNDER ALL CONDITIONS FOR NEARSHORE DESIGN AND PLANNING PROBLEMS |

Table 1. (cont.)

| WAVE SOURCES | ERRORS & LIMITATIONS |
|---|---|
| CHESAPEAKE LIGHTSHIP OBSERVATIONS | 1) Inner shelf (40 ft. depths) conditions<br>2) Ambiguity and errors with coding of data<br>3) Unreliable wave observers<br>4) Evacuated during extreme events<br>5) Short duration of record<br>PROVIDES A WAVE CLIMATOLOGY, ALTHOUGH NOT PRECISE FOR MIDDEPTH CONDITIONS |
| SHIPBOARD WAVE OBSERVATIONS | 1) Deep water conditions<br>2) Data grouped from many locations and depths<br>3) Ambiguity and errors due to coding of data<br>4) Unreliable, untrained wave observers<br>5) Ships avoid extreme wave events<br>PROVIDES A WAVE CLIMATOLOGY, ALTHOUGH NOT PRECISE FOR DEEP WATER CONDITIONS |
| SMB HINDCAST COMPUTATIONS | 1) Assume deep water conditions 360° around site<br>2) Simple model used to generate the wave parameters<br>3) Short period of record<br>4) Changing metereological conditions since sample period (1948-1950)<br>5) Appears to give highest % of larger wave heights, and therefore may be biased towards extreme events<br>PROVIDES A SIMPLE, ALTHOUGH NOT PRECISE ESTIMATE OF WAVE CONDITIONS FOR DEEP WATER |

Table 2.

COSOP 4/54-12/65

Average Percentages for Significant
Wave Heights (rows) by Direction (columns)

| | North | NE | East | SE | South | SW | West | NW | Total |
|---|---|---|---|---|---|---|---|---|---|
| 0-1 | .00 | .02 | .16 | .06 | .00 | .00 | .00 | .00 | .24 |
| 1-2 | .02 | 5.04 | 18.72 | 12.79 | .00 | .00 | .00 | .00 | 36.58 |
| 2-3 | .01 | 8.80 | 17.70 | 13.99 | .03 | .00 | .00 | .00 | 40.53 |
| 3-4 | .00 | 6.34 | 5.77 | 3.98 | .00 | .00 | .00 | .00 | 16.10 |
| 4-5 | .00 | 2.51 | 1.26 | .64 | .00 | .00 | .00 | .00 | 4.41 |
| 5-6 | .00 | .91 | .41 | .09 | .00 | .00 | .00 | .00 | 1.41 |
| 6-7 | .01 | .34 | .18 | .08 | .00 | .00 | .00 | .00 | .60 |
| 7-8 | .00 | .03 | .02 | .03 | .00 | .00 | .00 | .00 | .07 |
| 8-9 | .00 | .02 | .00 | .02 | .00 | .00 | .00 | .00 | .04 |
| 9-10 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| 10+ | .00 | .00 | .01 | .00 | .00 | .00 | .00 | .00 | .02 |
| | | | | | | | | | 100.00 |
| Total | .04 | 24.00 | 44.23 | 31.68 | .04 | .01 | .00 | .00 | 100.00 |
| % ≥ 5 feet | .01 | 1.30 | .61 | .22 | 0 | 0 | 0 | 0 | 2.14 |

Table 3.

CHESAPEAKE LIGHTSHIP 1/70-12/72

Average Percentages for Significant
Wave Heights (rows) by Direction (columns)

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 2.18 | 4.23 | 3.25 | 3.73 | 5.2 | 5.93 | 4.85 | 29.37 |
| 1-1.5 | 3.85 | 7.7 | 6.38 | 7.93 | 6.78 | 7.58 | 3.95 | 44.17 |
| 2-2.5 | .31 | 1.3 | 1.28 | .75 | .6 | .38 | .38 | 5.0 |
| 3-3.5 | .1 | .58 | .15 | .33 | .03 | .05 | .05 | 1.29 |
| 4-5.5 | .05 | 0 | 0 | .03 | .03 | 0 | 0 | .11 |
| 6-7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 6.485 | 13.08 | 11.05 | 12.75 | 12.63 | 13.93 | 9.23 | 79.94 |
| % ≥ 3 meters | .15 | .58 | .15 | .36 | .06 | .05 | .05 | 1.40 |

Table 4.

SHIP OBSERVATIONS 12/48-12/72

Average Percentages for Significant Wave Heights (rows) by Direction (columns)

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 2.78 | 2.98 | 3.25 | 3.03 | 2.48 | 4.23 | 4.48 | 23.23 |
| 1-1.5 | 4.7 | 3.8 | 4.96 | 4.03 | 2.48 | 4.03 | 3.83 | 27.83 |
| 2-2.5 | 1.23 | 1.2 | 1.2 | .5 | .35 | .43 | .53 | 5.44 |
| 3-3.5 | .35 | .4 | .33 | .18 | .04 | .13 | .1 | 1.53 |
| 4-5.5 | .06 | .1 | .21 | .06 | .03 | 0 | .05 | .5 |
| 6-7.5 | 0 | .06 | .01 | 0 | 0 | 0 | 0 | .07 |
| 8-9.5 | 0 | .01 | .01 | 0 | 0 | 0 | 0 | .02 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 9.12 | 8.55 | 9.97 | 7.8 | 5.38 | 8.82 | 8.99 | 58.62 |
| % ≥ 3 meters | .41 | .5 | .54 | .24 | .07 | .13 | .15 | 2.1 |

Table 5.

SMB HINDCAST 1/48-12/50

Average Percentages for Significant Wave Heights (rows) by Direction (columns)

| | North | NNE | NE | ENE | East | ESE | SE | SSE | South | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| .5- 2 | 0 | 0 | 8.16 | 17.66 | 8.57 | 1.93 | 1.31 | .65 | .46 | 38.74 |
| 2- 4 | 0 | .03 | 5.83 | 12.94 | 5.10 | 1.71 | 1.23 | .70 | .62 | 28.16 |
| 4- 6 | 0 | .12 | 2.86 | 7.28 | 2.34 | 1.03 | .73 | .35 | .14 | 14.85 |
| 6- 8 | .01 | 0 | 2.05 | 3.50 | 1.11 | .44 | .34 | .23 | .14 | 7.91 |
| 8-10 | 0 | .13 | 1.12 | 1.40 | .72 | .35 | .34 | .11 | .09 | 4.26 |
| 10-12 | 0 | 0 | .62 | .73 | .40 | .08 | .20 | .11 | .10 | 2.24 |
| 12-14 | 0 | .12 | .62 | .43 | .15 | .18 | .11 | 0 | .03 | 1.64 |
| 14-16 | 0 | 0 | .37 | .34 | .05 | .06 | .05 | .02 | 0 | .89 |
| 16-18 | 0 | .01 | .20 | .11 | .03 | .03 | .02 | 0 | .02 | .42 |
| 18-20 | 0 | 0 | .14 | .11 | .05 | .02 | .02 | 0 | 0 | .32 |
| 20-25 | 0 | .02 | .15 | .15 | .05 | 0 | .02 | .05 | 0 | .44 |
| 25-30 | 0 | .01 | .04 | .09 | 0 | 0 | 0 | 0 | 0 | .14 |
| Total | .01 | .44 | 21.16 | 44.74 | 18.53 | 5.83 | 4.37 | 2.22 | 1.6 | 100.01 |
| % ≥ 10 feet | 0 | .16 | 2.4 | 5.8 | .69 | .37 | .42 | .18 | .15 | 10.17 |

Table 6.

## VIRGINIA BEACH GAGE 4/64-10/69

Average Percentages of Significant Height (columns) versus Period (rows)

| | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0- 1.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.0- 2.9 | .03 | .15 | .08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .21 |
| 3.0- 3.9 | .53 | 2.68 | .94 | .13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.92 |
| 4.0- 4.9 | .30 | 2.10 | 2.35 | .83 | .25 | .11 | 0 | 0 | 0 | 0 | 0 | 0 | 5.63 |
| 5.0- 5.9 | .38 | 3.21 | 3.66 | 1.61 | .58 | .38 | .03 | 0 | 0 | 0 | 0 | 0 | 9.47 |
| 6.0- 6.9 | .53 | 4.22 | 2.38 | 1.09 | .81 | .56 | .28 | .08 | 0 | 0 | 0 | 0 | 9.42 |
| 7.0- 7.9 | 1.06 | 5.64 | 2.43 | .78 | .48 | .38 | .28 | .18 | .11 | 0 | 0 | 0 | 10.28 |
| 8.0- 8.9 | 1.97 | 10.56 | 5.38 | .73 | .45 | .23 | .11 | .11 | .13 | .15 | .08 | .10 | 18.03 |
| 9.0- 9.9 | 1.06 | 9.88 | 2.68 | .58 | .20 | .15 | .11 | 0 | .15 | 0 | 0 | 0 | 13.75 |
| 10.0-10.9 | 1.21 | 5.33 | 2.27 | .56 | .28 | .01 | .15 | .03 | .03 | .03 | 0 | 0 | 8.79 |
| 11.0-11.9 | .53 | 2.58 | .99 | .30 | .08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.95 |
| 12.0-12.9 | .51 | 2.30 | 1.04 | .91 | .28 | .13 | .13 | 0 | 0 | 0 | 0 | 0 | 4.79 |
| 13.0-13.9 | .15 | .76 | .30 | .15 | .08 | .08 | 0 | 0 | 0 | 0 | 0 | 0 | 1.37 |
| 14.0-14.9 | .18 | .71 | .58 | .25 | .18 | .18 | .03 | .03 | 0 | 0 | 0 | 0 | 1.96 |
| 15.0-15.9 | .08 | .08 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .08 |
| 16.0-16.9 | 0 | .11 | .05 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .16 |
| Total | 8.52 | 50.30 | 26.15 | 7.98 | 3.67 | 2.29 | 1.11 | 1.09 | .41 | .18 | .08 | .10 | 100.00 |

Table 7.

SEASONAL AVERAGE SIGNIFICANT WAVE HEIGHT ($\bar{H}_s$) IN METERS AND STANDARD DEVIATION ($\sigma$)

| Source | $\bar{H}_s$ Winter | $\sigma$ Winter | $\bar{H}_s$ Spring | $\sigma$ Spring | $\bar{H}_s$ Summer | $\sigma$ Summer | $\bar{H}_s$ Fall | $\sigma$ Fall | Years |
|---|---|---|---|---|---|---|---|---|---|
| Ship Obser. | 1.23 | .85 | 1.12 | .77 | .80 | .57 | 1.15 | .76 | 12/48-12/73 |
| Ches. Light | 1.10 | .63 | 1.02 | .57 | .99 | .54 | 1.24 | .66 | 1/70-12/72 |
| SMB Hindcast | 1.28 | 1.10 | 1.09 | .90 | 1.11 | .93 | 1.07 | .94 | 1/48- 1/50 |
| COSOP | .76 | .93 | .71 | .85 | .73 | .94 | .79 | 1.03 | 4/54-12/65 |
| Va. Beach Gage | .70 | 1.43 | .61 | 1.08 | .58 | 1.15 | .74 | 1.23 | 4/64-10/69 |

Table 8.

SEASONAL AVERAGE SIGNIFICANT WAVE PERIOD ($\bar{T}_s$) AND STANDARD DEVIATION ($\sigma$)

| Source | $T_s$ Winter | $\sigma$ Winter | $T_s$ Spring | $\sigma$ Spring | $T_s$ Summer | $\sigma$ Summer | $T_s$ Fall | $\sigma$ Fall | Years |
|---|---|---|---|---|---|---|---|---|---|
| Ship Obser. | 5.37 | 1.7 | 5.21 | 1.87 | 5.18 | 1.44 | 5.43 | 1.71 | 12/48-12/73 |
| Ches. Light | 4.54 | .51 | 4.52 | .3 | 4.56 | .54 | 4.50 | .17 | 1/70-12/72 |
| SMB Hindcast | 10.44 | 2.92 | 10.0 | 2.41 | 9.56 | 2.84 | 9.89 | 2.96 | 1/48- 1/50 |
| COSOP | 5.9 | .77 | 5.98 | .64 | 6.01 | .70 | 5.93 | .78 | 4/54-10/65 |
| Va. Beach Gage | 8.2 | 2.71 | 7.93 | 2.39 | 8.49 | 2.10 | 8.80 | 2.48 | 4/64-10/69 |

Table 9.

CERC-COAST GUARD COOPERATIVE SURF OBSERVATION PROGRAM 4/54-12/65

Average Percentagés for Wave
Heights (rows) by Direction (columns)
December-March

| | North | N. East | East | S. East | South | S. West | Total |
|---|---|---|---|---|---|---|---|
| 0-1 | 0 | .1 | .3 | .1 | 0 | 0 | .5 |
| 1-2 | .1 | 7.5 | 20.9 | 7.4 | 0 | 0 | 35.9 |
| 2-3 | .06 | 13.4 | 17.0 | 10.0 | .2 | 0 | 40.66 |
| 3-4 | 0 | 8.2 | 5.0 | 2.7 | .1 | 0 | 16.0 |
| 4-5 | .05 | 3.0 | 1.2 | .6 | 0 | 0 | 4.85 |
| 5-6 | 0 | .8 | .3 | .1 | 0 | 0 | 1.2 |
| 6-7 | 0 | .4 | .4 | .2 | 0 | 0 | 1.0 |
| 7-8 | 0 | .2 | .1 | 0 | 0 | 0 | .3 |
| 8-9 | 0 | 0 | .2 | 0 | 0 | 0 | .2 |
| 9-10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | .21 | 33.6 | 45.4 | 21.1 | .3 | 0 | 100.6 |
| % ≥ 5 feet | 0 | 1.4 | 1.0 | .3 | 0 | 0 | 2.7 |

April-May

| | North | N. East | East | S. East | South | S. West | Total |
|---|---|---|---|---|---|---|---|
| 0-1 | 0 | .10 | .16 | .04 | 0 | 0 | .235 |
| 1-2 | 0 | 3.31 | 18.57 | 15.69 | 0 | 0 | 37.595 |
| 2-3 | 0 | 6.43 | 18.8 | 17.74 | 0 | 0 | 42.955 |
| 3-4 | 0 | 4.69 | 5.41 | 4.96 | 0 | 0 | 15.055 |
| 4-5 | 0 | 1.88 | 1.14 | .30 | 0 | 0 | 3.32 |
| 5-6 | 0 | .53 | .10 | .19 | 0 | 0 | .67 |
| 6-7 | 0 | .14 | 0 | 0 | 0 | 0 | .14 |
| 7-8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8-9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9-10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | 17.08 | 44.18 | 38.8 | 0 | 0 | 99.34 |
| % ≥ 5 feet | 0 | .67 | .1 | .19 | 0 | 0 | .96 |

Table 9. (cont.)

CERC-COAST GUARD COOPERATIVE SURF OBSERVATION PROGRAM 4/54-12/65

Average Percentages for Wave
Heights (rows) by Direction (columns)
June-September

| | North | N. East | East | S. East | South | S. West | Total |
|---|---|---|---|---|---|---|---|
| 0-1 | 0 | 0 | 0 | .12 | 0 | 0 | .18 |
| 1-2 | 0 | 2.66 | 17.30 | 19.18 | 0 | 0 | 39.15 |
| 2-3 | 0 | 4.00 | 16.87 | 17.92 | .03 | 0 | 38.81 |
| 3-4 | .05 | 4.07 | 5.92 | 5.13 | 0 | 0 | 15.13 |
| 4-5 | 0 | 2.11 | 1.31 | .74 | 0 | 0 | 4.16 |
| 5-6 | 0 | 1.13 | .62 | .16 | 0 | 0 | 1.82 |
| 6-7 | 0 | .89 | .19 | .17 | 0 | 0 | .54 |
| 7-8 | 0 | 0 | .05 | .10 | 0 | 0 | .12 |
| 8-9 | 0 | 0 | 0 | .06 | 0 | 0 | .06 |
| 9-10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | .05 | 14.2 | 42.32 | 43.43 | .03 | 0 | 100.03 |
| % ≥ 5 feet | 0 | 2.02 | .86 | .49 | 0 | 0 | 2.6 |

October-November

| | North | N. East | East | S. East | South | S. West | Total |
|---|---|---|---|---|---|---|---|
| 0-1 | 0 | 0 | .02 | .24 | .11 | 0 | .38 |
| 1-2 | 0 | .05 | 6.83 | 17.56 | 7.19 | 0 | 31.63 |
| 2-3 | 0 | .02 | 12.11 | 19.01 | 9.53 | .03 | 40.71 |
| 3-4 | 0 | 0 | 9.13 | 6.79 | 3.05 | 0 | 18.98 |
| 4-5 | 0 | 0 | 3.07 | 1.48 | .9 | 0 | 5.45 |
| 5-6 | 0 | 0 | 1.04 | .67 | .12 | 0 | 1.83 |
| 6-7 | 0 | .05 | .81 | .14 | 0 | 0 | .99 |
| 7-8 | 0 | 0 | 0 | .02 | 0 | 0 | .03 |
| 8-9 | 0 | 0 | .03 | 0 | 0 | 0 | .02 |
| 9-10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10+ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | .12 | 33.03 | 45.91 | 20.91 | .03 | 100.0 |
| % ≥ 5 feet | 0 | .05 | 1.88 | .83 | .12 | 0 | 2.87 |

Table 10.

CHESAPEAKE LIGHTSHIP 1/70-12/72

Seasonal Average Percentages for Significant
Wave Heights (rows) by Direction (columns)

December-March

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 3.1 | 5.6 | 3.6 | 2.2 | 3.1 | 3.6 | 4.9 | 26.1 |
| 1-1.5 | 3.7 | 7.0 | 6.6 | 3.9 | 4.5 | 5.4 | 4.7 | 35.8 |
| 2-2.5 | .8 | 1.2 | .7 | .4 | .2 | .5 | .2 | 4.0 |
| 3-3.5 | .1 | .2 | .2 | .2 | .1 | 0 | .1 | .9 |
| 4-5.5 | .1 | 0 | 0 | 0 | 0 | 0 | 0 | .1 |
| 6-7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 7.8 | 13.9 | 11.0 | 6.7 | 7.8 | 9.5 | 9.9 | 66.9 |
| % ≥ 3 meters | .2 | .2 | .2 | .2 | .1 | 0 | .1 | 1.0 |

April-May

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 3.5 | 2.4 | 2.5 | 4.2 | 4.6 | 7.4 | 6.7 | 31.3 |
| 1-1.5 | 3.7 | 7.1 | 5.1 | 9.6 | 6.1 | 11.1 | 3.5 | 46.2 |
| 2-2.5 | 0 | .3 | .5 | .3 | .7 | .2 | .2 | 2.2 |
| 3-3.5 | .3 | 1.3 | 0 | 0 | 0 | 0 | 0 | 1.6 |
| 4-5.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6-7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 7.6 | 11.1 | 8.1 | 14.2 | 11.3 | 18.7 | 10.5 | 81.3 |
| % ≥ 3 meters | .3 | 1.3 | 0 | 0 | 0 | 0 | 0 | 1.6 |

Table 10. (cont.)

CHESAPEAKE LIGHTSHIP 1/70-12/72

Seasonal Average Percentages for Significant
Wave Heights (rows) by Direction (columns)
June-September

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | .7 | 3.8 | 4.1 | 5.9 | 9.5 | 8.7 | 5.6 | 38.3 |
| 1-1.5 | 4.0 | 6.9 | 4.0 | 8.0 | 9.0 | 9.2 | 5.5 | 46.6 |
| 2-2.5 | .3 | 1.1 | 1.4 | .5 | .1 | .5 | .5 | 4.4 |
| 3-3.5 | 0 | .1 | .1 | .5 | 0 | .1 | .1 | .9 |
| 4-5.5 | .1 | 0 | 0 | 0 | .1 | 0 | 0 | .2 |
| 6-7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 5.1 | 11.8 | 9.5 | 14.9 | 18.6 | 18.5 | 11.6 | 90.4 |
| % ≥ 3 meters | .1 | .1 | .1 | .5 | 0 | .1 | .1 | 1.1 |

October-November

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 1.4 | 5.1 | 2.8 | 2.6 | 3.6 | 4.0 | 2.2 | 21.7 |
| 1-1.5 | 4.0 | 9.8 | 9.8 | 10.2 | 7.5 | 4.6 | 2.1 | 48.0 |
| 2-2.5 | 1.4 | 2.6 | 2.5 | 1.8 | 1.4 | .3 | .6 | 10.6 |
| 3-3.5 | 0 | .8 | .3 | .6 | 0 | .1 | 0 | 1.8 |
| 4-5.5 | 0 | 0 | 0 | .1 | 0 | 0 | 0 | .1 |
| 6-7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 6.8 | 18.4 | 15.4 | 15.4 | 12.4 | 9.0 | 4.8 | 82.2 |
| % ≥ 3 meters | 0 | .8 | .3 | .7 | 0 | .1 | 0 | 1.9 |

Table 11.

SHIP OBSERVATIONS 12/48-12/72

Seasonal Average Percentages for Significant Wave Heights (rows) by Direction (columns)
December-March

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 3.4 | 3.4 | 2.7 | 2.0 | 1.6 | 2.5 | 2.6 | 18.2 |
| 1-1.5 | 6.1 | 4.8 | 4.4 | 2.9 | 1.7 | 2.7 | 3.5 | 26.1 |
| 2-2.5 | 1.8 | 1.2 | 1.8 | .4 | .3 | .5 | .6 | 6.6 |
| 3-3.5 | .4 | .3 | .4 | .1 | .05 | .2 | .2 | 1.65 |
| 4-5.5 | .05 | .1 | .2 | .05 | 0 | 0 | .05 | .45 |
| 6-7.5 | 0 | .1 | 0 | 0 | 0 | 0 | 0 | .1 |
| 8-9.5 | 0 | .05 | .05 | 0 | 0 | 0 | 0 | .1 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 11.7 | 9.8 | 9.5 | 5.3 | 3.6 | 5.8 | 6.9 | 53.2 |
| % ≥ 3 meters | .45 | .55 | .65 | .15 | .05 | .2 | .25 | 2.3 |

April-May

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 2.4 | 2.5 | 3.4 | 3.4 | 2.6 | 4.9 | 5.7 | 24.9 |
| 1-1.5 | 4.0 | 5.3 | 4.6 | 5.2 | 2.1 | 5.6 | 4.6 | 31.4 |
| 2-2.5 | 1.0 | .9 | .6 | .5 | .3 | .4 | .7 | 4.49 |
| 3-3.5 | .3 | .4 | .1 | .1 | .05 | .1 | .05 | 1.1 |
| 4-5.5 | 0 | 0 | 0 | .05 | 0 | 0 | .1 | .2 |
| 6-7.5 | 0 | .05 | 0 | 0 | 0 | 0 | 0 | .05 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 7.7 | 9.2 | 8.8 | 9.3 | 5.1 | 11.0 | 11.1 | 62.14 |
| % ≥ 3 meters | .3 | .45 | .1 | .15 | .1 | .1 | .15 | 1.35 |

Table 11. (cont.)

