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COMPARISONS OF HINDCAST AND MEASURED DEEPWATER, SIGNIFICANT WAVE HEIGHTS

by

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WIS REPORT 3

May 1981

WAVE INFORMATION STUDIES OF U. S. COASTLINES

Prepared for Office, Chief of Engineers, U. S. Army
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Descriptive techniques (time series plots, cross plots, difference of the means and mean absolute difference computations, and percent occurrence computations and plots) are employed to compare recorded and computed wave heights for the Atlantic Ocean. The comparisons indicate a random difference of approximately 1.0 m and a bias of approximately 0.04 m. Based on the results of the comparisons, the wave climates produced by the hindcast of

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deepwater, significant wave data for the Atlantic Coast Wave Information Study are considered valid. Consequently, they should provide excellent data bases for applications in coastal and ocean engineering.

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Preface

In late 1976, a study to produce a wave climate for U. S. coastal waters was initiated at the U. S. Army Engineer Waterways Experiment Station (WES). The Wave Information Study (WIS) was authorized by the Office, Chief of Engineers, U. S. Army, as a part of the Field Data Collection Program which is managed by the U. S. Army Coastal Engineering Research Center. The U. S. Army Engineer Division, South Atlantic, and the U. S. Army Engineer Division, New England, also authorized funds during the initial year of this study (FY 1978) to expedite execution of the Atlantic coast portion of this program.

This report, the third in a series, presents comparisons of measured and computed deepwater, significant wave heights. The study was conducted in the Hydraulics Laboratory under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, Dr. R. W. Whalin, Chief of the Wave Dynamics Division, Mr. C. E. Chatham, Jr., Chief of the Wave Processes Branch, and Dr. D. T. Resio, Project Manager. This report was prepared by Mr. W. D. Corson and Dr. Resio.

Commanders and Directors of WES during the conduct of the study and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

Summary

In late 1976 a study to produce a wave climate for U. S. coastal waters was initiated at the U. S. Army Engineer Waterways Experiment Station. This climatological information is to be produced by numerical simulation of wave growth, propagation, and decay under historical wind fields. It is imperative, if such an approach is to be used for applications of significant economic consequences, that the entire set of input data, all numerical techniques, and all general assumptions be thoroughly investigated and documented to determine the types and magnitudes of errors intrinsic to their use.

There are four basic steps in the calculation of waves from past meteorological data. First, pressure data must be assimilated into a pressure field that depicts all important synoptic weather features. Gradients of pressure in time and space, along with certain thermal characteristics of the planetary boundary layer, are then used to construct an estimate of a quasi-geostrophic wind speed and direction at some level where it is assumed that the frictional effects of the ocean surface on the atmosphere are negligible. Next, an analysis of the vertical variation of the wind in the planetary boundary layer is used to reduce this wind to a common 19.5-m level. Finally, these surface winds are input into a numerical wave model to simulate wave generation, propagation, and decay.

If any one of the above steps contributes significant bias (on a geographical basis, seasonally or overall), it can introduce errors into the results that are difficult or even impossible to remove. Similarly, if any step contains a large random error, certain statistics (such as duration curves, extremes, and conditional probabilities) can be seriously affected. Thus, each step must be checked independently where possible. This serves to substantiate the merit of the physics and data processing techniques used in each step and hence tends to lend support to the worth of the final product more so than the performance of only wave comparisons, regardless of how extensive these comparisons may be. Indeed, if each step is shown to be physically valid, it can be argued

that the results should be as accurate in sites where there are no wave data for verification as they are in areas where large amounts of gage data are available. Additionally, if all steps are modeled correctly, factors such as direction and angular spreading, which are not generally available for comparisons, can reasonably be assumed to be at least approximately correct.