SHIP OBSERVATIONS 12/48-12/72

Seasonal Average Percentages for Significant Wave Heights (rows) by Direction (columns)

June-September

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 2.2 | 2.9 | 3.8 | 3.9 | 3.6 | 6.2 | 6.7 | 29.3 |
| 1-1.5 | 2.7 | 3.7 | 5.4 | 3.7 | 3.1 | 5.2 | 5.0 | 28.8 |
| 2-2.5 | .4 | 1.0 | 1.1 | .4 | .4 | .4 | .4 | 4.1 |
| 3-3.5 | .1 | .2 | .3 | .2 | .05 | .1 | .05 | 1.1 |
| 4-5.5 | .1 | .1 | .05 | .05 | .05 | 0 | 0 | .35 |
| 6-7.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 5.6 | 7.9 | 10.6 | 8.3 | 7.1 | 11.9 | 12.3 | 63.65 |
| % ≥ 3 meters | .2 | .3 | .35 | .25 | .1 | .1 | .05 | 1.45 |

October-November

| | 345°-15° | 15°-45° | 45°-75° | 75°-105° | 105°-135° | 135°-165° | 165°-195° | Total |
|---|---|---|---|---|---|---|---|---|
| < 1 | 3.1 | 3.1 | 3.1 | 2.8 | 2.1 | 3.3 | 2.9 | 20.4 |
| 1-1.5 | 6.0 | 5.2 | 5.4 | 4.3 | 3.0 | 2.6 | 2.2 | 28.7 |
| 2-2.5 | 1.7 | 1.7 | 1.3 | .7 | .4 | .4 | .4 | 6.6 |
| 3-3.5 | .6 | .7 | .5 | .3 | 0 | .1 | .1 | 2.3 |
| 4-5.5 | .1 | .2 | .1 | .1 | 0 | 0 | .05 | .55 |
| 6-7.5 | 0 | .1 | .05 | 0 | 0 | 0 | 0 | .15 |
| 8-9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| > 9.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 11.4 | 11.1 | 10.6 | 8.3 | 5.5 | 6.5 | 5.7 | 58.7 |
| % ≥ 3 meters | .7 | .0 | .65 | .4 | 0 | .1 | .15 | 3.0 |

Table 12.

## SMB HINDCAST 1/48-12/50

Seasonal Average Percentages for Significant
Wave Heights (rows) by Direction (columns)
December-March

| | North | NNE | NE | ENE | East | ESE | SE | SSE | South | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| .5-2 | 0 | 0 | 3.86 | 13.83 | 10.48 | 2.34 | 1.02 | .41 | .37 | 32.31 |
| 2-4 | 0 | .12 | 8.82 | 14.63 | 3.08 | 1.60 | 1.02 | .82 | .20 | 30.29 |
| 4-6 | 0 | .29 | 3.45 | 5.42 | 1.35 | .90 | .61 | .52 | .08 | 12.62 |
| 6-8 | .04 | 0 | 4.18 | 5.05 | .92 | .27 | .25 | .16 | .12 | 10.95 |
| 8-10 | 0 | .53 | 1.68 | 2.46 | .49 | .20 | .12 | .08 | 0 | 5.56 |
| 10-12 | 0 | 0 | .82 | 1.68 | .33 | 0 | 0 | 0 | .29 | 3.12 |
| 12-14 | 0 | .46 | .74 | .33 | .08 | 0 | 0 | 0 | 0 | 1.61 |
| 14-16 | 0 | 0 | .61 | .53 | .08 | 0 | 0 | 0 | 0 | 1.22 |
| 16-18 | 0 | .04 | .25 | .16 | .04 | 0 | 0 | 0 | .04 | .49 |
| 18-20 | 0 | 0 | .33 | .16 | .12 | 0 | 0 | 0 | 0 | .61 |
| 20-25 | 0 | .08 | .37 | .08 | .04 | 0 | 0 | 0 | 0 | .57 |
| 25-30 | 0 | .04 | .08 | .21 | 0 | 0 | 0 | 0 | 0 | .33 |
| Total | .04 | 1.56 | 25.19 | 44.53 | 17.01 | 5.31 | 3.02 | 1.99 | 1.1 | 99.68 |
| % ≥ 10 feet | 0 | .62 | 3.2 | 3.15 | .69 | 0 | 0 | 0 | 0 | 7.66 |

April-May

| | North | NNE | NE | ENE | East | ESE | SE | SSE | South | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| .5-2 | 0 | 0 | 7.07 | 24.08 | 5.33 | .61 | 0 | .92 | .10 | 38.11 |
| 2-4 | 0 | 0 | 4.61 | 19.26 | 6.15 | 1.02 | 1.02 | 1.33 | .92 | 34.31 |
| 4-6 | 0 | 0 | 2.15 | 9.02 | 1.64 | .20 | .20 | 0 | .10 | 13.31 |
| 6-8 | 0 | 0 | 1.13 | 3.59 | .82 | 0 | .10 | .10 | 0 | 5.74 |
| 8-10 | 0 | .20 | 1.02 | 1.43 | .40 | .10 | .20 | 0 | 0 | 3.35 |
| 10-12 | 0 | 0 | .92 | 1.22 | .20 | 0 | 0 | 0 | 0 | 2.34 |
| 12-14 | 0 | 0 | .72 | .82 | 0 | 0 | 0 | 0 | 0 | 1.54 |
| 14-16 | 0 | 0 | .72 | .82 | 0 | 0 | 0 | 0 | 0 | 1.54 |
| 16-18 | 0 | 0 | .10 | 0 | 0 | 0 | 0 | 0 | 0 | .10 |
| 18-20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20-25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25-30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 0 | .20 | 18.44 | 59.42 | 14.54 | 1.93 | 1.52 | 2.35 | 1.12 | 100.21 |
| % ≥ 10 feet | 0 | 0 | 2.46 | 2.86 | .20 | 0 | 0 | 0 | 0 | 5.52 |

Table 12. (cont.)

SMB HINDCAST 1/48-12/50

Seasonal Average Percentages for Significant Wave Heights (rows) by Direction (columns)
June-September

| | North | NNE | NE | ENE | East | ESE | SE | SSE | South | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| .5-2 | 0 | 0 | 13.07 | 14.45 | 4.92 | 1.62 | 1.56 | 1.20 | .96 | 37.78 |
| 2-4 | 0 | 0 | 4.86 | 8.96 | 5.65 | 1.74 | 1.48 | 1.68 | 3.37 | 28.78 |
| 4-6 | 0 | 0 | 3.42 | 5.03 | 2.57 | 1.44 | 1.50 | .78 | .18 | 14.87 |
| 6-8 | 0 | 0 | 1.20 | 2.28 | 1.86 | 1.08 | 1.02 | .24 | .12 | 7.80 |
| 8-10 | 0 | 0 | .84 | .48 | 1.08 | .84 | .84 | .24 | .30 | 4.62 |
| 10-12 | 0 | 0 | .54 | .60 | .54 | .72 | .78 | .30 | 0 | 3.48 |
| 12-14 | 0 | 0 | .24 | .54 | .18 | .24 | .36 | 0 | .06 | 1.62 |
| 14-16 | 0 | 0 | .06 | .24 | .06 | 0 | .18 | .06 | 0 | .60 |
| 16-18 | 0 | 0 | .30 | .12 | .06 | .12 | .06 | 0 | 0 | .66 |
| 18-20 | 0 | 0 | .24 | .18 | .12 | 0 | .06 | 0 | 0 | .60 |
| 20-25 | 0 | 0 | .24 | .06 | .06 | .18 | 0 | 0 | 0 | .54 |
| 25-30 | 0 | .06 | .06 | .06 | 0 | 0 | 0 | 0 | 0 | .18 |
| Total | 0 | .06 | 25.07 | 33.00 | 17.05 | 7.98 | 7.84 | 4.50 | 4.99 | 101.53 |
| % ≥ 10 feet | 0 | .06 | 1.68 | 1.8 | 1.02 | 1.26 | 1.44 | .36 | .06 | 7.68 |

October-November

| | North | NNE | NE | ENE | East | ESE | SE | SSE | South | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| .5-2 | 0 | 0 | 7.86 | 18.28 | 10.15 | 2.42 | 2.08 | .40 | .27 | 41.46 |
| 2-4 | 0 | 0 | 5.04 | 9.94 | 7.00 | 2.28 | .87 | .20 | .20 | 25.53 |
| 4-6 | 0 | .20 | 2.42 | 8.26 | 4.23 | 1.21 | .81 | .54 | .07 | 17.74 |
| 6-8 | 0 | 0 | 1.68 | 4.57 | 1.41 | .20 | 0 | .47 | .27 | 8.60 |
| 8-10 | 0 | 0 | .94 | .67 | .74 | .02 | 0 | .07 | .07 | 2.51 |
| 10-12 | 0 | 0 | .20 | .27 | .33 | .33 | 0 | .07 | 0 | 1.20 |
| 12-14 | 0 | 0 | .54 | .40 | .20 | .20 | 0 | 0 | 0 | 1.34 |
| 14-16 | 0 | 0 | .07 | .40 | 0 | .07 | 0 | 0 | 0 | .54 |
| 16-18 | 0 | 0 | .13 | .07 | 0 | 0 | 0 | 0 | 0 | .20 |
| 18-20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20-25 | 0 | 0 | .42 | 0 | 0 | 0 | 0 | 0 | 0 | .42 |
| 25-30 | 0 | 0 | .20 | .20 | 0 | 0 | 0 | 0 | 0 | .40 |
| Total | 0 | .20 | 19.50 | 43.06 | 24.06 | 6.73 | 3.76 | 1.75 | .88 | 99.94 |
| % ≥ 10 feet | 0 | 0 | 1.56 | 1.14 | .53 | .60 | 0 | .07 | .07 | 3.97 |

Table 13.

VIRGINIA BEACH GAGE

Duration (hours) of the Highest .3% Waves

| | (calculated) | | (calculated) | | (calculated) | |
|---|---|---|---|---|---|---|
| | 9.5 feet | $H_s$ | 10.5 feet | $H_s$ | 11.5 feet | |
| | 12.2′ | $H_{1/10}$ | 13.4′ | $H_{1/10}$ | 14.7′ | |
| | 16.82′ | $H_{max}$ | 18.6′ | $H_{max}$ | 20.4′ | |
| | | | | | | Total |
| December | 0 hours | | 7.3 hours | | 0 hours | 7.3 hours |
| January | 24.8 | | 19.3 | | 19.3 | 63.4 |
| March | 6.0 | | 6.0 | | 0 | 12.0 |
| May | 12.5 | | 0 | | 0 | 12.5 |
| October | 5.5 | | 0 | | 0 | 5.5 |
| Total | 48.8 | | 32.6 | | 19.3 | 100.7 |

Total of 100.7 hours of waves between 9-12 feet $H_s$ out of 32,338 hours of record, or .3%.

Table 14.

VIRGINIA BEACH GAGE

Occurence of Extratropical Storms
During Period of Operation

| Name | Date of Storm | Surge | WIND Speed (mph) | WIND Direction | WAVE HEIGHT $H_s$ | WAVE HEIGHT $H_{1/10}$ | WAVE HEIGHT $H_{max}$ | Va. Beach Gage Operating (?) |
|---|---|---|---|---|---|---|---|---|
| | 1/04/64 | 2.0′ | 28 | W | * | * | * | √ |
| | 1/12/64 | 2.5′ | 42 | E | 11.0 | 14.1 | 19.5 | √ |
| | 2/12/64 | 2.0′ | 32 | E | 10.0 | 12.8 | 17.7 | √ |
| | 1/16/65 | 4.0′ | 35 | NE | 12.1 | 15.5 | 21.5 | √ |
| | 1/22/65 | 3.0′ | 36 | E | | | | - |
| | 1/29/66 | 3.5′ | 37 | E | 11.5 | 14.7 | 20.4 | √ |
| | 12/24/66 | 2.3′ | 31 | NE | 6.7 | 8.6 | 11.9 | √ |
| | 2/07/67 | 2.7′ | 33 | NE | 6.0 | 7.7 | 10.7 | √ |
| | 12/12/67 | 2.0′ | 30 | E | 1.5 | 2.0 | 2.7 | √ |
| | 12/29/67 | 2.0′ | 31 | W | 6.0 | 7.7 | 10.7 | √ |
| | 1/14/68 | 2.3′ | 33 | E | 11.0 | 14.1 | 19.6 | √ |
| | 2/08/68 | 2.5′ | 30 | NE | 8.5 | 10.9 | 15.1 | √ |
| | 11/10/68 | 4.3′ | 34 | N | 8.5 | 10.9 | 15.1 | √ |
| | 11/12/68 | 2.5′ | 47 | NE | 9.7 | 12.4 | 17.1 | √ |
| | 3/02/69 | 6.0′ | 40 | N | 10.4 | 13.3 | 18.5 | √ |
| | 11/02/69 | 2.5′ | 36 | NE | 12.0 | 15.4 | 21.2 | √ |
| **Occurence of Tropical Storms During Period of Operation** | | | | | | | | |
| Cleo | 9/01/64 | 1.0′ | 42 | ESE | | | | - |
| Dora | 9/13/64 | 3.5′ | 61 | NE | 12.5 | 16.0 | 22.1 | √ |
| Gladys | 9/23/64 | 2.2′ | 44 | N | 8.5 | 10.9 | 15.1 | √ |
| Isabell | 10/16/64 | 2.5′ | 50 | NE | 9.5 | 12.2 | 16.8 | √ |
| Alma | 6/13/66 | 1.0′ | 40 | N | 8.0 | 10.2 | 14.2 | √ |
| Doria | 9/16/67 | 4.0′ | 55 | N | 8.0 | 10.2 | 14.2 | √ |
| Gladys | 10/20/68 | 1.3′ | 46 | NE | 8.5 | 10.9 | 15.1 | √ |

*Gage was operating but record not available to author at this time

Table 15.

DECREASE OF COMPUTED WAVE HEIGHTS DUE TO REFRACTION, FRICTION AND SHOALING AT DAM NECK-VIRGINIA BEACH

(Average of 6-10 Wave Rays from Goldsmith, et al., 1974)

T = 8 seconds
$H_o$ = 6 feet
Tide = 0

| Water Depths | Northeast | East | Southeast |
|---|---|---|---|
| 20 feet | 1.19′ | 1.57′ | 2.18′ |
| 30 feet | 1.14′ | 1.59′ | 2.33′ |
| 150 feet ("deep" water) | 6.0′ | 6.0′ | 6.0′ |

T = 10 seconds
$H_o$ = 6 feet
Tide = 0

| Water Depths | Northeast | East | Southeast |
|---|---|---|---|
| 20 feet | 0.98′ | 1.9′ | 1.15′ |
| 30 feet | 0.97′ | 2.0′ | 1.18′ |
| 250 feet ("deep" water) | 6.0′ | 6.0′ | 6.0′ |

Table 16.

DAILY VOLUNTEER WAVE OBSERVATIONS AVERAGED BY SEASON

July 1974-Aug. 1976

| | | Winter | | | Spring | | | Summer | | | Fall | | | Total # obs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T | H | D° | T | H | D° | T | H | D° | T | H | D° | |
| Virginia Beach | 39th Street | 8.09 | 1.97 | 83.44 | | | | | | | | | | 28 |
| | 73rd Street | 6.54 | 1.68 | 94.54 | 6.66 | 1.72 | 89.06 | | | | | | | 168 |
| | Howard Johnson | | | | 7.71 | 1.5 | 100.78 | | | | | | | 9 |
| | Hilton Inn | | | | | | | 6.54 | 1.9 | 90.42 | 5.34 | 1.15 | 90.94 | 306 |
| | 7th St. | 10.84 | 1.93 | 91.08 | 9.68 | 2.30 | 91.40 | 10.76 | 2.02 | 98.04 | 10.86 | 2.60 | 91.68 | 341 |
| | Dam Neck | 8.66 | 1.52 | 91.33 | 8.6 | 1.32 | 91.4 | 10.50 | 1.97 | 97.52 | 10.32 | 2.13 | 8.55 | 529 |
| | Sandbridge | 9.44 | 1.91 | 93.33 | 8.26 | 2.68 | 87.13 | | | | | | | 39 |
| | Beacon Rest. | 7.05 | 1.68 | 38.56 | 8.90 | 1.42 | 36.27 | 8.37 | 2.52 | 93.43 | 9.86 | 1.86 | 94.5 | 268 |
| | Back Bay | 7.89 | 1.32 | 34. | 7.53 | 1.24 | 48.88 | 7.87 | 3.5 | 84.96 | 4.36 | 1.62 | 27.08 | 120 |
| | Currituck Beach Lt. North Carolina | | | | 8.11 | 2.25 | 87.78 | 7.72 | 2.22 | 68.05 | | | | 74 |
| | | | | | | | | | | | | | (Total) | 1882 |

T = Time (seconds)

H = Wave Height (feet) (1 ft. - 0.305 m)

D° = Direction (degrees: 90° = due east)

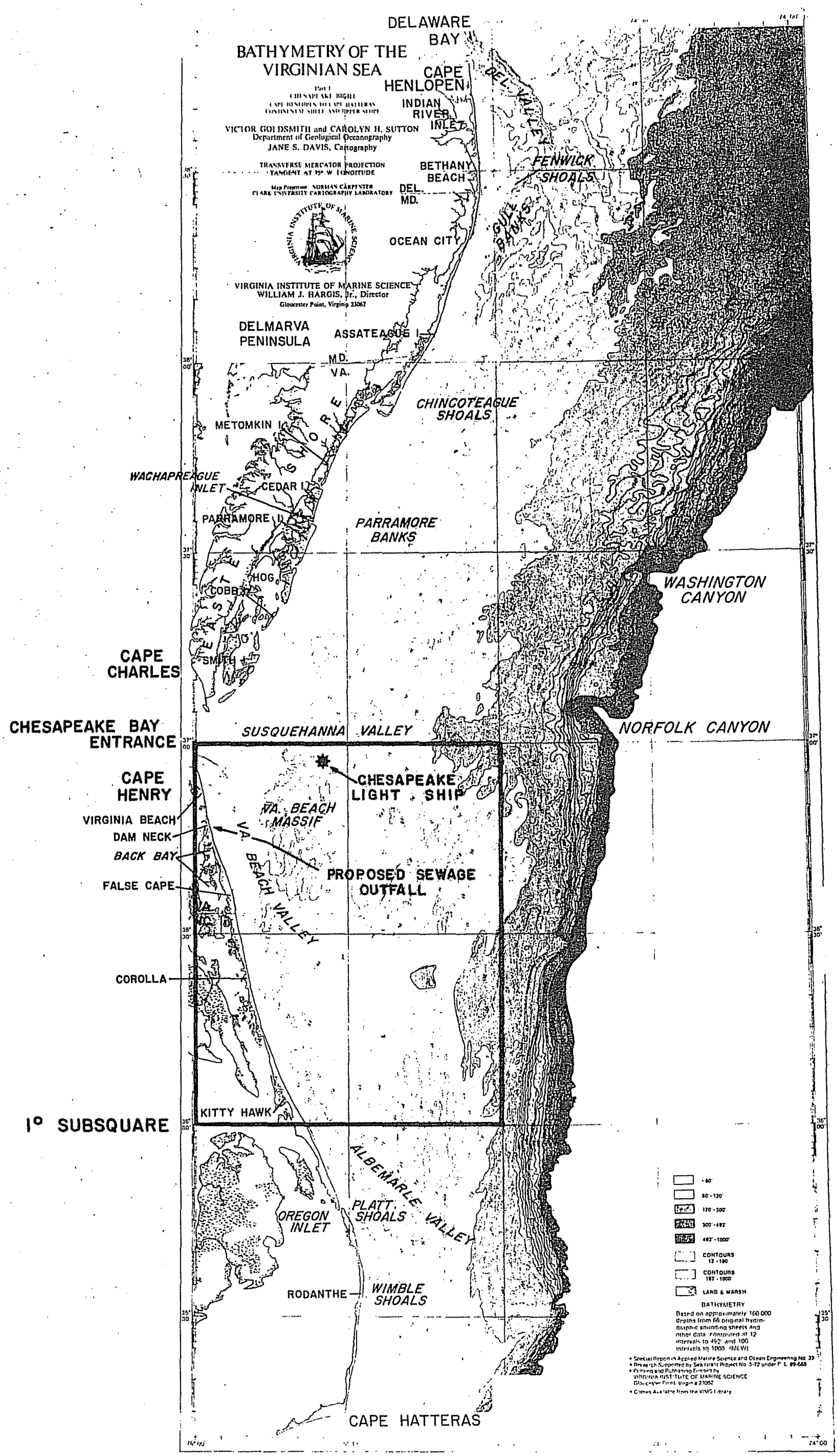



Figure 1a. Location Map

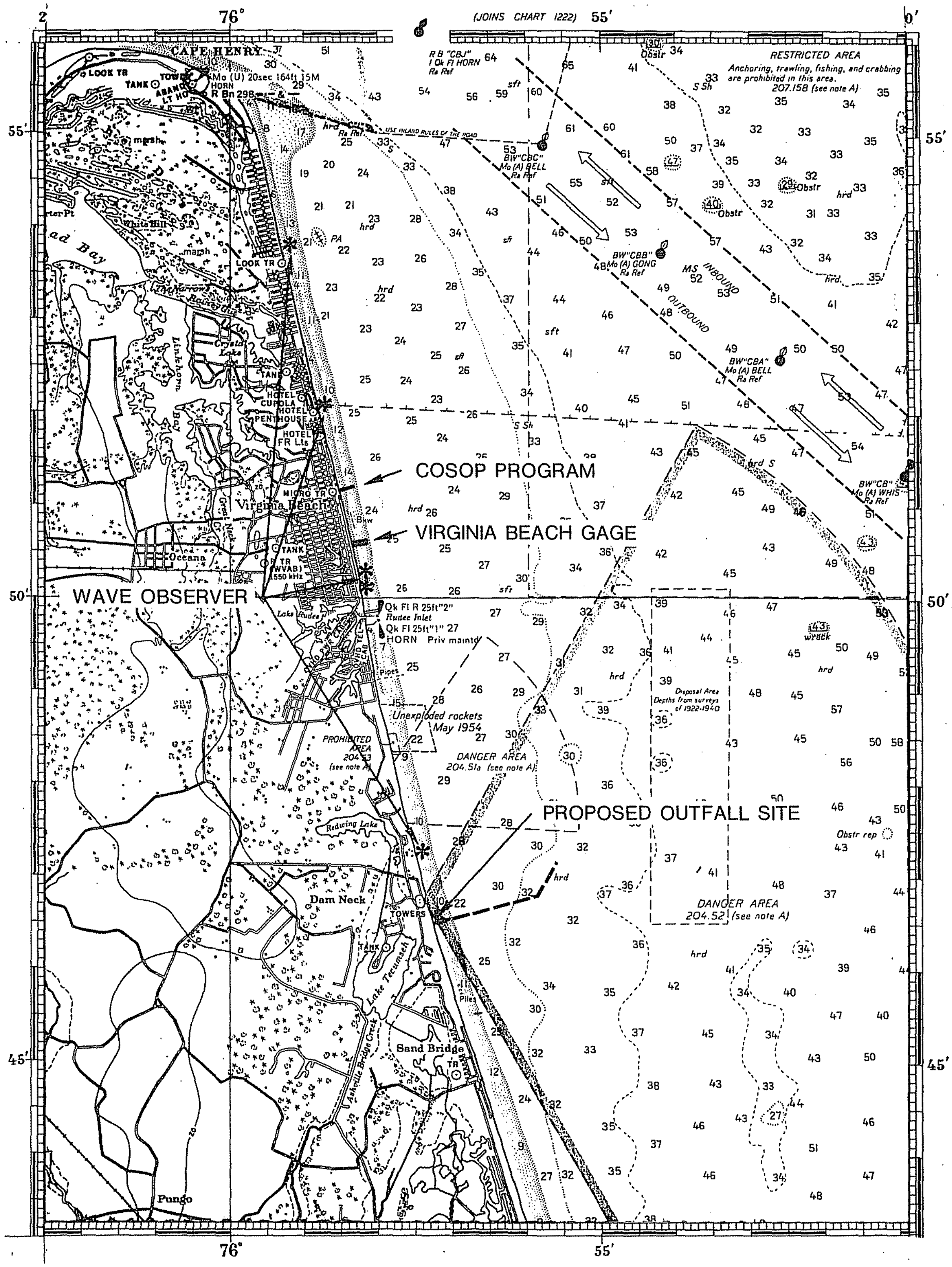



Figure 1b. Location Map

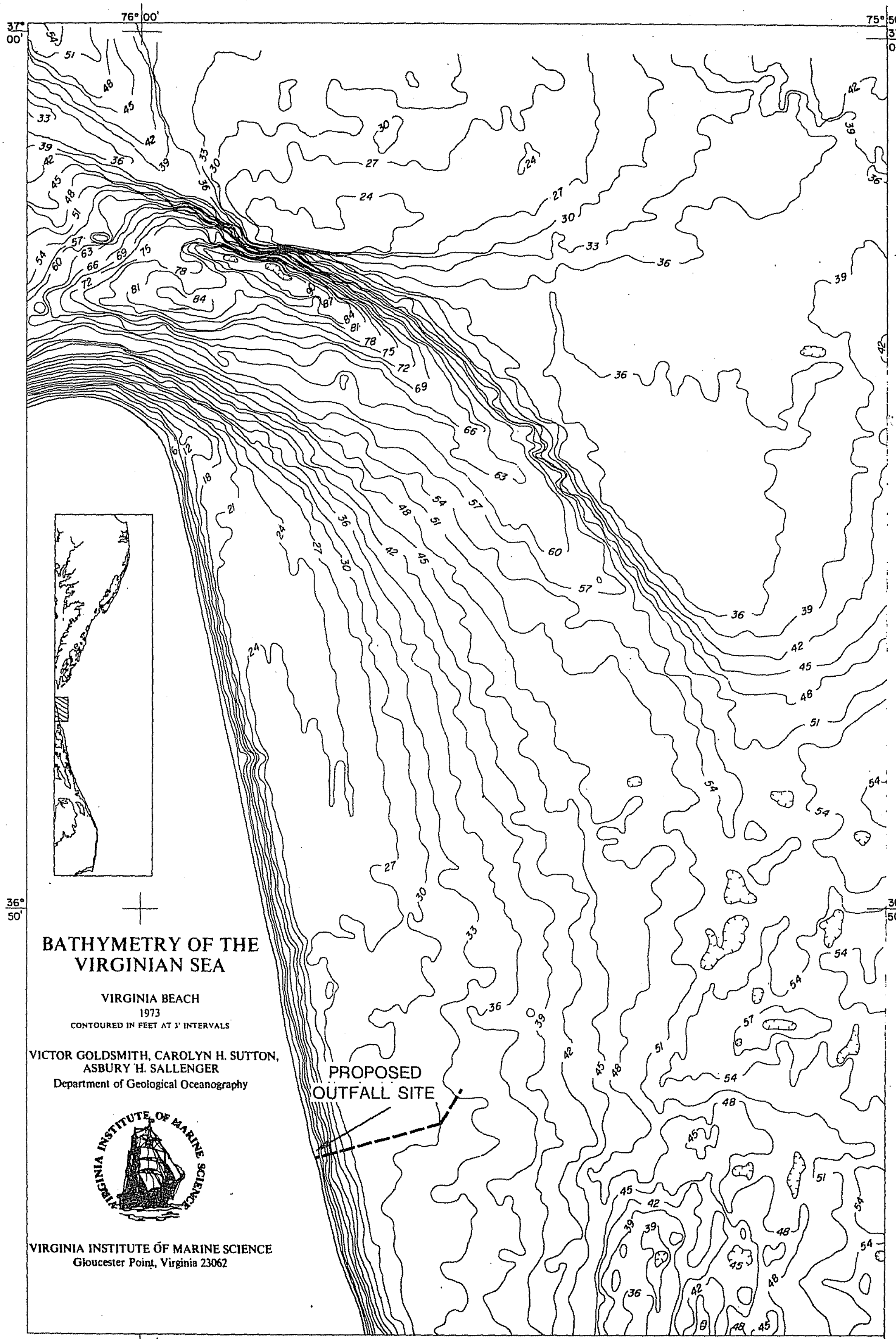



Figure 1c. Location Map

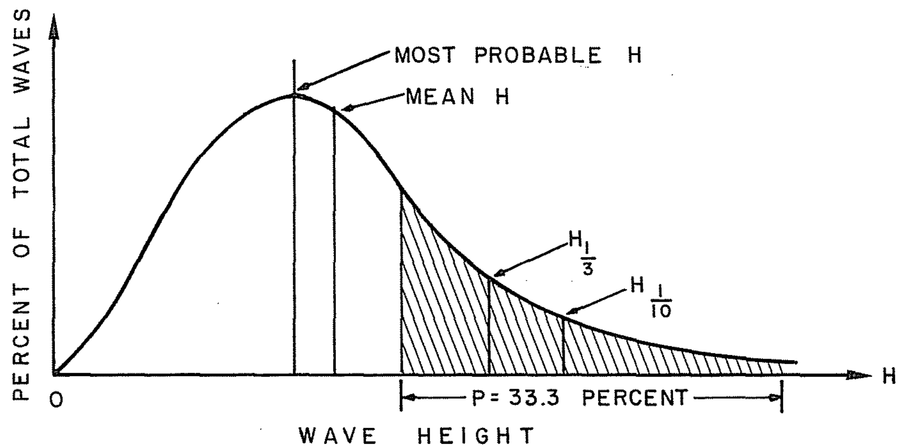



Figure 1d. Statistical Distribution of Wave Heights

Figure 2.

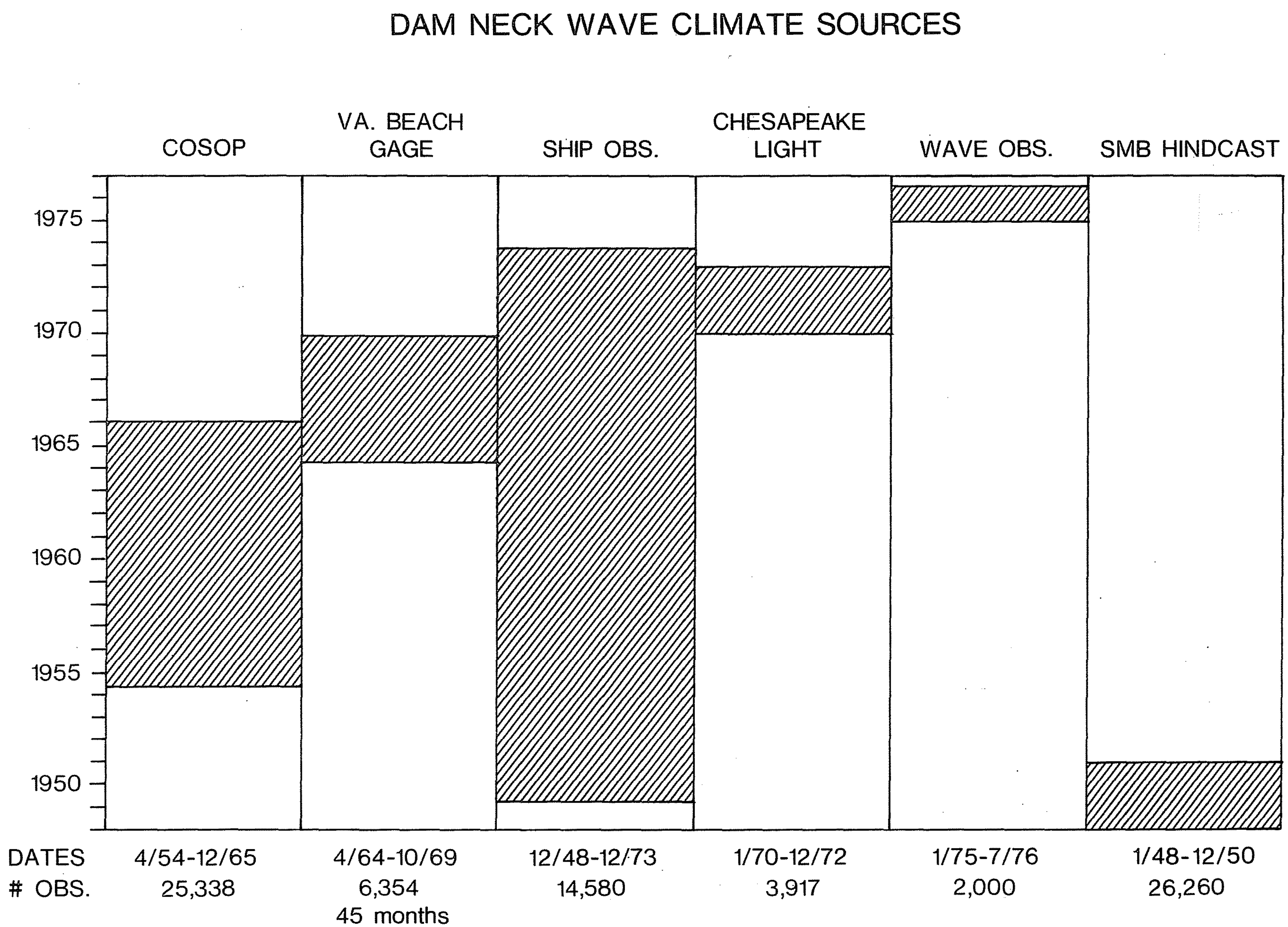
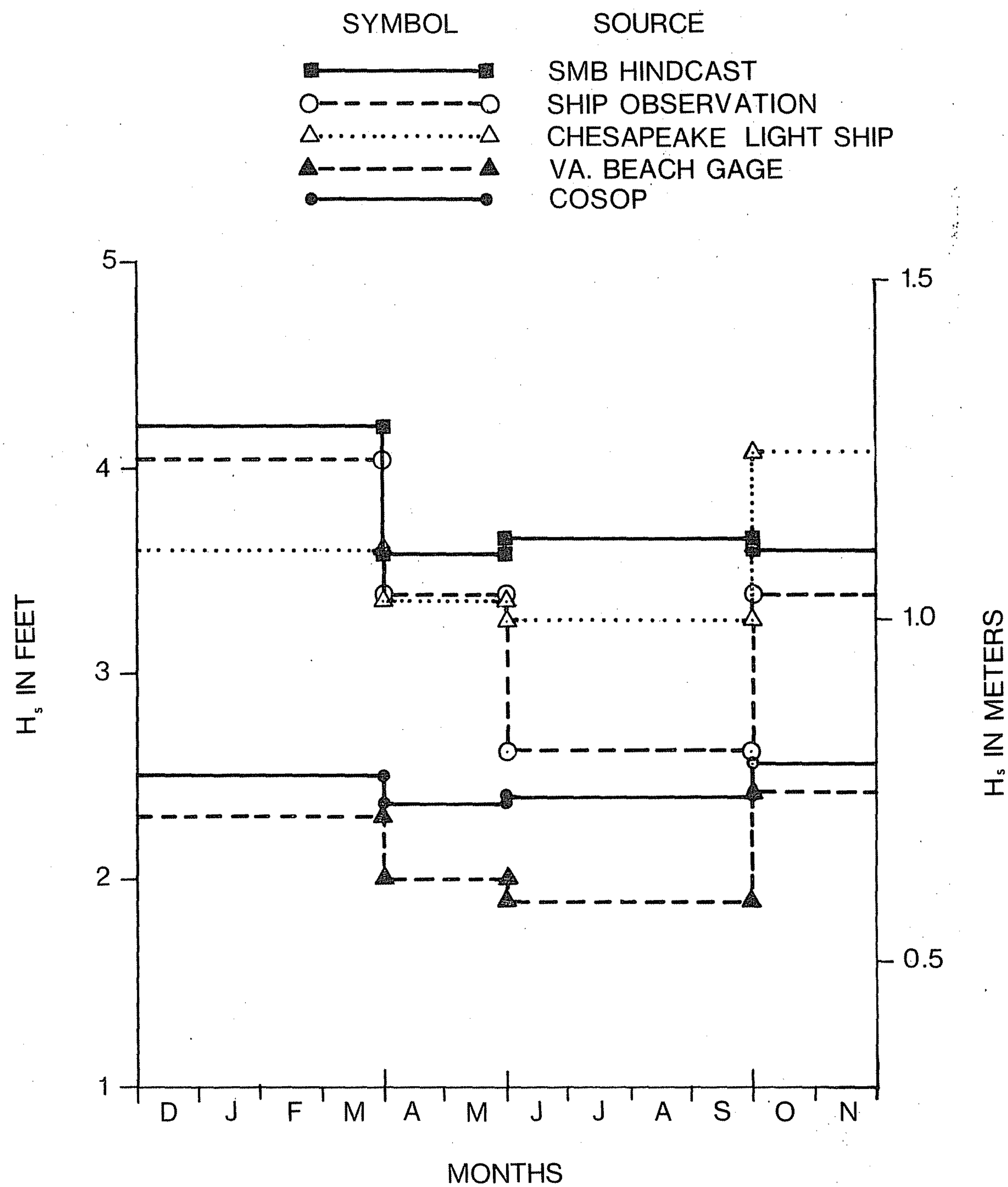

DAM NECK WAVE CLIMATE SOURCES
COSOP
VA. BEACH GAGE
SHIP OBS.
CHESAPEAKE LIGHT
WAVE OBS.
SMB HINDCAST
1975
1970
1965
1960
1955
1950
DATES
# OBS.
4/54-12/65
25,338
4/64-10/69
6,354
45 months
12/48-12/73
14,580
1/70-12/72
3,917
1/75-7/76
2,000
1/48-12/50
26,260

Figure 3.

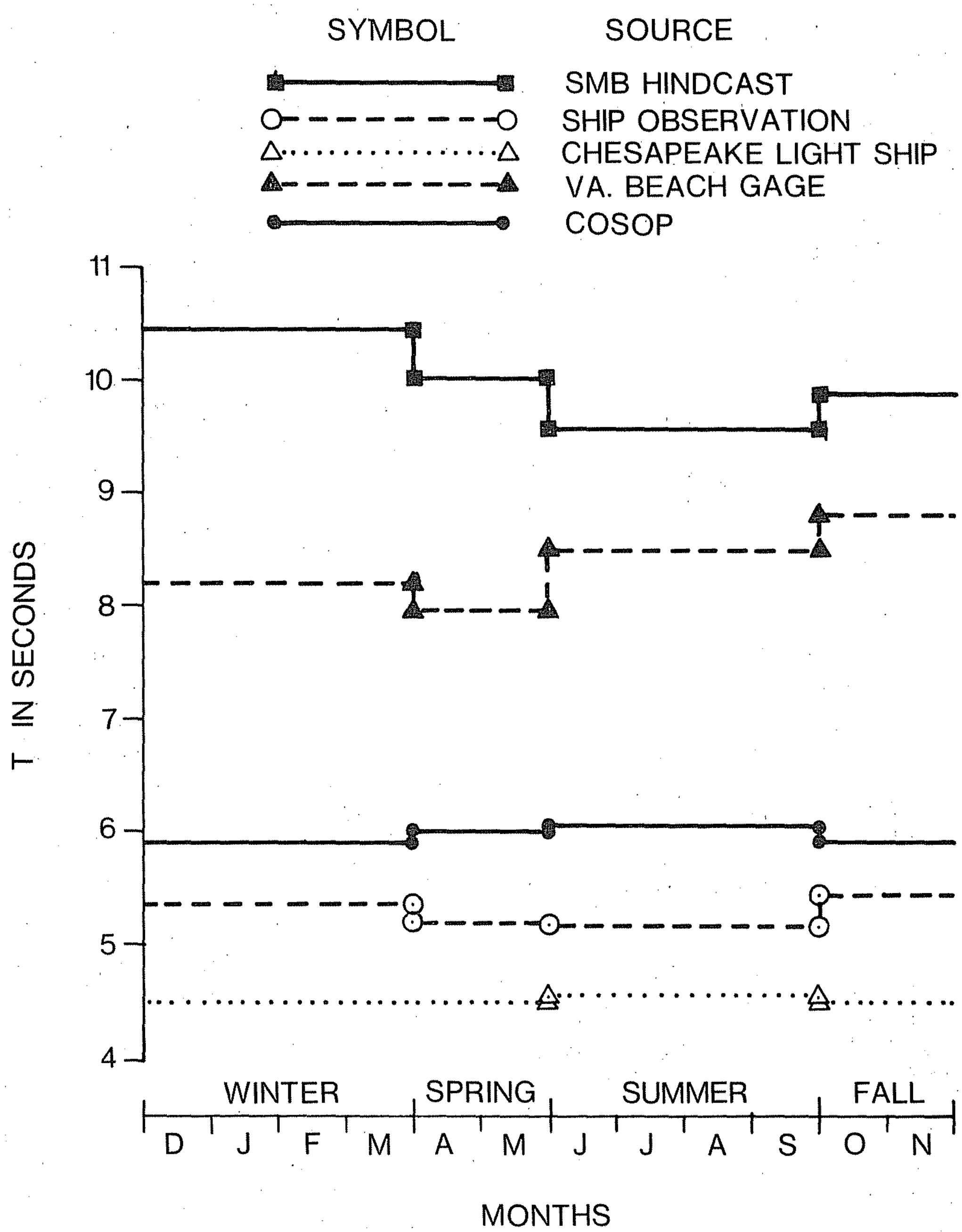
# SEASONAL
# AVERAGE SIGNIFICANT WAVE HEIGHT ($H_s$)




COMPILED BY GUTMAN, VIMS, 10/76

Figure 4.

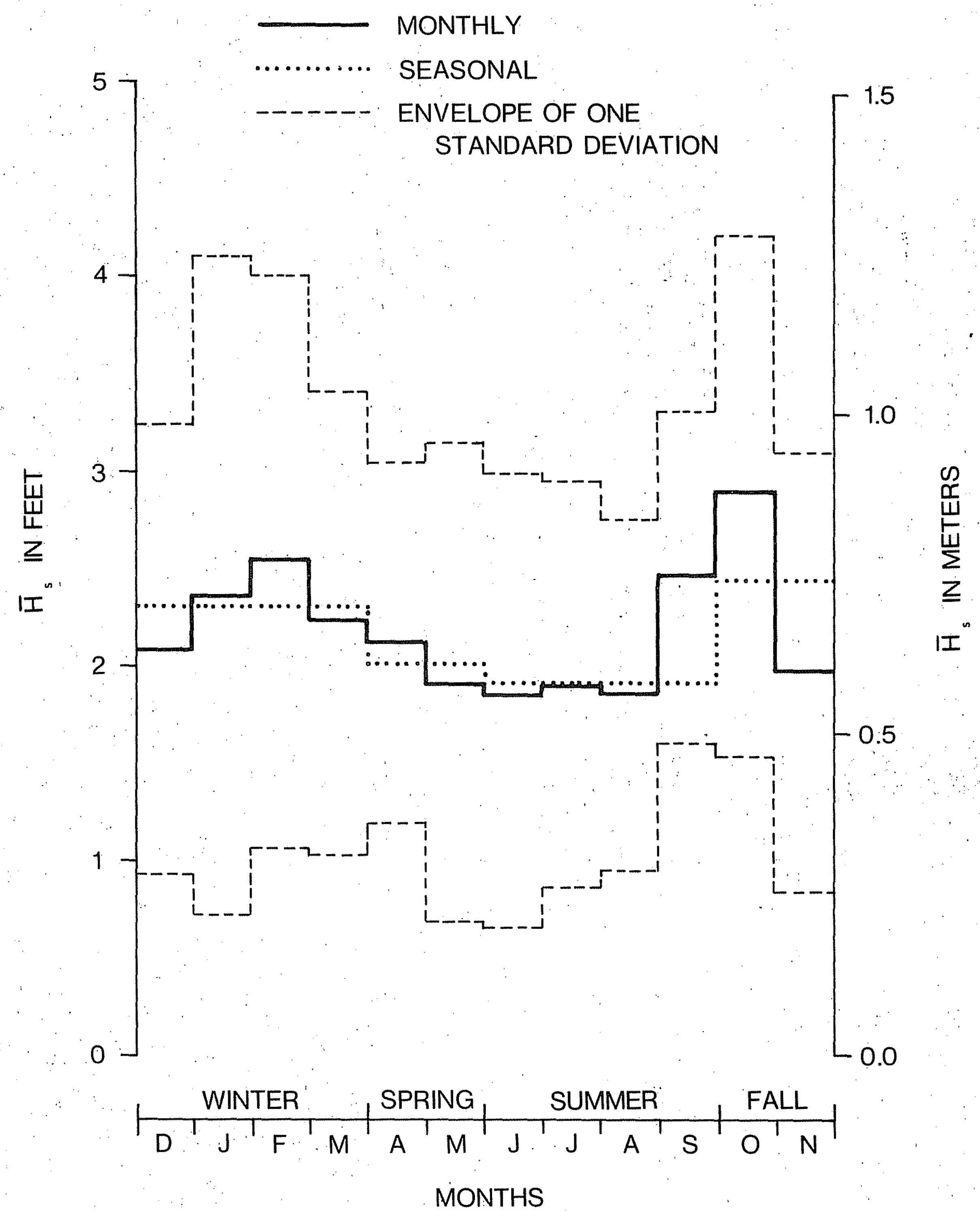
## SEASONAL
## AVERAGE SIGNIFICANT WAVE PERIOD ($T_s$)




COMPILED BY GUTMAN, VIMS, 10/76

Figure 5.