This report will compare the hindcast waves, using constructed oceanic wind fields, with measured wave data. This report is consequently the report that documents the cumulative effects of the errors from all four steps in the hindcast procedure. It is our belief that numerical modeling of surface waves represents an evolution toward a more reliable means of obtaining wave information for climatological purposes. Coupled with the concurrent evolution of statistical methods, data processing technology, and planning and design capabilities, this tool offers a vastly improved ability to deal with coastal problems. Furthermore, by relating data to physical processes, an underlying understanding of the wave phenomena is gained. This can increase confidence in recognizing the significance of trends, distributions, and correlations among various data elements, which can, in turn, increase confidence in many basic planning, design, construction, operation, and maintenance decisions.

Contents

COMPARISONS OF HINDCAST AND MEASURED DEEPWATER, SIGNIFICANT WAVE HEIGHTS

Introduction

1. The analysis of wave climatology by the Atlantic Coast Wave Information Study (ACWIS) has been separated into three phases:

Phase I - Numerical hindcast of deepwater wave data from historical surface pressure and wind data.

Phase II - Derivation of wave data which have been subjected to refraction, diffraction, shoaling, and bottom friction.

Phase III - Transformation of Phase II wave data into shallow water and inclusion of long waves.

Figure 1 presents a schematic of the relationship of the three phases and their approximate boundaries.

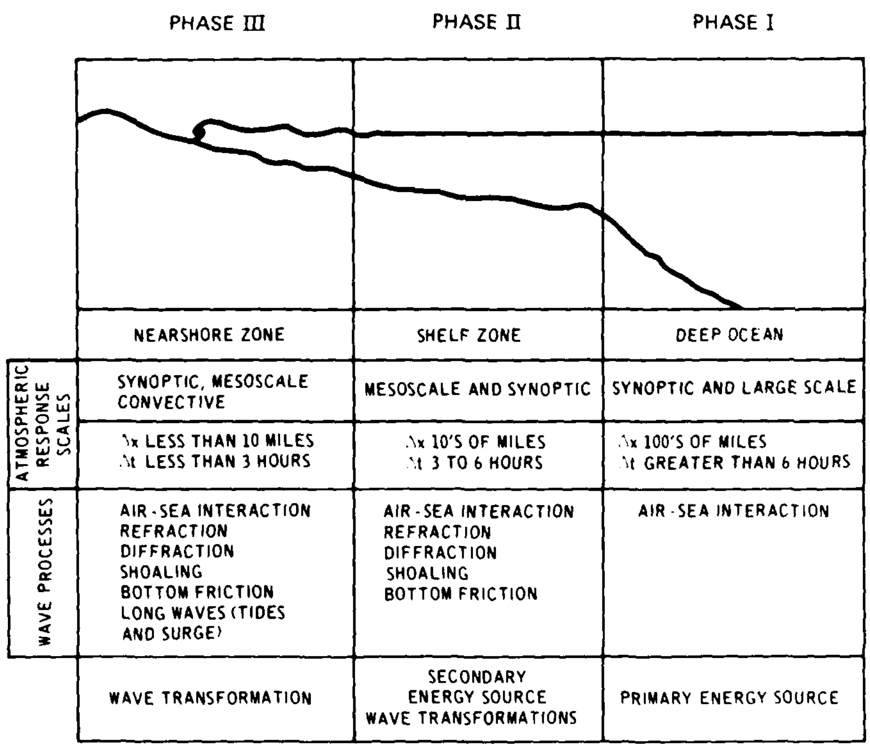

Figure 1. Conceptual diagram of the three phases of the Wave Information Study (WIS)

2. After Phase I hindcast computations were complete, a literature search was undertaken in order to find available measured deepwater wave recordings within the ACWIS grid (Figure 2). No visually estimated (observed) wave-height recordings are used in the time-paired comparisons. For one area, significant wave height (H_s) recorded onboard ships (which includes visual observations) was used in order to compare long-term computed and observed data sets. The purpose of this report is to present the comparisons of ACWIS hindcast, deepwater, significant wave heights with measured deepwater, significant wave heights and to use the comparisons in order to determine the validity of Phase I ACWIS wave data.

Locations of Comparisons

3. Phase I ACWIS wave data were computed and stored in a spherical orthogonal grid which covers the North Atlantic Ocean (Figure 2). Although primary interest is in the area adjacent to the U. S. Atlantic coast, data from locations throughout the North Atlantic were saved and some are used in this report for comparison purposes.