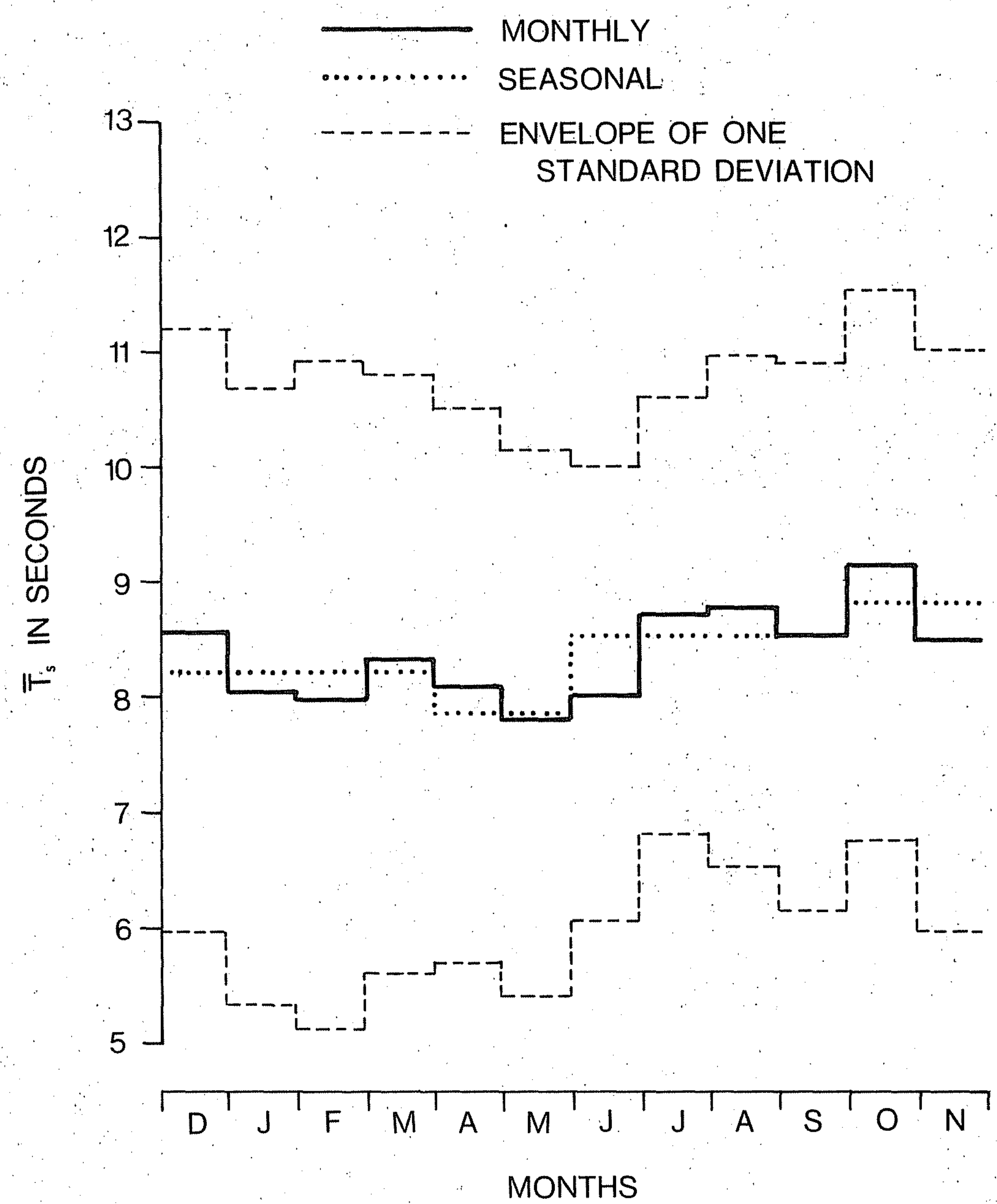
VIRGINIA BEACH GAGE
AVERAGE SIGNIFICANT WAVE HEIGHT ($\bar{H}_s$)



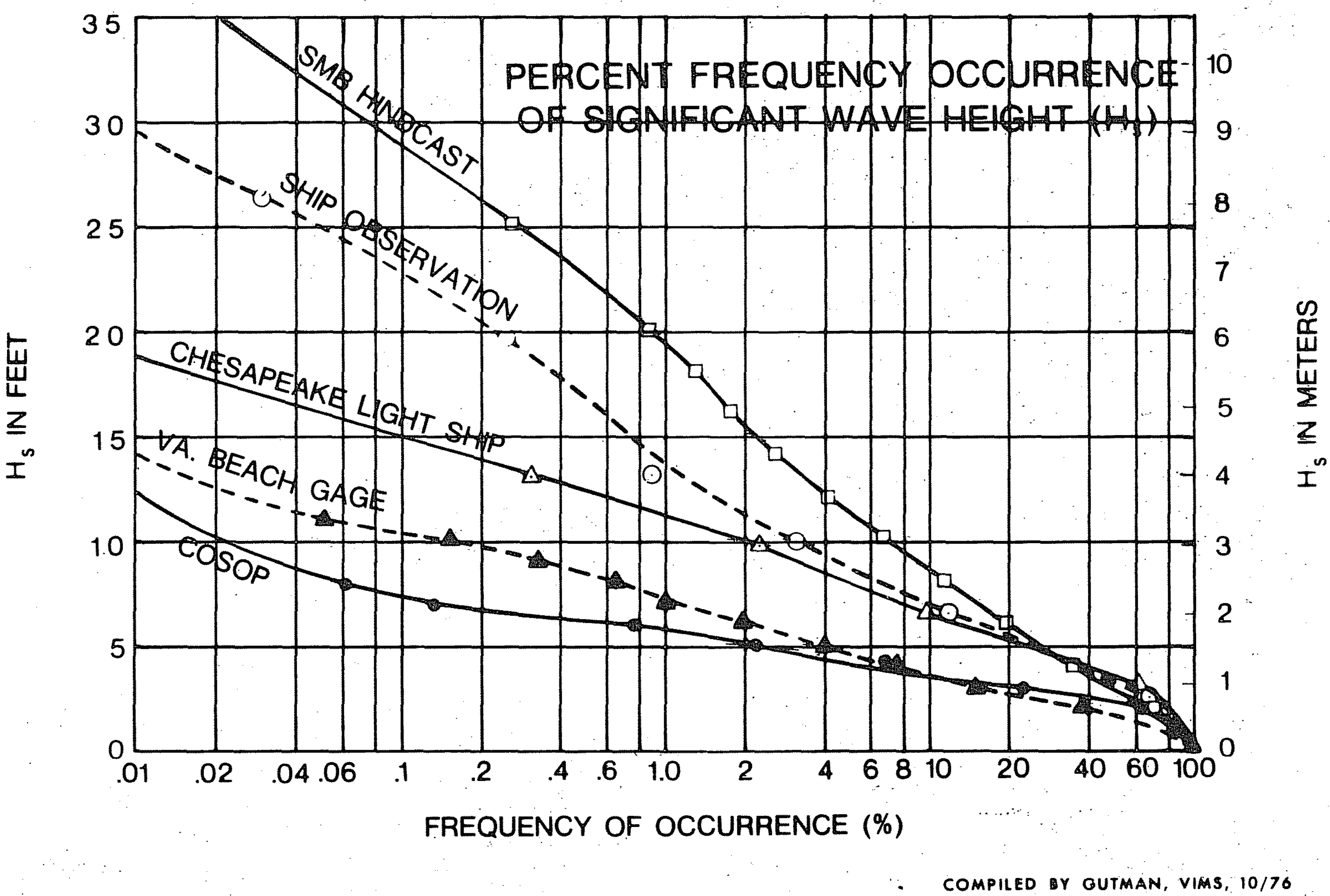

COMPILED BY GUTMAN, VIMS, 10/76

Figure 6.

## VIRGINIA BEACH GAGE
## AVERAGE SIGNIFICANT WAVE PERIOD ($\overline{T}_s$)

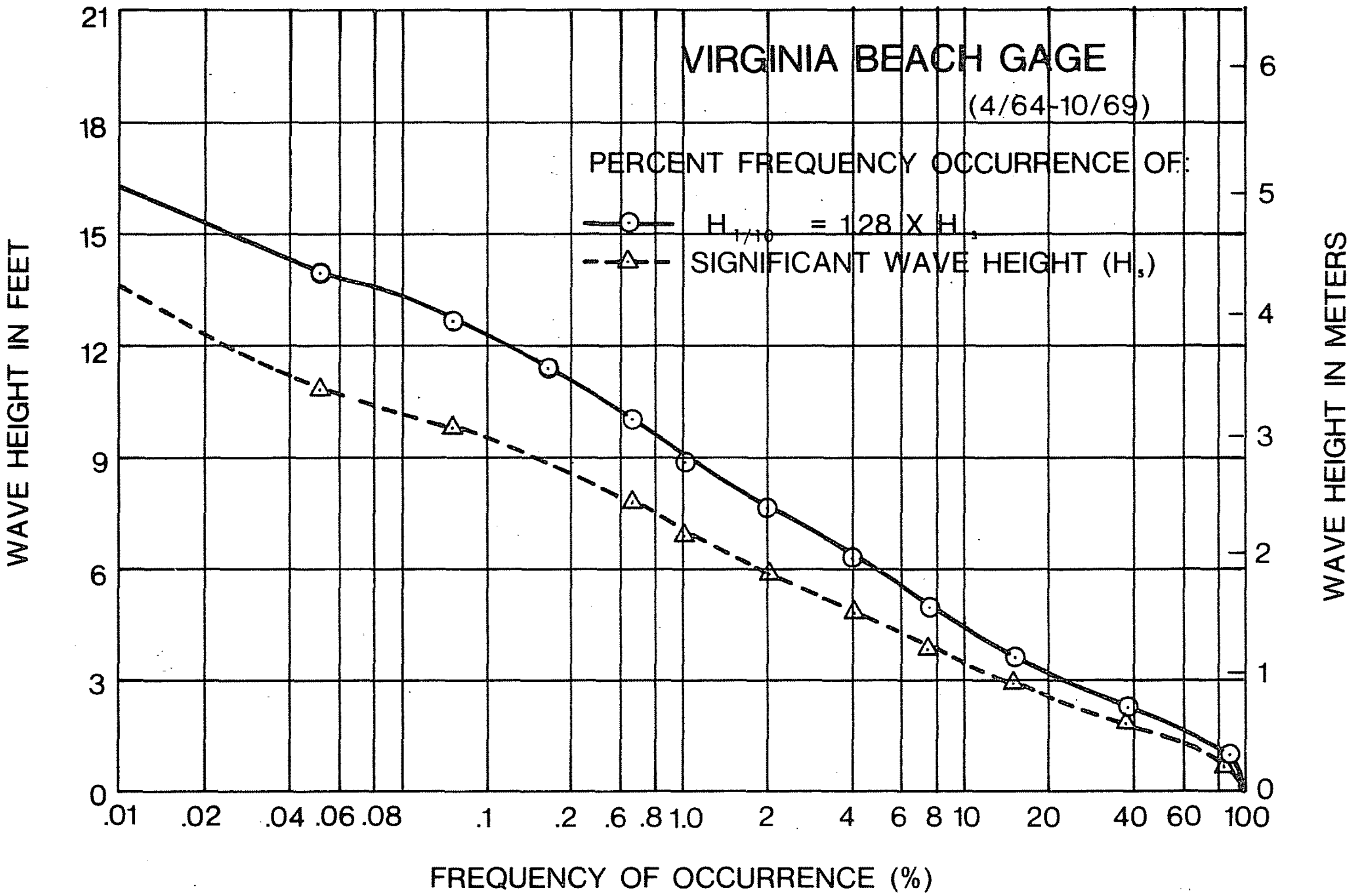



COMPILED BY GUTMAN, VIMS, 10/76



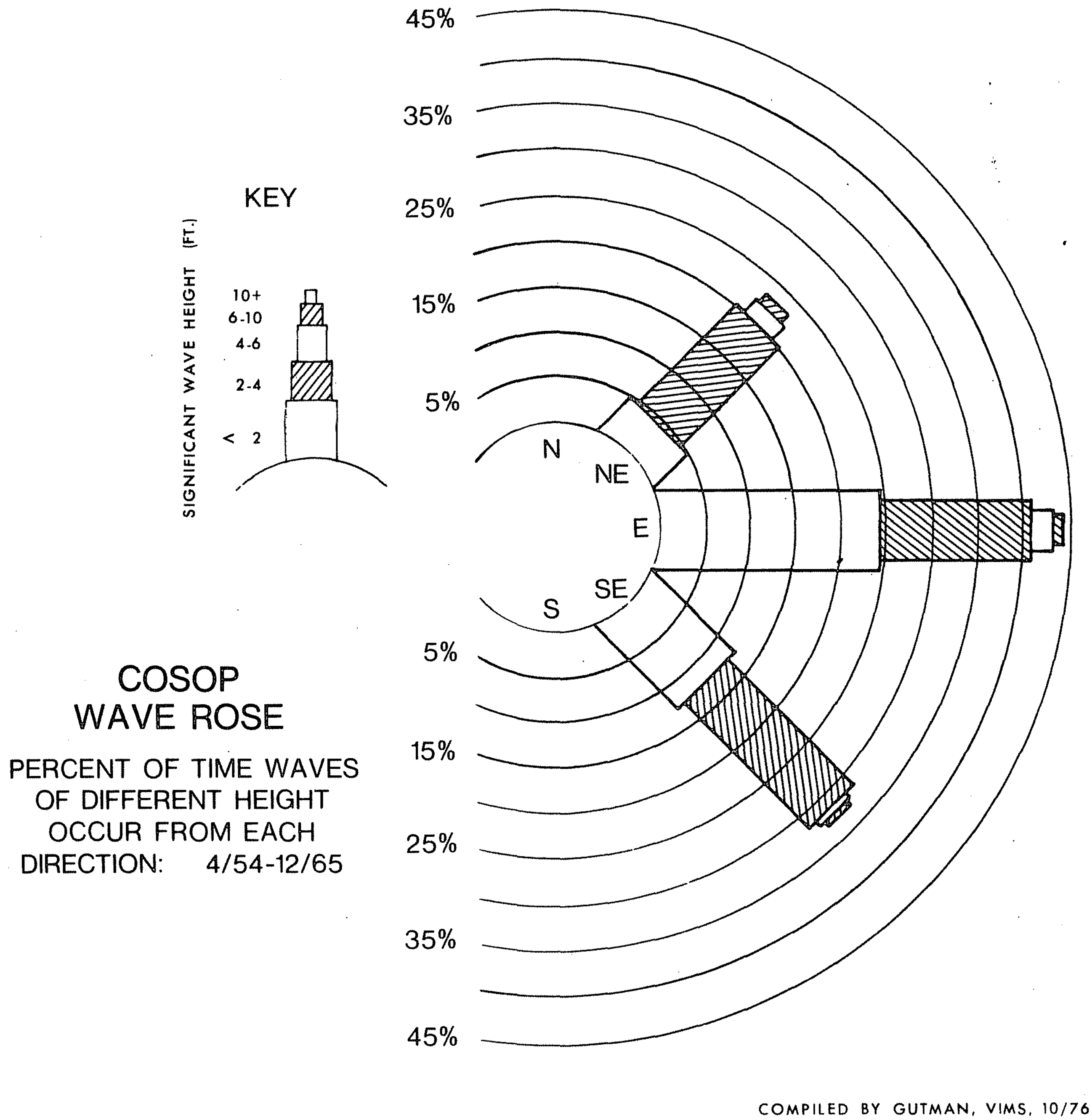
PERCENT FREQUENCY OCCURRENCE
OF SIGNIFICANT WAVE HEIGHT ($H_s$)
SMB HINDCAST
SHIP OBSERVATION
CHESAPEAKE LIGHT SHIP
VA. BEACH GAGE
COSOP
$H_s$ IN FEET
$H_s$ IN METERS
FREQUENCY OF OCCURRENCE (%)
35
30
25
20
15
10
5
0
10
9
8
7
6
5
4
3
2
1
0
.01 .02 .04 .06 .1 .2 .4 .6 1.0 2 4 6 8 10 20 40 60 100
COMPILED BY GUTMAN, VIMS, 10/76


Figure 7.




COMPILED BY GUTMAN, VIMS, 10/76

Figure 8.



45%
35%
25%
15%
5%
N
NE
E
SE
S
5%
15%
25%
35%
45%
KEY
SIGNIFICANT WAVE HEIGHT (FT.)
10+
6-10
4-6
2-4
< 2
COSOP
WAVE ROSE
PERCENT OF TIME WAVES
OF DIFFERENT HEIGHT
OCCUR FROM EACH
DIRECTION: 4/54-12/65
COMPILED BY GUTMAN, VIMS, 10/76


Figure 9.

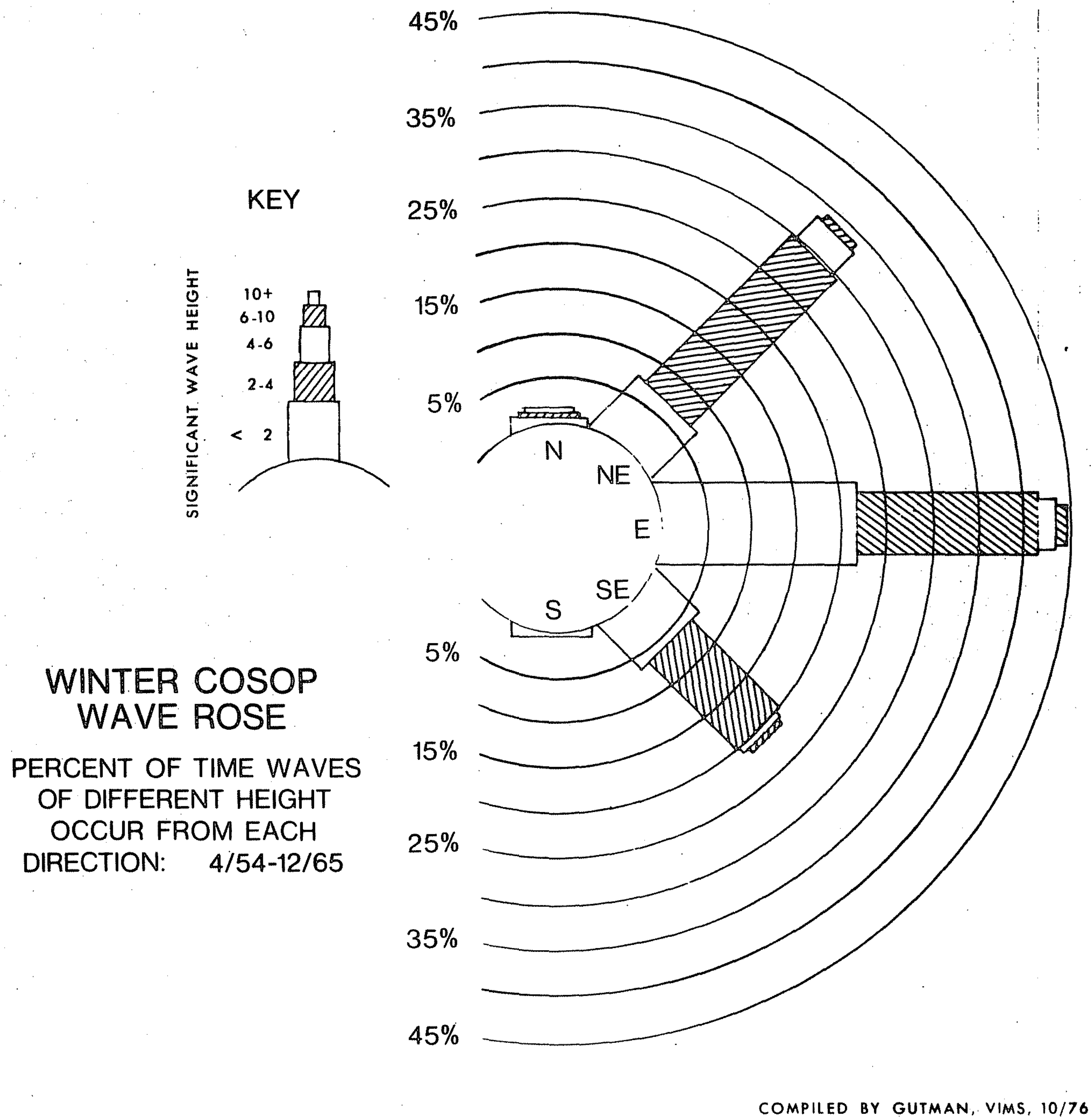

KEY
SIGNIFICANT WAVE HEIGHT
10+
6-10
4-6
2-4
< 2
45%
35%
25%
15%
5%
N
NE
E
SE
S
5%
15%
25%
35%
45%
WINTER COSOP
WAVE ROSE
PERCENT OF TIME WAVES
OF DIFFERENT HEIGHT
OCCUR FROM EACH
DIRECTION: 4/54-12/65
COMPILED BY GUTMAN, VIMS, 10/76

Figure 10.

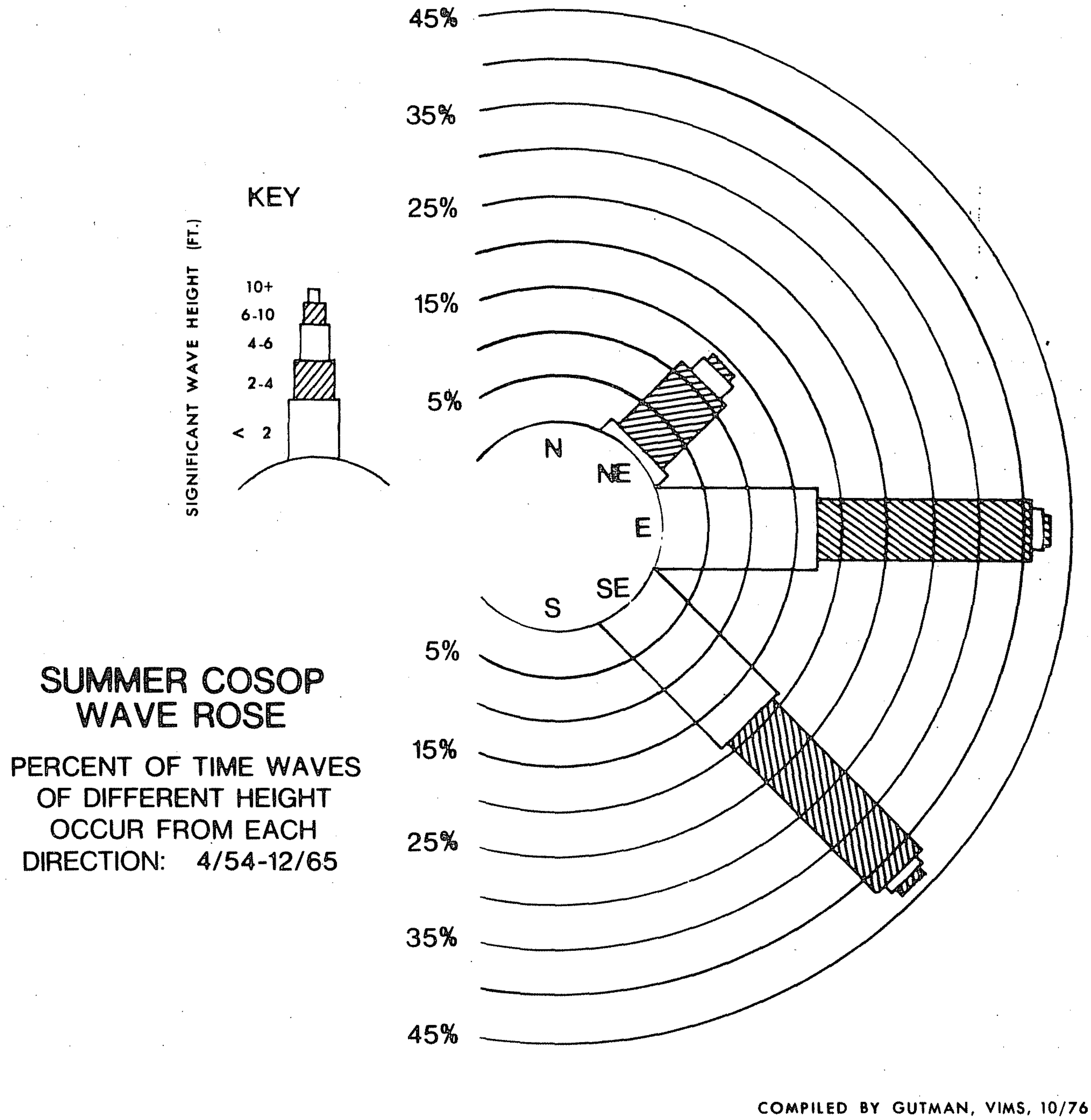
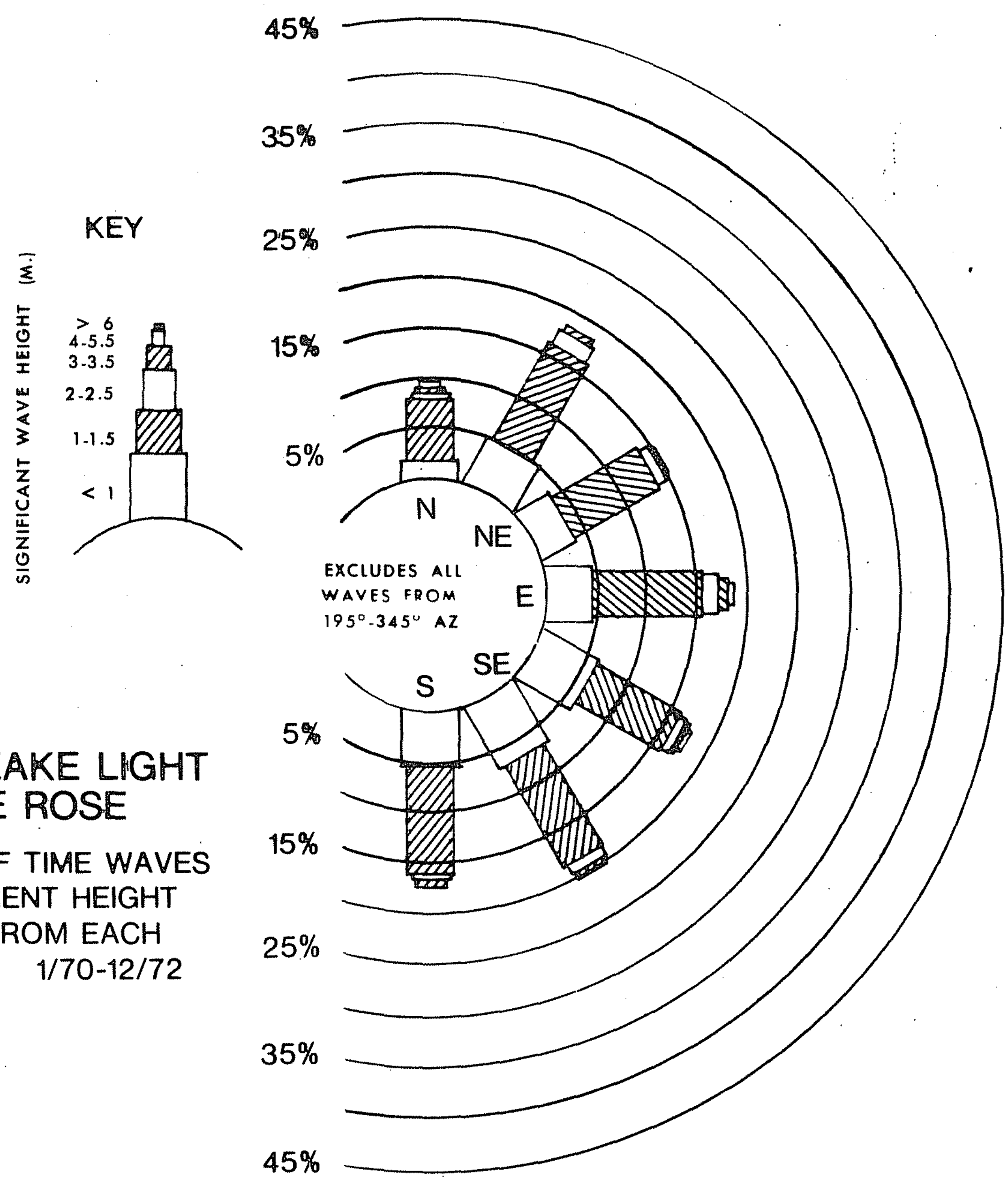

KEY
SIGNIFICANT WAVE HEIGHT (FT.)
10+
6-10
4-6
2-4
< 2
45%
35%
25%
15%
5%
N
NE
E
SE
S
5%
15%
25%
35%
45%
SUMMER COSOP
WAVE ROSE
PERCENT OF TIME WAVES
OF DIFFERENT HEIGHT
OCCUR FROM EACH
DIRECTION: 4/54-12/65
COMPILED BY GUTMAN, VIMS, 10/76

Figure 11.

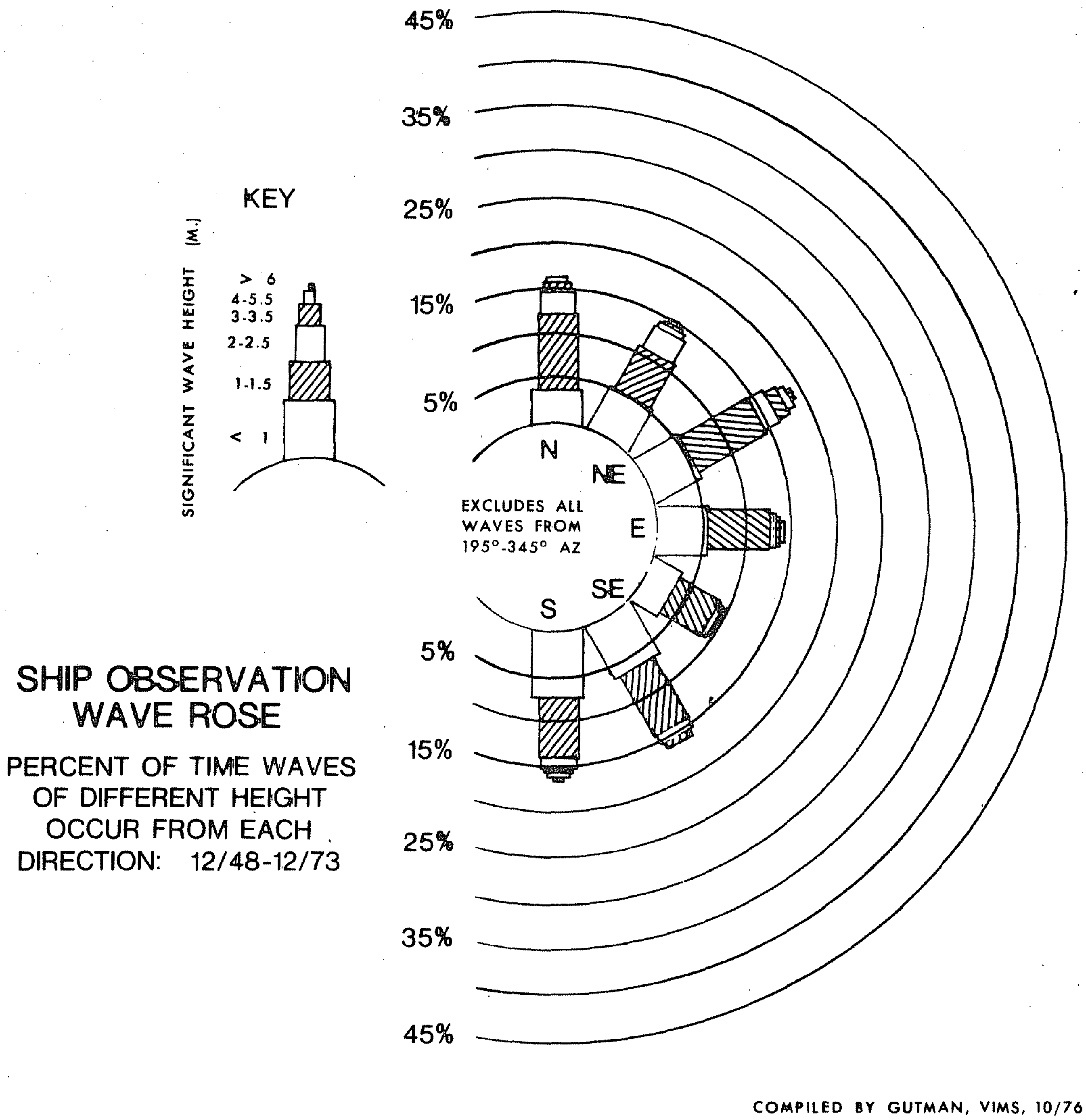



## CHESAPEAKE LIGHT WAVE ROSE

PERCENT OF TIME WAVES OF DIFFERENT HEIGHT OCCUR FROM EACH DIRECTION: 1/70-12/72

COMPILED BY GUTMAN, VIMS, 10/76

Figure 12.



45%
35%
25%
15%
5%
KEY
SIGNIFICANT WAVE HEIGHT (M.)
> 6
4-5.5
3-3.5
2-2.5
1-1.5
< 1
N
NE
E
SE
S
EXCLUDES ALL WAVES FROM 195°-345° AZ
5%
15%
25%
35%
45%
SHIP OBSERVATION WAVE ROSE
PERCENT OF TIME WAVES OF DIFFERENT HEIGHT OCCUR FROM EACH DIRECTION: 12/48-12/73
COMPILED BY GUTMAN, VIMS, 10/76


Figure 13.

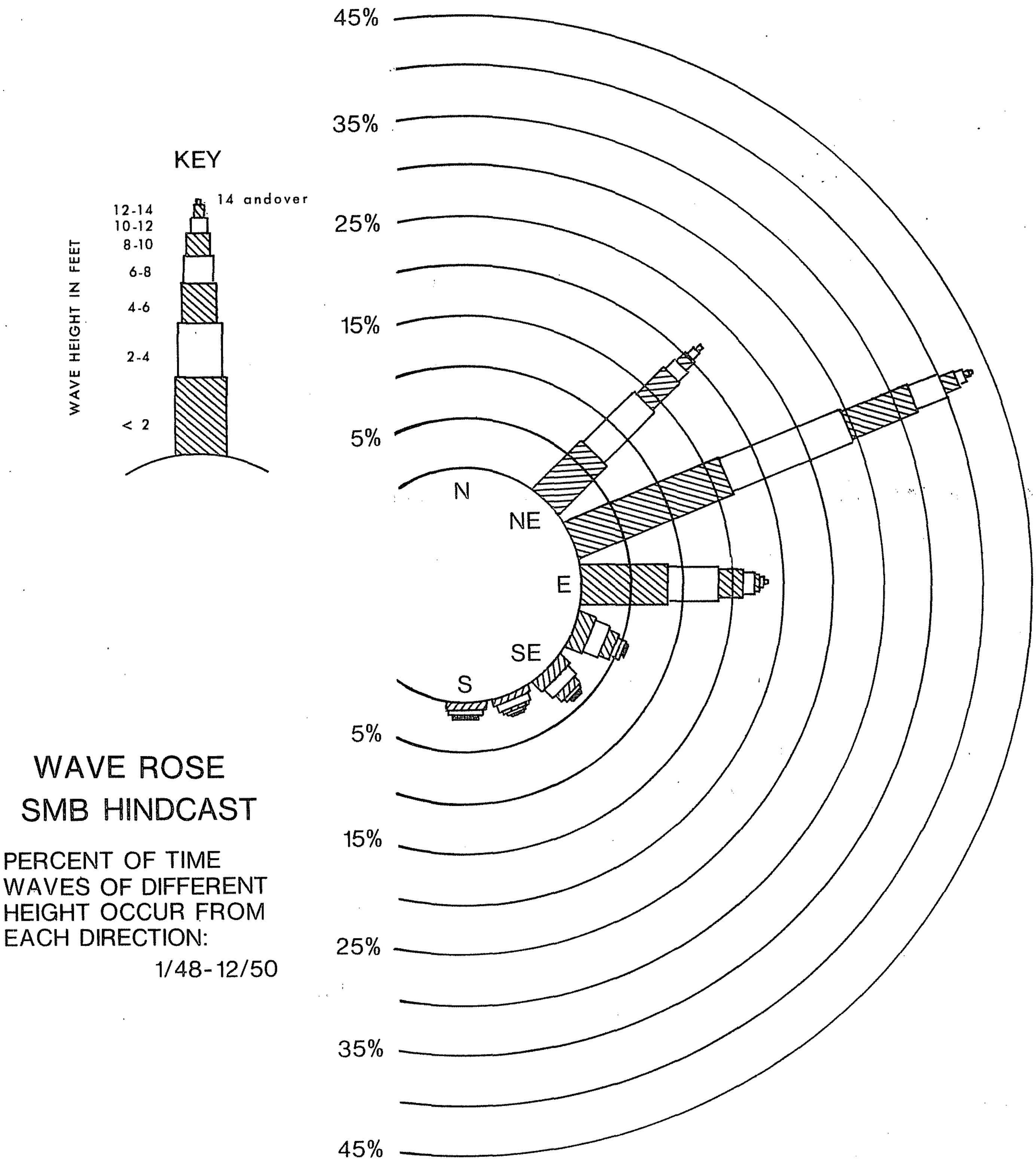
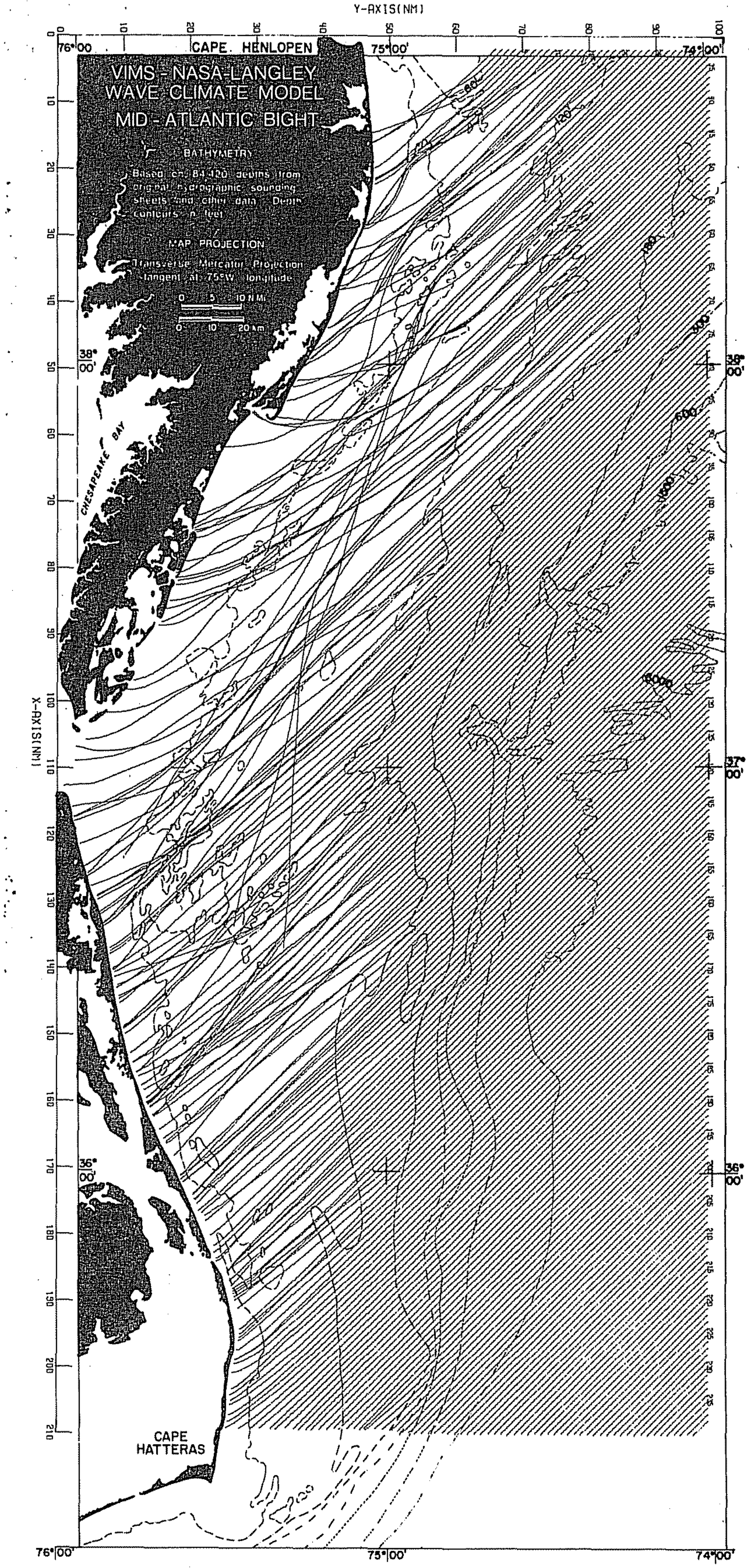
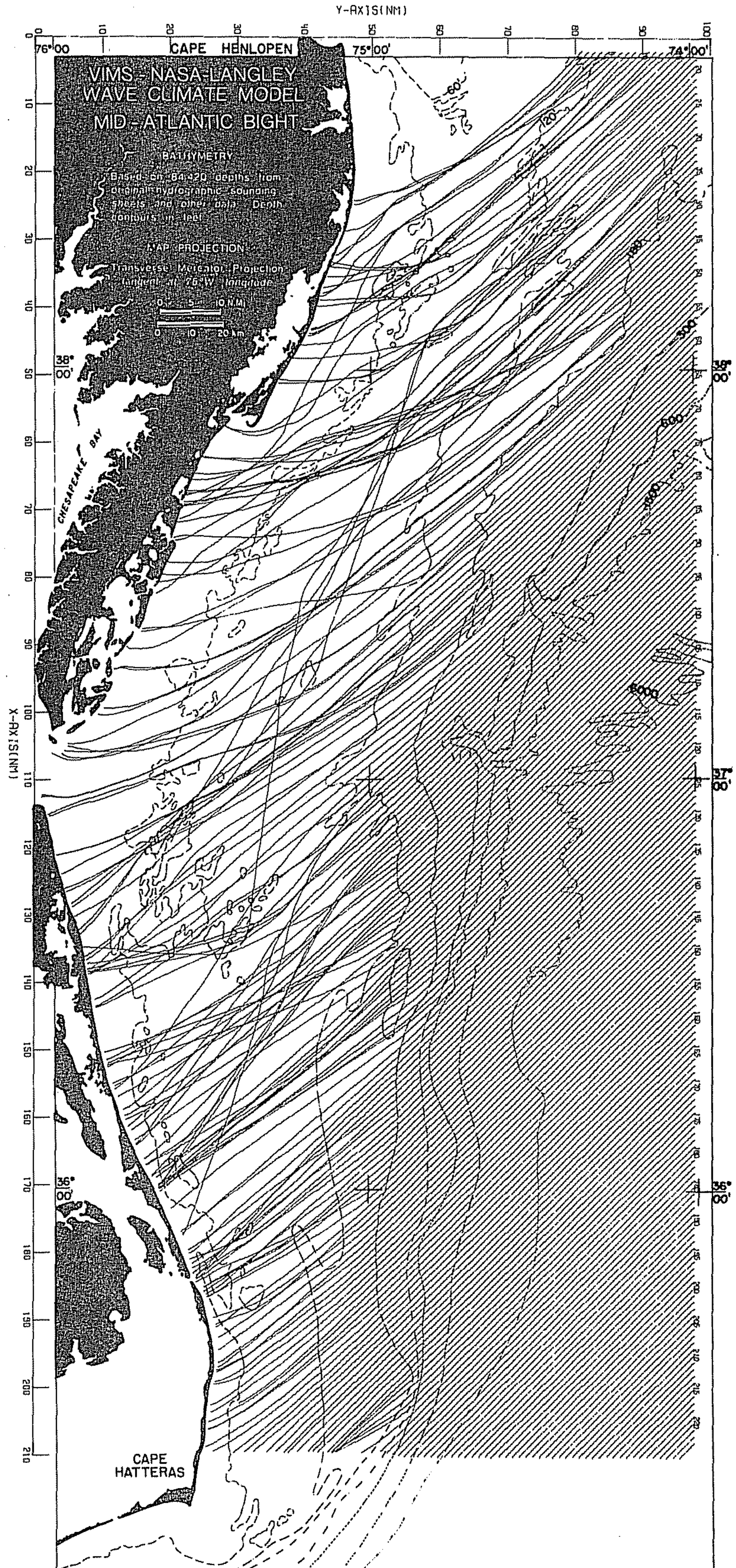


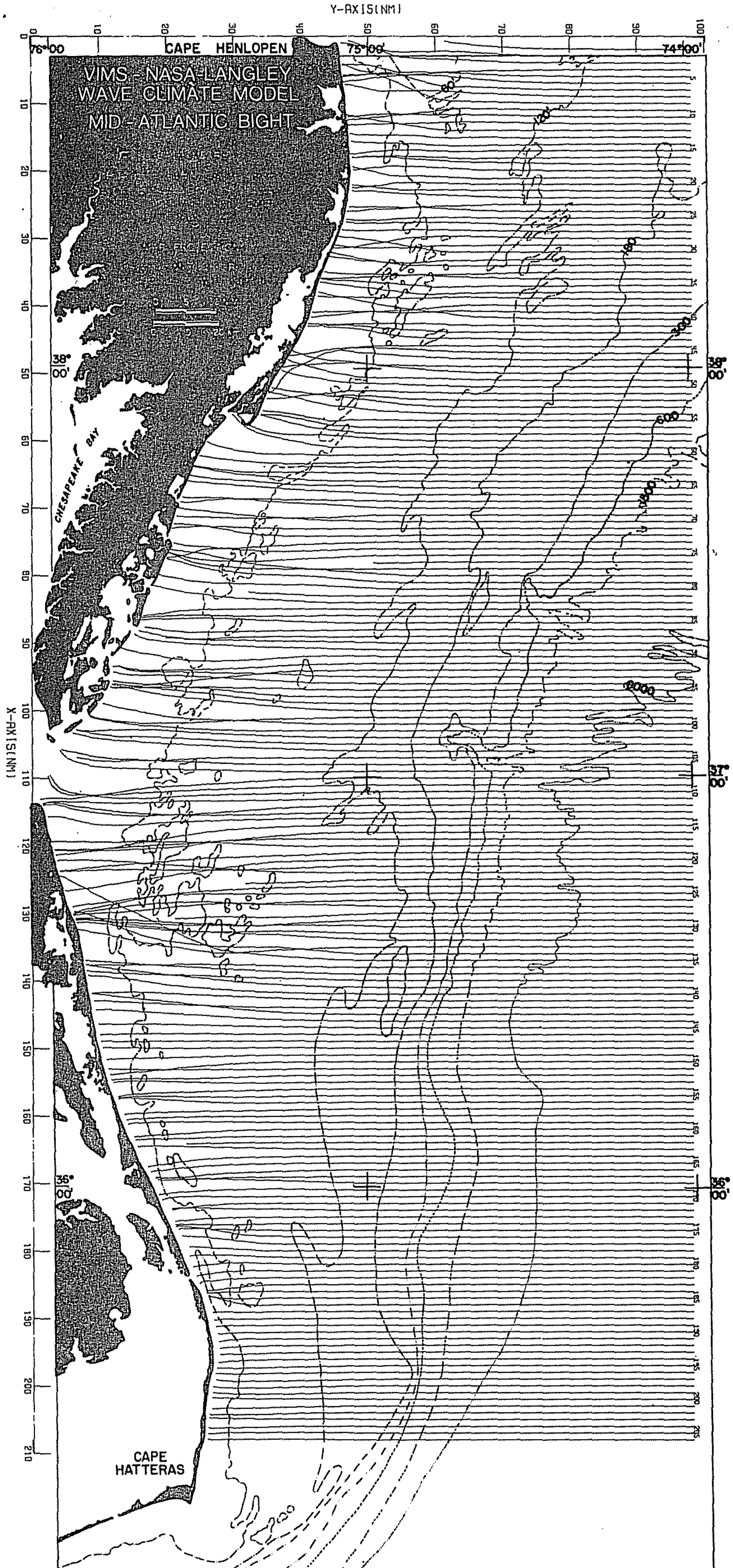

Figure 14. (after Saville, 1954)



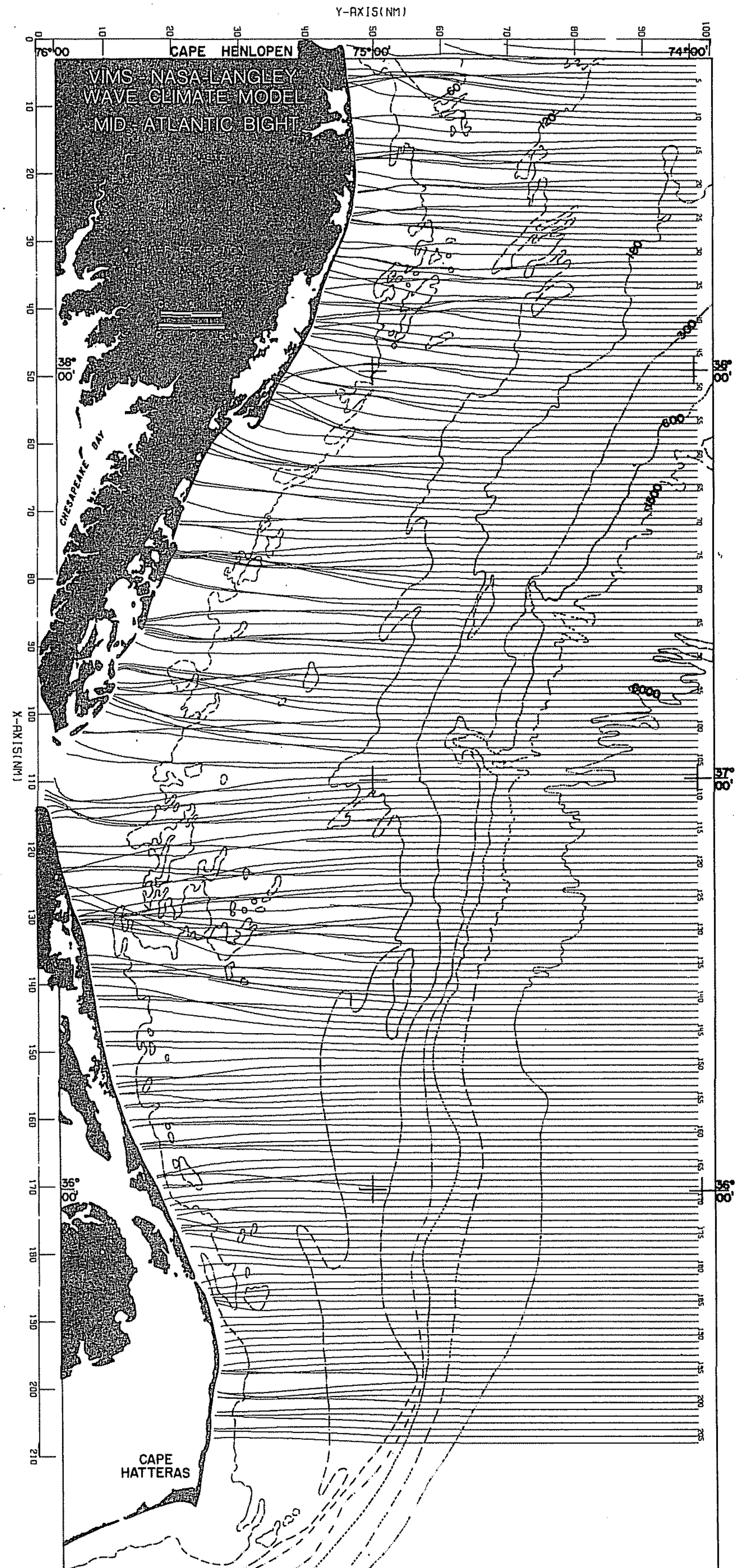

Wave rays computed with following input conditions
AZ = 45°; T = 8 sec; Tide = 0
Figure 15. (after Goldsmith et al., 1974)



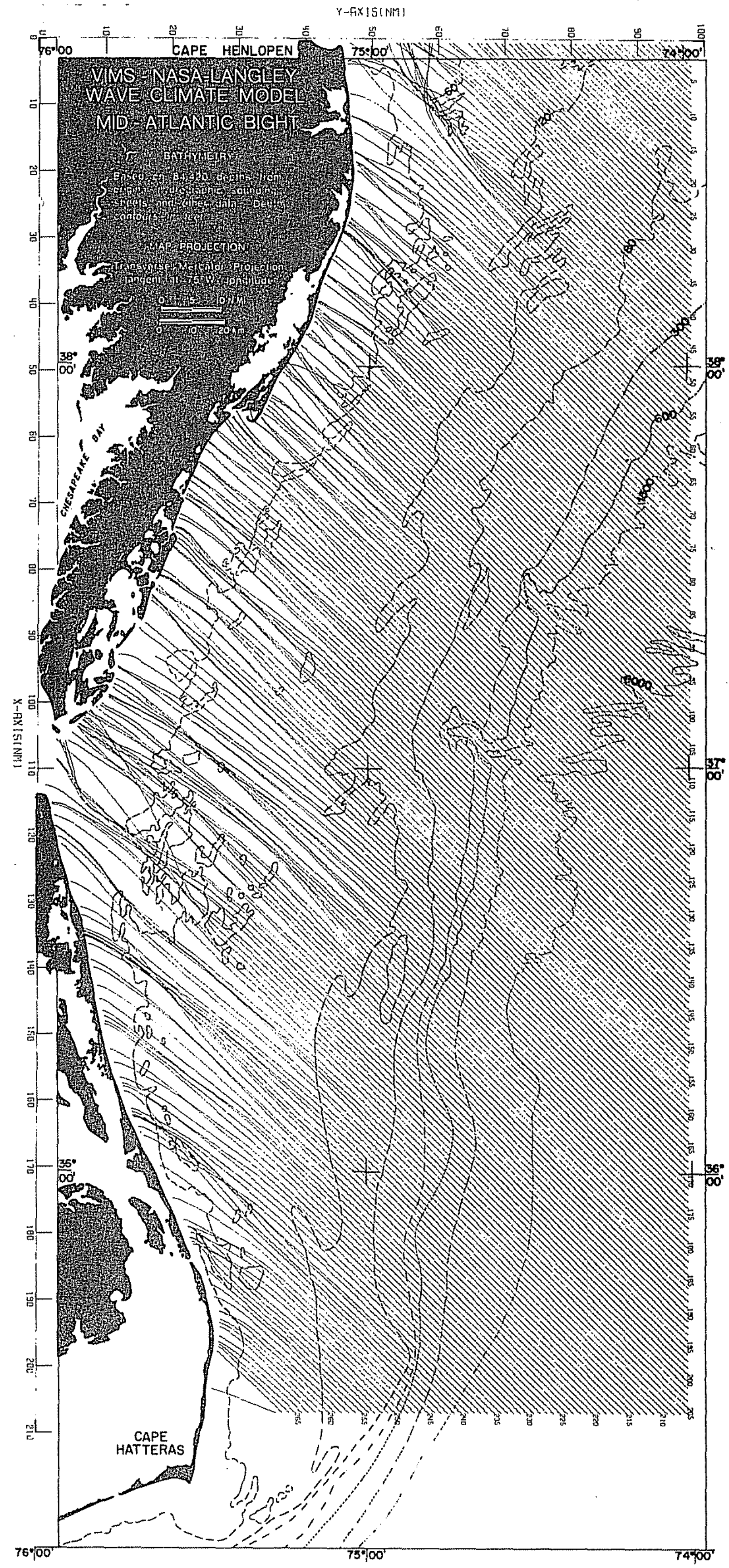

Wave rays computed with following input conditions:
AZ = 45°; T = 10 sec; Tide = 0
Figure 16. (after Goldsmith et al., 1974)



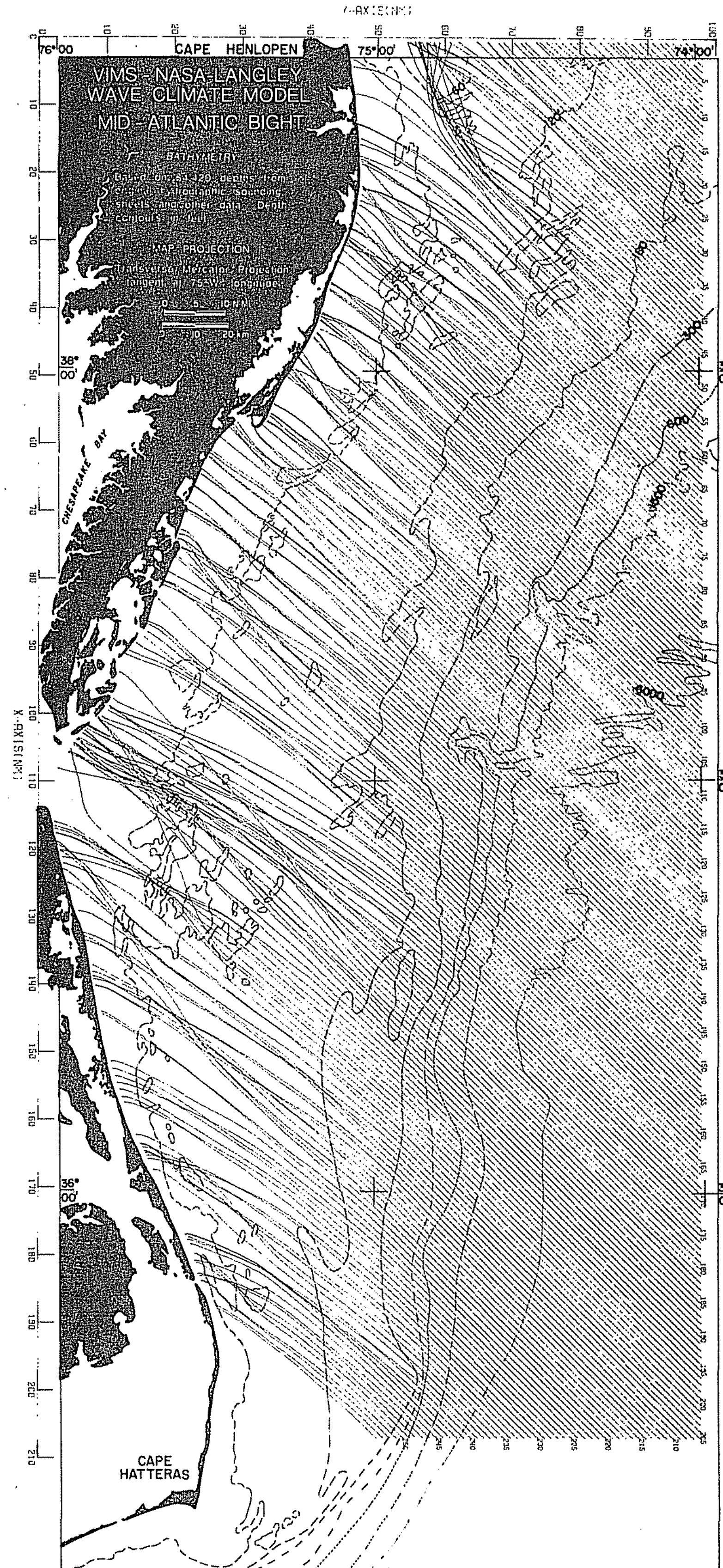

Wave rays computed with following input conditions:
AZ = 90°; T = 8 sec; Tide = 0
Figure 17. (after Goldsmith et al., 1974)




Wave rays computed with following input conditions:
AZ = 90°; T = 10 sec; Tide = 0
Figure 18. (after Goldsmith et al., 1974)




Wave rays computed with following input conditions:
AZ = 135°; T = 8 sec; Tide = 0
Figure 19. (after Goldsmith et al., 1974)




Wave rays computed with following input conditions:
AZ = 135°; T = 10 sec; Tide = 0
Figure 20. (after Goldsmith et al., 1974)

# APPENDIX A.

## COSOP Sample Wave Observer Form

# SURF OBSERVATION FORM

(Instructions on Reverse Side)

Cooperative Surf Observation Program

Coastal Engineering Research Center

Sheet Number ________________

Station ________________

☐☐ ________________

| Date 1 | | Time 2 | Period 3 | Height 4 | Dir 5 | Type 6 | Remarks 7 | Observer 8 |
|---|---|---|---|---|---|---|---|---|
| Year | | 0400 | | | | | | |
| | | 0800 | | | | | | |
| Month | | 1200 | | | | | | |
| | | 1600 | | | | | | |
| Day | | 2000 | | | | | | |
| | | 2400 | | | | | | |
| Month | | 0400 | | | | | | |
| | | 0800 | | | | | | |
| | | 1200 | | | | | | |
| Day | | 1600 | | | | | | |
| | | 2000 | | | | | | |
| | | 2400 | | | | | | |
| Month | | 0400 | | | | | | |
| | | 0800 | | | | | | |
| | | 1200 | | | | | | |
| Day | | 1600 | | | | | | |
| | | 2000 | | | | | | |
| | | 2400 | | | | | | |

CERC 69
21 April 70

Signature: ________________________
Commanding Officer

# APPENDIX B.

## VIMS-CERC Sample Wave Observer Form

Return to V. Goldsmith
VIMS
Gloucester Pt., Va. 23062

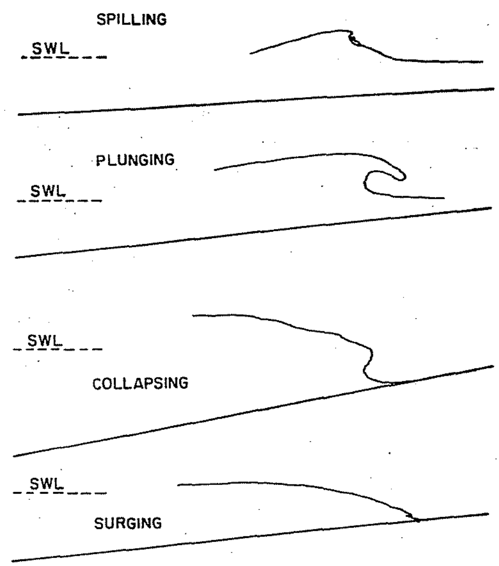
# WAVE OBSERVATION REPORT

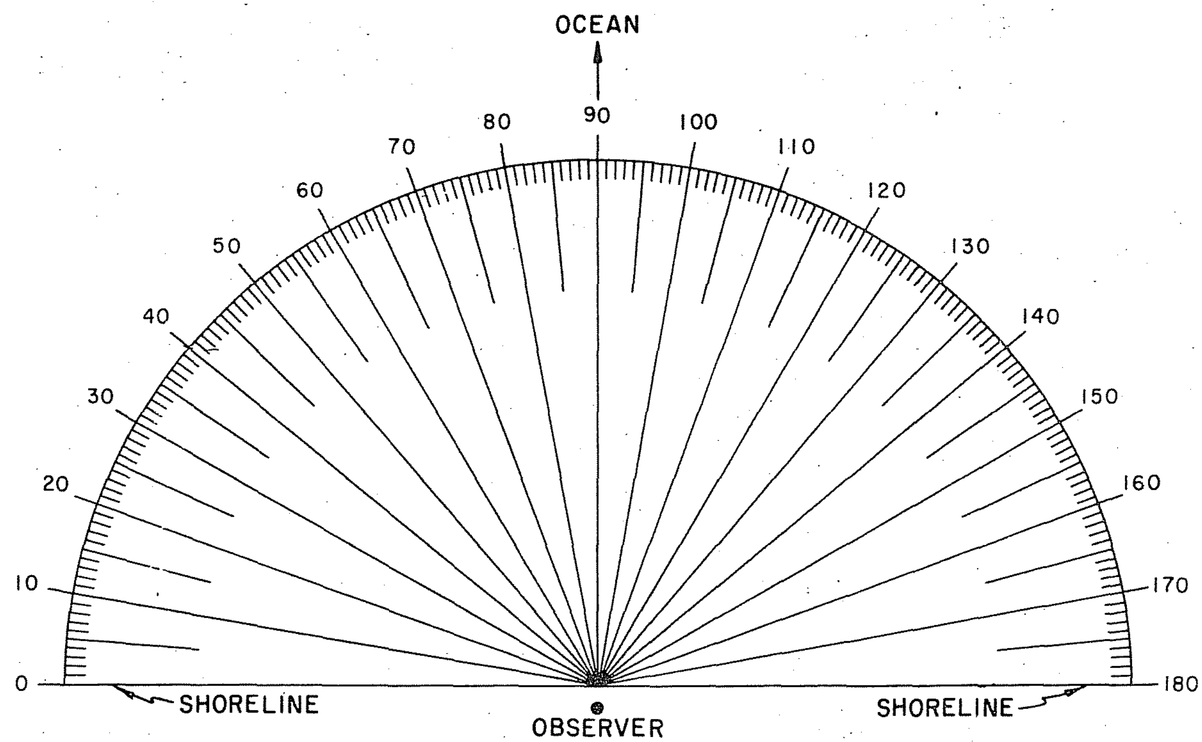
RECORD ALL DATA CAREFULLY AND LEGIBLY

SITE NAME

OBSERVER

| | YEAR MONTH DAY | TIME | WAVE PERIOD | BREAKER HEIGHT | WAVE ANGLE AT BREAKER | WAVE TYPE |
|---|---|---|---|---|---|---|
| | | Record time using the 24 hour system. | Record the time in seconds for eleven (11) wave crests to pass a stationary point. If calm record 0. | Record the best estimate of the significant wave height to the nearest half of a foot. | Record to the nearest degree the direction the waves are coming from using the protractor on the reverse side. | 0 - Calm<br>1 - Spilling<br>2 - Plunging<br>3 - Surging<br>4 - Spilling / Plunging<br>5 - Collapsing |
| SITE NUMBERS 1 2 3 4 5 | 6 7 8 9 10 11 | 12 13 14 15 | 16 17 18 | 19 20 • 21 | 22 23 24 | 25 |
| SUN | | | | | | |
| MON | | | | | | |
| TUE | 6 7 8 9 10 11 | 12 13 14 15 | 16 17 18 | 19 20 • 21 | 22 23 24 | 25 |
| WED | | | | | | |
| THU | 6 7 8 9 10 11 | 12 13 14 15 | 16 17 18 | 19 20 • 21 | 22 23 24 | 25 |
| FRI | | | | | | |
| SAT | 6 7 8 9 10 11 | 12 13 14 15 | 16 17 18 | 19 20 • 21 | 22 23 24 | 25 |




NOTE: If a pier is used for an observation platform: place 0-180 line on the rail parallel to the centerline of the pier, site along the crest of the breaking waves and record the angle observed.

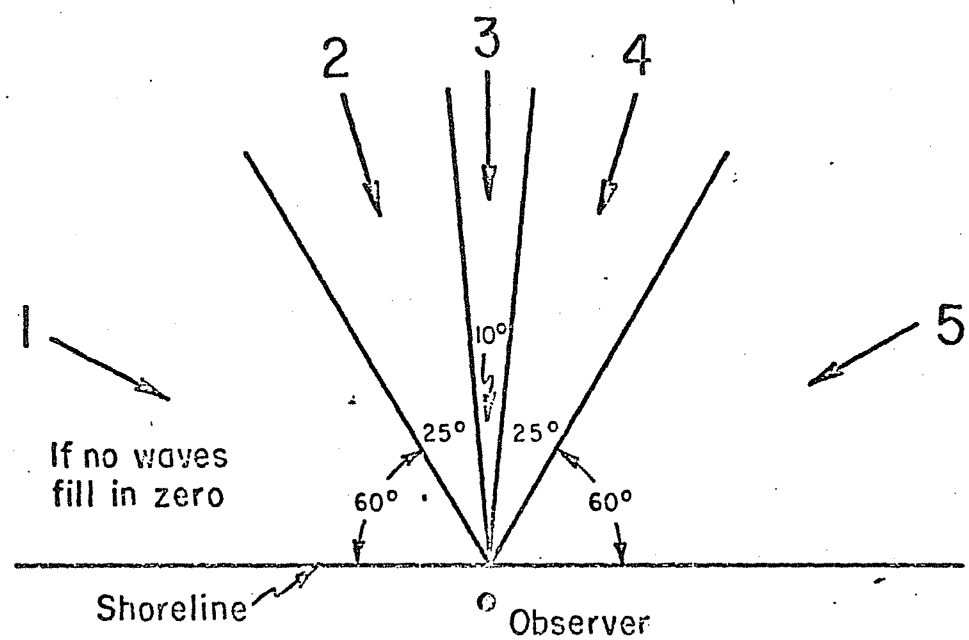



Figure I. WAVE DIRECTION CODE FOR WAVES AT BREAKING

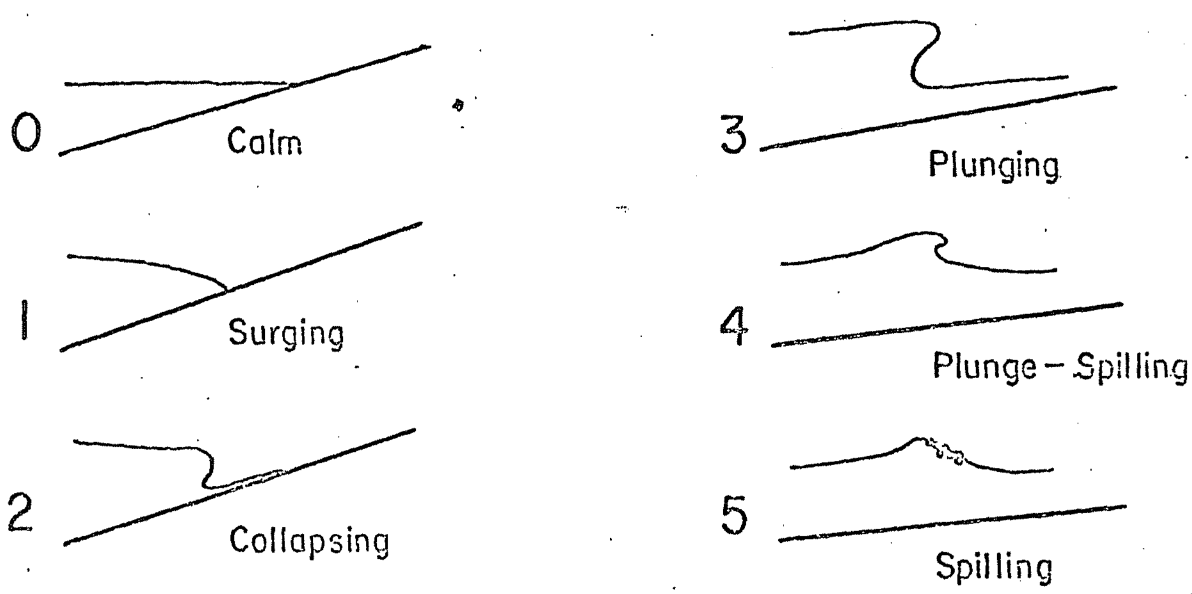



Figure 2. BREAKER TYPE NUMBERS

# APPENDIX C.

## Time of Operation of Virginia Beach Gage

C orm 174-74
18 Mar 74

COASTAL ENGINEERING R ...CH CENTER WAVE GAGE HISTORY

COORDINATES: N 36° 51' W 75° 58'    LOCATION: 15th St. Fishing Pier, Virginia Beach, Virginia

| Type of Gage | Beginning of Proper Operation | End of Proper Operation | Explanation | Gage Length (feet) | Gage Range (ft MSL) | Water Depth (ft MSL) | Distance from seaward end of pier | P Lo (f |
|---|---|---|---|---|---|---|---|---|
| Step Resistance (SR) Staff - Parallel Type | 13 Oct 62 | 26 Nov 62 | Gage and part of pier destroyed by storm | 25 | | 18 | 60 (on N. side of pier) | 80 |
| SR Staff - Relay Type | 2 Mar 63 | 17 Jan 65 | Gage and part of pier destroyed by storm | 25 | | 18 | " | 80 |
| SR Staff - Relay Type | 29 Nov 65 | 20 Sep 66 | Gage temporarily removed during pier repair | 25 | | 20 | 12 (on N. side of pier) | 90 |
| SR Staff - Relay Type | 3 Nov 66 | 31 Mar 70 | Recorder house vandalized | 25 | | 20 | " | 90 |
| | 22 Apr 70 | 26 Mar 71 | Gage destroyed by storm-not replaced | | | | | |

# APPENDIX D.

## Virginia Beach Gage-Monthly Summaries

WAVE CLIMATOLOGY FOR VIRGINIA BEACH, VIRGINIA
DISTRIBUTION OF SIGNIFICANT HEIGHT VS PERIOD (IN OBSERVATIONS PER 1000 OBS)
536 OBSERVATIONS SUMMARY FOR JAN 66 JAN 67 JAN 68

| PERIOD (SECS) | HEIGHT (FT) 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] - 1.9 | 2 | | | | | | | | | | | | | 1000 | .00 |
| [illegible] - 2.9 | | | | | | | | | | | | | | 1000 | .00 |
| [illegible] - 3.9 | | | | | | | | | | | | | | 1000 | .00 |
| [illegible] | 6 | 11 | | | | | | | | | | | 17 | 1000 | 1.17 |
| [illegible] | | 24 | 6 | | | | | | | | | | 30 | 983 | 1.69 |
| [illegible] - 4.9 | 4 | 49 | 37 | 9 | | | | | | | | | 99 | 953 | 2.03 |
| [illegible] - 5.9 | 2 | 54 | 50 | 22 | 11 | 2 | | | | | | | 142 | 854 | 2.45 |
| [illegible] - 6.9 | 6 | 54 | 37 | 4 | 7 | 2 | 4 | 2 | | | | | 116 | 712 | 2.35 |
| [illegible] - 7.9 | 11 | 56 | 6 | 4 | 6 | 9 | 6 | 6 | 4 | 2 | | | 103 | 596 | 2.97 |
| [illegible] - 8.9 | 26 | 62 | 6 | 7 | 2 | 4 | 2 | 2 | 2 | 2 | 2 | | 116 | 488 | 2.19 |
| [illegible] - 9.9 | 35 | 86 | 9 | 6 | 2 | | 4 | | | | 2 | 2 | 146 | 372 | 1.81 |
| [illegible] -10.9 | 9 | 52 | 2 | 2 | 2 | | | 2 | | | | | 69 | 226 | 1.69 |
| [illegible] -11.9 | 4 | 43 | 7 | 2 | | | | 2 | | 2 | 2 | 2 | 64 | 157 | 2.59 |
| [illegible] -12.9 | 2 | 22 | 9 | 6 | 2 | | 4 | | 2 | | | | 47 | 93 | 2.70 |
| [illegible] | 2 | 15 | 7 | 4 | 4 | 2 | | | | | | | 34 | 47 | 2.44 |
| [illegible] | | 7 | 2 | 4 | | | | | | | | | 13 | 13 | 2.21 |
| [illegible] | 108 | 535 | 179 | 69 | 35 | 19 | 19 | 13 | 7 | 6 | 6 | 4 | | | 2.25 |
| [illegible] | 1000 | 892 | 356 | 177 | 108 | 73 | 54 | 35 | 22 | 15 | 9 | 4 | | | |
| [illegible] | 8.59* | 8.19 | 6.90 | 7.96 | 7.87 | 8.00 | 8.80 | 8.50 | 9.00 | 9.17 | 9.83 | 10.50 | 6.02 | | |

AVERAGE SIG. HEIGHT = 2.25 FT — AVERAGE WAVE PERIOD = 6.02 SEC*
VARIANCE OF SIG. HEIGHT = 3.11 FT SQ — VARIANCE OF WAVE PERIOD = 7.39 SEC SQ*
STANDARD DEVIATION OF HEIGHT = 1.76 FT — STANDARD DEVIATION OF PERIOD = 2.72 SEC*

[illegible] OBTAINED FROM 7-MINUTE PEN AND INK RECORDS TAKEN WITH A STEP RESISTANCE RELAY
~~[illegible] LOCATED AT 15TH STREET PIER~~.
[illegible] ARE OMITTED.

WAVE CLIMATOLOGY FOR VIRGINIA BEACH, VIRGINIA
DISTRIBUTION OF SIGNIFICANT HEIGHT VS PERIOD (IN OBSERVATIONS PER 1000 OBS)

468 OBSERVATIONS SUMMARY FOR FEB 66 FEB 67 FEB 68

PERIOD (SECS) — HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | TOT.* | CUM. TOT.* | AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 83 | | | | | | | | | | 1000 | .00 |
| 2.0 - 2.4 | | | | | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | | | | | | | | | | 1000 | .00 |
| 3.0 - 3.4 | 9 | 15 | | | | | | | | 26 | 1000 | 1.14 |
| 3.5 - 3.9 | 13 | 26 | 4 | | | | | | | 47 | 974 | 1.30 |
| 4.0 - 4.9 | 9 | 53 | 34 | 11 | 2 | 2 | | | | 121 | 928 | 2.06 |
| 5.0 - 5.9 | 6 | 43 | 36 | 15 | 4 | 4 | 2 | | | 121 | 807 | 2.40 |
| 6.0 - 6.9 | 8 | 51 | 26 | 13 | 6 | 8 | 4 | | | 119 | 685 | 2.46 |
| 7.0 - 7.9 | 6 | 32 | 21 | 6 | 11 | 4 | 2 | | | 91 | 566 | 2.55 |
| 8.0 - 8.9 | 15 | 43 | 4 | 2 | 2 | 2 | 2 | | | 77 | 476 | 1.77 |
| 9.0 - 9.9 | 17 | 62 | 24 | 6 | 4 | 2 | | | | 126 | 399 | 1.85 |
| 10.0 -10.9 | 11 | 45 | 19 | 4 | 2 | 8 | 4 | 2 | | 100 | 273 | 2.31 |
| 11.0 -11.9 | 9 | 49 | 17 | | 2 | | 2 | | | 86 | 172 | 1.82 |
| 12.0 -12.9 | 6 | 21 | 9 | 2 | | | 2 | | | 44 | 86 | 1.92 |
| 13.0 -13.9 | 2 | 11 | 4 | 4 | | 2 | | | | 26 | 42 | 2.32 |
| 14.0 -14.9 | 2 | 9 | | | | 2 | | | | 14 | 16 | 2.00 |
| 15.0 -15.9 | | | | | | | | | 2 | 2 | 2 | 8.50 |
| TOTAL | 192 | 459 | 199 | 64 | 34 | 28 | 19 | 2 | 2 | | | 1.97 |
| CUM. TOTAL | 1000 | 808 | 348 | 150 | 85 | 51 | 24 | 4 | 2 | | | |
| PER. AVG. | 7.94* | 8.09 | 7.65 | 7.33 | 7.62 | 8.50 | 8.83 | 10.50 | 15.50 | 7.96 | | |

AVERAGE SIG. HEIGHT = 1.97 FT AVERAGE WAVE PERIOD = 7.96 SEC*
VARIANCE OF SIG. HEIGHT = 1.84 FT SQ VARIANCE OF WAVE PERIOD = 6.33 SEC SQ*
STANDARD DEVIATION OF HEIGHT = 1.36 FT STANDARD DEVIATION OF PERIOD = 2.69 SEC*

323 OBSERVATIONS SUMMARY FOR MAR 66 MAR 68

PERIOD (SECS) — HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | TOT.* | CUM. TOT.* | AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 115 | | | | | | | | | | | 1000 | .00 |
| 2.0 - 2.4 | 3 | | | | | | | | | | 3 | 1000 | .50 |
| 2.5 - 2.9 | | | | | | | | | | | | 997 | .00 |
| 3.0 - 3.4 | 6 | 6 | | | | | | | | | 14 | 997 | 1.00 |
| 3.5 - 3.9 | 9 | 19 | 15 | | | | | | | | 49 | 983 | 1.64 |
| 4.0 - 4.9 | | 37 | 37 | 3 | | | | | | | 87 | 934 | 2.06 |
| 5.0 - 5.9 | 9 | 26 | 40 | 3 | | | | | | | 91 | 846 | 1.96 |
| 6.0 - 6.9 | 19 | 34 | 15 | 3 | 3 | | 3 | | | 3 | 91 | 755 | 2.15 |
| 7.0 - 7.9 | 6 | 46 | 15 | 6 | | | 3 | 3 | | | 91 | 664 | 2.19 |
| 8.0 - 8.9 | 15 | 50 | 15 | 9 | 6 | 3 | 3 | | | | 115 | 573 | 2.14 |
| 9.0 - 9.9 | 37 | 99 | 22 | 3 | 3 | | | | | | 185 | 458 | 1.50 |
| 10.0 -10.9 | 19 | 77 | 19 | 3 | | | | | | | 133 | 273 | 1.55 |
| 11.0 -11.9 | 6 | 46 | 15 | 3 | | 3 | | | | | 84 | 140 | 1.86 |
| 12.0 -12.9 | 9 | 15 | | 3 | | | | | | | 31 | 56 | 1.39 |
| 13.0 -13.9 | 6 | 3 | | | | | | | | | 10 | 24 | .83 |
| 14.0 -14.9 | | 3 | | | | | | | | | 3 | 14 | 1.50 |
| 15.0 -15.9 | 3 | 6 | | | | | | | | | 10 | 10 | 1.17 |
| TOTAL | 263 | 471 | 195 | 37 | 12 | 6 | 9 | 3 | | 3 | | | 1.66 |
| CUM. TOTAL | 1000 | 737 | 266 | 71 | 34 | 22 | 15 | 6 | 3 | 3 | | | |
| PER. AVG. | 8.60* | 8.64 | 7.04 | 8.42 | 8.25 | 10.00 | 7.50 | 7.50 | .00 | 6.50 | 8.25 | | |

AVERAGE SIG. HEIGHT = 1.66 FT AVERAGE WAVE PERIOD = 8.25 SEC*
VARIANCE OF SIG. HEIGHT = 1.33 FT SQ VARIANCE OF WAVE PERIOD = 7.11 SEC SQ*
STANDARD DEVIATION OF HEIGHT = 1.16 FT STANDARD DEVIATION OF PERIOD = 2.67 SEC*

DATA WERE OBTAINED FROM 7-MINUTE PEN AND INK RECORDS TAKEN WITH A STEP RESISTANCE RELAY WAVE GAGE LOCATED AT 15TH STREET PIER .
* CALMS ARE OMITTED.

WAVE CLIMATOLOGY FOR VIRGINIA BEACH, VIRGINIA
DISTRIBUTION OF SIGNIFICANT HEIGHT VS PERIOD (IN OBSERVATIONS PER 1000 OBS)

572 OBSERVATIONS SUMMARY FOR APR 64 APR 66 APR 67 APR 68

HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 5 | | | | | | | | | 1000 | .00 |
| 2.0 - 2.4 | | | | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | | | | | | | | | 1000 | .00 |
| 3.0 - 3.4 | 2 | 17 | 2 | | | | | | 21 | 1000 | 1.50 |
| 3.5 - 3.9 | 2 | 16 | 3 | | | | | | 21 | 979 | 1.58 |
| 4.0 - 4.9 | 2 | 24 | 21 | 5 | 5 | | | | 56 | 958 | 2.29 |
| 5.0 - 5.9 | | 33 | 72 | 14 | 7 | 2 | | | 123 | 930 | 2.41 |
| 6.0 - 6.9 | 3 | 66 | 37 | 17 | 2 | 5 | | | 132 | 777 | 2.22 |
| 7.0 - 7.9 | | 63 | 37 | 10 | 10 | | | | 121 | 646 | 2.24 |
| 8.0 - 8.9 | 16 | 93 | 63 | 9 | 2 | | | | 182 | 525 | 1.68 |
| 9.0 - 9.9 | 10 | 73 | 28 | 9 | 3 | | | 2 | 126 | 342 | 1.94 |
| 10.0 -10.9 | 2 | 58 | 37 | 2 | | | | | 98 | 216 | 1.89 |
| 11.0 -11.9 | 2 | 28 | 14 | 10 | | | 2 | | 56 | 118 | 2.25 |
| 12.0 -12.9 | 2 | 21 | 12 | 2 | | 2 | | | 39 | 61 | 2.05 |
| 13.0 -13.9 | | 9 | 5 | | | 2 | | | 16 | 23 | 2.28 |
| 14.0 -14.9 | | | 3 | 2 | | 2 | | | 7 | 7 | 3.50 |
| TOTAL | 44 | 502 | 334 | 80 | 24 | 12 | 2 | 2 | | | 2.09 |
| CUM. TOTAL | 1000 | 956 | 455 | 121 | 40 | 16 | 3 | 2 | | | |
| COL. AVG. | 8.37* | 8.18 | 7.91 | 7.91 | 7.00 | 9.36 | 11.50 | 9.50 | 8.07 | | |

AVERAGE SIG. HEIGHT = 2.09 FT
VARIANCE OF SIG. HEIGHT = .87 FT SQ
STANDARD DEVIATION OF HEIGHT = .93 FT

AVERAGE WAVE PERIOD = 8.07 SEC*
VARIANCE OF WAVE PERIOD = 5.84 SEC SQ*
STANDARD DEVIATION OF PERIOD = 2.42 SEC*

816 OBSERVATIONS SUMMARY FOR MAY 66 MAY 67 MAY 68

HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 46 | | | | | | | | | | | | | 1000 | .00 |
| 2.0 - 2.4 | | | | | | | | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | 2 | | | | | | | | | | | 3 | 1000 | 1.50 |
| 3.0 - 3.4 | | 7 | | | | | | | | | | | 6 | 997 | 1.50 |
| 3.5 - 3.9 | 2 | 38 | 7 | | | | | | | | | | 50 | 990 | 1.60 |
| 4.0 - 4.9 | 2 | 48 | 29 | 5 | 2 | 2 | | | | | | | 93 | 940 | 2.09 |
| 5.0 - 5.9 | 2 | 31 | 39 | 12 | | 2 | | | | | | | 91 | 846 | 2.31 |
| 6.0 - 6.9 | 2 | 70 | 10 | 10 | 7 | 2 | | | 2 | | | | 108 | 756 | 2.22 |
| 7.0 - 7.9 | 19 | 89 | 41 | 5 | | | | | | | | | 161 | 647 | 1.70 |
| 8.0 - 8.9 | 14 | 111 | 31 | 2 | | | 2 | | | | | | 169 | 486 | 1.71 |
| 9.0 - 9.9 | 17 | 91 | 26 | 2 | 2 | | | | 2 | | | 2 | 151 | 317 | 1.93 |
| 10.0 -10.9 | 14 | 46 | 24 | 12 | 2 | | | | | 5 | | | 108 | 166 | 2.27 |
| 11.0 -11.9 | 10 | 10 | 5 | 2 | | | | | | | | | 28 | 58 | 1.50 |
| 12.0 -12.9 | 2 | 7 | 2 | | | | | | | | | | 13 | 30 | 1.50 |
| 13.0 -13.9 | | 7 | | | | | | | | | | | 8 | 18 | 1.50 |
| 14.0 -14.9 | 2 | | | | | | | | | | | | 3 | 10 | .50 |
| 15.0 -15.9 | 5 | | | | | | | | | | | | 5 | 8 | .50 |
| 16.0 -16.9 | 2 | | | | | | | | | | | | 3 | 3 | .50 |
| TOTAL | 142 | 596 | 214 | 50 | 14 | 7 | 2 | | 5 | 5 | | 2 | | | 1.85 |
| CUM. TOTAL | 1000 | 858 | 300 | 87 | 36 | 22 | 14 | 12 | 12 | 7 | 2 | 2 | | | |
| COL. AVG. | 9.53* | 7.65 | 7.44 | 7.60 | 7.33 | 5.50 | 8.50 | .00 | 8.00 | 10.50 | .00 | 9.50 | 7.79 | | |

AVERAGE SIG. HEIGHT = 1.85 FT
VARIANCE OF SIG. HEIGHT = 1.52 FT SQ
STANDARD DEVIATION OF HEIGHT = 1.23 FT

AVERAGE WAVE PERIOD = 7.79 SEC*
VARIANCE OF WAVE PERIOD = 5.55 SEC SQ*
STANDARD DEVIATION OF PERIOD = 2.36 SEC*

RESULTS OBTAINED FROM 7-MINUTE PEN AND INK RECORDS TAKEN WITH A STEP RESISTANCE RELAY
WAVE GAGE LOCATED AT 15TH STREET PIER

* CALMS ARE OMITTED.

WAVE CLIMATOLOGY FOR VIRGINIA BEACH, VIRGINIA
DISTRIBUTION OF SIGNIFICANT HEIGHT VS PERIOD (IN OBSERVATIONS PER 1000 OBS)
360 OBSERVATIONS SUMMARY FOR JUN 66 JUN 67

PERIOD (SECS) / HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | | | | | | | | | | | 1000 | .00 |
| 2.0 - 2.4 | | | | | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | | | | | | | | | | 1000 | .00 |
| 3.0 - 3.4 | 8 | 6 | | | | | | | | 14 | 1000 | .50 |
| 3.5 - 3.9 | | 36 | 3 | | | | | | | 39 | 986 | 1.57 |
| 4.0 - 4.9 | | 28 | 6 | | | | | | | 33 | 947 | 1.67 |
| 5.0 - 5.9 | 6 | 28 | 19 | | | | | | | 53 | 910 | 1.76 |
| 6.0 - 6.9 | | 64 | 11 | | | 3 | 6 | 6 | 3 | 92 | 861 | 2.62 |
| 7.0 - 7.9 | 25 | 167 | 22 | 6 | | | 6 | 8 | | 233 | 769 | 1.87 |
| 8.0 - 8.9 | 19 | 183 | 17 | | | 3 | | | 3 | 225 | 536 | 1.62 |
| 9.0 - 9.9 | 14 | 214 | 17 | | | | | | | 204 | 311 | 1.50 |
| 10.0 -10.9 | 6 | 28 | | | | | | | | 33 | 67 | 1.33 |
| 11.0 -11.9 | 3 | 8 | | | | | | | | 11 | 33 | 1.75 |
| 12.0 -12.9 | 3 | 3 | | | | | | | | 6 | 22 | 1.00 |
| 13.0 -13.9 | | 6 | 3 | | | | | | | 8 | 17 | 1.83 |
| 14.0 -14.9 | | 8 | | | | | | | | 8 | 8 | 1.50 |
| TOTAL | 83 | 778 | 97 | 6 | | 6 | 11 | 14 | 6 | | | 1.72 |
| CUM. TOTAL | 1000 | 917 | 139 | 42 | 36 | 36 | 31 | 19 | 6 | | | |
| COL. AVG. | 8.01* | 8.11 | 7.39 | 7.50 | .00 | 7.50 | 7.00 | 7.10 | 7.50 | 7.99 | | |

AVERAGE SIG. HEIGHT = 1.72 FT
VARIANCE OF SIG. HEIGHT = 1.29 FT SQ
STANDARD DEVIATION OF HEIGHT = 1.14 FT

AVERAGE WAVE PERIOD = 7.99 SEC*
VARIANCE OF WAVE PERIOD = 3.69 SEC SQ*
STANDARD DEVIATION OF PERIOD = 1.92 SEC*

451 OBSERVATIONS SUMMARY FOR JUL 64 JUL 66 JUL 67

PERIOD (SECS) / HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | | | | | | | | | | 1000 | .00 |
| 2.0 - 2.4 | | | | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | | | | | | | | | 1000 | .00 |
| 3.0 - 3.4 | | | 4 | | | | | | 4 | 1000 | 2.50 |
| 3.5 - 3.9 | | 7 | 4 | | | | | | 11 | 996 | 1.90 |
| 4.0 - 4.9 | | 7 | 9 | 4 | | | | | 20 | 984 | 2.39 |
| 5.0 - 5.9 | | 18 | 16 | 4 | 2 | | | | 40 | 965 | 2.28 |
| 6.0 - 6.9 | 2 | 22 | 11 | 11 | 9 | 11 | | | 67 | 925 | 3.03 |
| 7.0 - 7.9 | 16 | 73 | 42 | 7 | 2 | 7 | 4 | | 151 | 858 | 2.13 |
| 8.0 - 8.9 | 40 | 197 | 33 | 7 | 9 | 4 | | | 295 | 707 | 1.69 |
| 9.0 - 9.9 | 33 | 182 | 33 | 4 | 2 | | | 2 | 257 | 412 | 1.61 |
| 10.0 -10.9 | 11 | 62 | 13 | 2 | | | | | 89 | 155 | 1.57 |
| 11.0 -11.9 | 2 | 11 | 4 | | | | | | 18 | 67 | 1.62 |
| 12.0 -12.9 | 4 | 7 | 2 | | | | | | 13 | 49 | 1.35 |
| 13.0 -13.9 | 2 | 11 | | | | | | | 13 | 35 | 1.33 |
| 14.0 -14.9 | 2 | 7 | 9 | 2 | | | | | 20 | 22 | 2.06 |
| 15.0 -15.9 | | | | | | | | | | 2 | .00 |
| 16.0 -16.9 | | 2 | | | | | | | 2 | 2 | 1.50 |
| TOTAL | 113 | 605 | 186 | 42 | 24 | 22 | 4 | 2 | | | 1.85 |
| CUM. TOTAL | 1000 | 887 | 282 | 95 | 53 | 29 | 7 | 2 | | | |
| COL. AVG. | 8.25* | 8.51 | 8.20 | 7.61 | 7.50 | 7.20 | 7.50 | 9.50 | 8.69 | | |

AVERAGE SIG. HEIGHT = 1.85 FT
VARIANCE OF SIG. HEIGHT = 1.11 FT SQ
STANDARD DEVIATION OF HEIGHT = 1.05 FT

AVERAGE WAVE PERIOD = 8.69 SEC*
VARIANCE OF WAVE PERIOD = 3.61 SEC SQ*
STANDARD DEVIATION OF PERIOD = 1.90 SEC*

RESULTS OBTAINED FROM 7-MINUTE PEN AND INK RECORDS TAKEN WITH A STEP RESISTANCE RELAY WAVE GAGE LOCATED AT 15TH STREET PIER

* CALMS ARE OMITTED.

WAVE CLIMATOLOGY FOR VIRGINIA BEACH, VIRGINIA
DISTRIBUTION OF SIGNIFICANT HEIGHT VS PERIOD (IN OBSERVATIONS PER 1000 OBS)
448 OBSERVATIONS SUMMARY FOR AUG 64 AUG 66 AUG 67

PERIOD (SECS) HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 16 | | | | | | 1000 | .00 |
| 2.0 - 2.4 | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | | | | | | 1000 | .00 |
| 3.0 - 3.4 | | 4 | 2 | | | 7 | 1000 | 1.63 |
| 3.5 - 3.9 | | | 4 | | | 5 | 993 | 2.50 |
| 4.0 - 4.9 | 2 | 11 | 9 | 7 | | 29 | 989 | 2.19 |
| 5.0 - 5.9 | 9 | 22 | 13 | 9 | 2 | 57 | 959 | 2.02 |
| 6.0 - 6.9 | 25 | 58 | 13 | 7 | | 104 | 902 | 1.52 |
| 7.0 - 7.9 | 54 | 83 | 11 | 11 | | 161 | 798 | 1.37 |
| 8.0 - 8.9 | 67 | 129 | 27 | 4 | 2 | 234 | 637 | 1.39 |
| 9.0 - 9.9 | 18 | 107 | 33 | | | 161 | 404 | 1.60 |
| 10.0 -10.9 | 18 | 42 | 31 | 11 | 2 | 107 | 243 | 1.90 |
| 11.0 -11.9 | 7 | 20 | 22 | 2 | 2 | 54 | 136 | 2.06 |
| 12.0 -12.9 | 4 | 11 | 7 | 2 | 9 | 34 | 82 | 2.50 |
| 13.0 -13.9 | 4 | 11 | 2 | 4 | | 23 | 48 | 1.80 |
| 14.0 -14.9 | 2 | 16 | 4 | 2 | | 25 | 25 | 1.77 |
| TOTAL | 225 | 516 | 181 | 60 | 18 | | | 1.53 |
| CUM. TOTAL | 1000 | 775 | 259 | 78 | 18 | | | |
| COL. AVG. | 8.45* | 8.72 | 8.95 | 8.43 | 10.75 | 8.72 | | |

AVERAGE SIG. HEIGHT = 1.63 FT
VARIANCE OF SIG. HEIGHT = .79 FT SQ
STANDARD DEVIATION OF HEIGHT = .89 FT

AVERAGE WAVE PERIOD = 8.72 SEC*
VARIANCE OF WAVE PERIOD = 4.89 SEC SQ*
STANDARD DEVIATION OF PERIOD = 2.21 SEC*

281 OBSERVATIONS SUMMARY FOR SEP 66 SEP 67

PERIOD (SECS) HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 11 | 4 | | | | | | | | 4 | 1000 | 1.50 |
| 2.0 - 2.4 | | | | | | | | | | | 996 | .00 |
| 2.5 - 2.9 | | | | | | | | | | | 996 | .00 |
| 3.0 - 3.4 | 4 | 11 | 7 | | | | | | | 22 | 996 | 1.67 |
| 3.5 - 3.9 | | 7 | 7 | | | | | | | 14 | 975 | 2.00 |
| 4.0 - 4.9 | | 28 | 11 | 7 | 4 | | | | | 50 | 960 | 2.21 |
| 5.0 - 5.9 | | 36 | 14 | 25 | 11 | 4 | | | | 90 | 910 | 2.74 |
| 6.0 - 6.9 | 4 | 21 | 7 | 21 | 18 | 11 | 7 | | | 90 | 820 | 3.50 |
| 7.0 - 7.9 | | 28 | 21 | 18 | 14 | 14 | 14 | 4 | 4 | 119 | 730 | 3.83 |
| 8.0 - 8.9 | 11 | 96 | 18 | 25 | 11 | 4 | | | 4 | 169 | 612 | 2.27 |
| 9.0 - 9.9 | 25 | 125 | 7 | 14 | 4 | 4 | 4 | | | 183 | 442 | 1.79 |
| 10.0 -10.9 | 18 | 68 | 11 | 4 | | | | | | 101 | 259 | 1.50 |
| 11.0 -11.9 | 18 | 36 | 14 | 14 | 7 | | | | | 90 | 158 | 2.02 |
| 12.0 -12.9 | 4 | 18 | | 7 | 4 | | 4 | | | 36 | 68 | 2.00 |
| 13.0 -13.9 | 11 | 11 | 11 | | | | | | | 32 | 32 | 1.50 |
| TOTAL | [illegible] | [illegible] | 128 | 135 | 71 | 36 | 28 | 4 | 7 | | | 2.36 |
| CUM. TOTAL | 1000 | 897 | 409 | 281 | 146 | 75 | 39 | 11 | 7 | | | |
| COL. AVG. | 10.16* | 8.67 | 7.97 | 7.97 | 7.70 | 7.30 | 8.13 | 7.50 | 8.00 | 8.48 | | |

AVERAGE SIG. HEIGHT = 2.36 FT
VARIANCE OF SIG. HEIGHT = 2.42 FT SQ
STANDARD DEVIATION OF HEIGHT = 1.56 FT

AVERAGE WAVE PERIOD = 8.51 SEC*
VARIANCE OF WAVE PERIOD = 5.81 SEC SQ*
STANDARD DEVIATION OF PERIOD = 2.41 SEC*

RESULTS OBTAINED FROM 7-MINUTE PEN AND INK RECORDS TAKEN WITH A STEP RESISTANCE RELAY WAVE GAGE LOCATED AT 15TH STREET PIER

* CALMS ARE OMITTED.

WAVE CLIMATOLOGY FOR VIRGINIA BEACH, VIRGINIA
DISTRIBUTION OF SIGNIFICANT HEIGHT VS PERIOD (IN OBSERVATIONS PER 1000 OBS)

300 OBSERVATIONS SUMMARY FOR OCT 64 OCT 67

HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 3 | | | | | | | | | | | 1000 | .00 |
| 2.0 - 2.9 | | | | | | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | | | | | | | | | | | 1000 | .00 |
| 3.0 - 3.4 | | 3 | | | | | | | | | 3 | 1000 | 1.50 |
| 3.5 - 3.9 | | | | | | | | | | | | 997 | .00 |
| 4.0 - 4.9 | | 7 | 7 | | | | | | | | 13 | 997 | 2.00 |
| 5.0 - 5.9 | | 23 | 27 | 10 | 7 | | | | | | 67 | 983 | 2.50 |
| 6.0 - 6.9 | | 27 | 37 | 30 | 30 | 10 | | | | | 134 | 916 | 3.20 |
| 7.0 - 7.9 | | 67 | 23 | 10 | 7 | 3 | | 3 | | 3 | 117 | 783 | 2.56 |
| 8.0 - 8.9 | 10 | 87 | 43 | 3 | 10 | 3 | 3 | | | | 161 | 666 | 2.12 |
| 9.0 - 9.9 | 30 | 100 | 20 | 10 | 7 | | | | | | 167 | 505 | 1.66 |
| 10.0 -10.9 | 7 | 63 | 20 | 7 | 13 | | 3 | | | | 114 | 338 | 2.24 |
| 11.0 -11.9 | 17 | 50 | 13 | 3 | 3 | | | | 3 | | 90 | 224 | 1.91 |
| 12.0 -12.9 | 7 | 37 | 17 | 7 | | 3 | | | | | 70 | 134 | 2.02 |
| 13.0 -13.9 | | 13 | 7 | 3 | | | | | | | 23 | 64 | 2.07 |
| 14.0 -14.9 | 3 | 30 | 3 | | | | | | | | 37 | 40 | 1.50 |
| 15.0 -15.9 | | 3 | | | | | | | | | 3 | 3 | 1.50 |
| TOTAL | 77 | 510 | 217 | 83 | 77 | 20 | 7 | 3 | 3 | 3 | | | 2.22 |
| CUM. TOTAL | 1000 | 923 | 413 | 197 | 113 | 37 | 17 | 10 | 7 | 3 | | | |
| COL. AVG. | 10.41* | 9.60 | 8.58 | 8.22 | 7.93 | 8.00 | 9.50 | 7.50 | 11.50 | 7.50 | 9.15 | | |

AVERAGE SIG. HEIGHT = 2.22 FT
VARIANCE OF SIG. HEIGHT = 1.78 FT SQ
STANDARD DEVIATION OF HEIGHT = 1.33 FT

AVERAGE WAVE PERIOD = 9.15 SEC*
VARIANCE OF WAVE PERIOD = 5.77 SEC SQ*
STANDARD DEVIATION OF PERIOD = 2.40 SEC*

526 OBSERVATIONS SUMMARY FOR NOV 64 NOV 66 NOV 67

HEIGHT (FT)

| PERIOD (SECS) | 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | TOT.* | CUM. TOT.* | ROW AVG.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 17 | | | | | | | | | | 1000 | .00 |
| 2.0 - 2.4 | | | | | | | | | | | 1000 | .00 |
| 2.5 - 2.9 | | | | | | | | | | | 1000 | .00 |
| 3.0 - 3.4 | 4 | 2 | | | | | | | | 6 | 1000 | .83 |
| 3.5 - 3.9 | 2 | 8 | 2 | | | | | | | 12 | 994 | 1.50 |
| 4.0 - 4.9 | 10 | 36 | 21 | 11 | | 2 | | | | 81 | 983 | 2.02 |
| 5.0 - 5.9 | 13 | 38 | 30 | 34 | 4 | | | | | 122 | 901 | 2.31 |
| 6.0 - 6.9 | 11 | 40 | 23 | 11 | 13 | 10 | 2 | | | 112 | 779 | 2.60 |
| 7.0 - 7.9 | 8 | 32 | 32 | 10 | 6 | | 4 | | 2 | 95 | 667 | 2.50 |
| 8.0 - 8.9 | 17 | 67 | 27 | | 6 | | | | | 118 | 573 | 1.73 |
| 9.0 - 9.9 | 32 | 99 | 30 | | 2 | | | | | 166 | 455 | 1.52 |
| 10.0 -10.9 | 17 | 72 | 30 | 2 | 4 | | | | | 128 | 288 | 1.73 |
| 11.0 -11.9 | | 55 | 19 | 4 | 4 | | | | | 83 | 161 | 1.97 |
| 12.0 -12.9 | 4 | 25 | 13 | 2 | | | | | | 44 | 77 | 1.80 |
| 13.0 -13.9 | | 6 | 2 | 2 | 4 | | | | | 14 | 33 | 2.79 |
| 14.0 -14.9 | 2 | 13 | 2 | 2 | | | | | | 19 | 19 | 1.70 |
| TOTAL | 137 | 492 | 232 | 78 | 42 | 11 | 6 | | 2 | | | 1.96 |
| CUM. TOTAL | 1000 | 863 | 371 | 139 | 61 | 19 | 8 | 2 | 2 | | | |
| COL. AVG. | 8.13* | 8.90 | 8.33 | 6.74 | 8.41 | 6.17 | 7.17 | .00 | 7.50 | 8.44 | | |

AVERAGE SIG. HEIGHT = 1.96 FT
VARIANCE OF SIG. HEIGHT = 1.26 FT SQ
STANDARD DEVIATION OF HEIGHT = 1.12 FT

AVERAGE WAVE PERIOD = 8.44 SEC*
VARIANCE OF WAVE PERIOD = 6.53 SEC SQ*
STANDARD DEVIATION OF PERIOD = 2.56 SEC*

RESULTS OBTAINED FROM 7-MINUTE PEN AND INK RECORDS TAKEN WITH A STEP RESISTANCE RELAY
WAVE GAGE LOCATED AT 15TH STREET PIER
* CALMS ARE OMITTED.

WAVE CLIMATOLOGY FOR VIRGINIA BEACH, VIRGINIA
DISTRIBUTION OF SIGNIFICANT HEIGHT VS PERIOD (IN OBSERVATIONS PER 1000 OBS)
606 OBSERVATIONS SUMMARY FOR DEC 64 DEC 65 DEC 66 DEC 67

| PERIOD (SECS) | HEIGHT (FT) 0-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | TOT. | CUM. TOT. | ROW AVG. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .0 - 1.9 | 2 | | | 2 | | | | | | | | 2 | 1000 | 3.50 |
| 2.0 - 2.4 | | | | | | | | | | | | | 998 | .00 |
| 2.5 - 2.9 | | | | | | | | | | | | | 998 | .00 |
| 3.0 - 3.4 | 2 | 13 | | | | | | | | | | 15 | 998 | 1.39 |
| 3.5 - 3.9 | 3 | 21 | 7 | | | | | | | | | 31 | 983 | 1.61 |
| 4.0 - 4.9 | 5 | 18 | 13 | 3 | 8 | | | | | | | 48 | 952 | 2.33 |
| 5.0 - 5.9 | 7 | 33 | 28 | 30 | 15 | 5 | | | | | | 117 | 904 | 2.74 |
| 6.0 - 6.9 | 8 | 36 | 28 | 17 | 15 | 7 | 3 | | | | | 110 | 787 | 2.73 |
| 7.0 - 7.9 | 12 | 26 | 21 | 8 | 3 | 3 | | | 2 | | | 76 | 673 | 2.51 |
| 8.0 - 8.9 | 10 | 58 | 25 | 8 | 2 | 3 | 2 | | | | 2 | 109 | 555 | 2.17 |
| 9.0 - 9.9 | 26 | 101 | 40 | 10 | | 2 | 2 | | 2 | | | 182 | 486 | 1.73 |
| 10.0 -10.9 | 18 | 69 | 26 | 7 | 3 | | | | | | | 124 | 306 | 1.75 |
| 11.0 -11.9 | 13 | 46 | 20 | 3 | | | | | | | | 83 | 180 | 1.66 |
| 12.0 -12.9 | 2 | 28 | 18 | 3 | | | | | | | | 51 | 98 | 1.95 |
| 13.0 -13.9 | | 13 | 10 | 3 | 2 | | | | | | | 28 | 86 | 2.26 |
| 14.0 -14.9 | 2 | 2 | 13 | | | | | | | | | 17 | 18 | 2.20 |
| 15.0 -15.9 | | | | | | | | | | | | | 2 | .00 |
| 16.0 -16.9 | | | | | 2 | | | | | | | 2 | 2 | 4.50 |
| TOTAL | 109 | 465 | 251 | 94 | 50 | 20 | 7 | | 3 | | 2 | | | 2.13 |
| CUM. TOTAL | 1000 | 891 | 426 | 175 | 81 | 31 | 12 | 5 | 5 | 2 | 2 | | | |
| COL. AVG. | 8.75* | 8.77 | 8.92 | 7.51 | 6.83 | 7.00 | 7.75 | .00 | 8.50 | .00 | 8.50 | 8.55 | | |

AVERAGE SIG. HEIGHT = 2.13 FT
VARIANCE OF SIG. HEIGHT = 1.56 FT SQ
STANDARD DEVIATION OF HEIGHT = 1.25 FT

AVERAGE WAVE PERIOD = 8.56 SEC*
VARIANCE OF WAVE PERIOD = 7.13 SEC SQ*
STANDARD DEVIATION OF PERIOD = 2.67 SEC*