4. Table 1 shows the latitude and longitude of locations at which measurements are available and the corresponding computational locations. It was not possible for computational locations to exactly match locations with measured information; therefore, the nearest available computational locations to measured locations were used (Figure 3). For the comparisons with data from site EB15, data from two model locations were averaged (referred to as ACWIS station "67") since EB15 was between two model grid locations. Other comparisons use one measured location and one computed location. The ships data compared with computed data were from latitude 30°N to 33°N and longitude 74°W to 76°W in Marsden square 116. Displacement of paired locations is expected to produce some discrepancies in the comparisons; however, these discrepancies are expected to be small relative to other sources of differences.

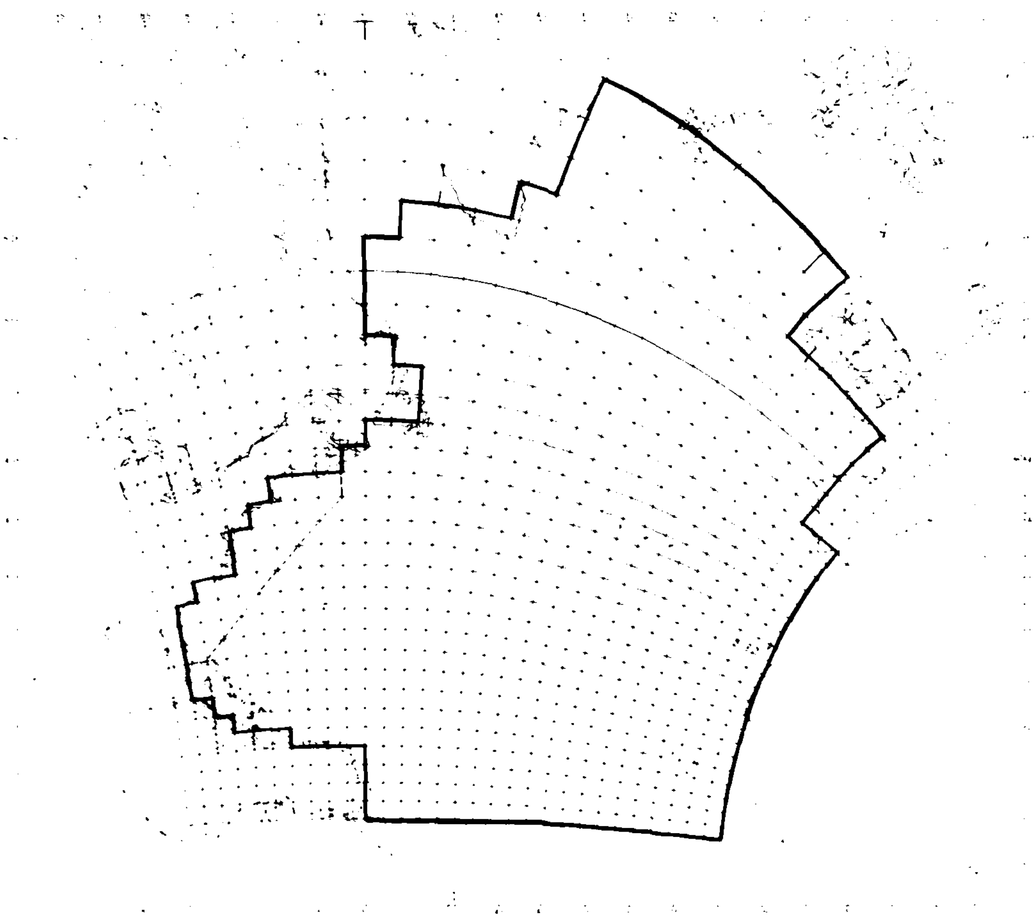

Figure 2. WIS spherical orthogonal grid on a Mercator projection. Heavy dark line is numerical boundary; dashed line is approximate limit of Phase II area

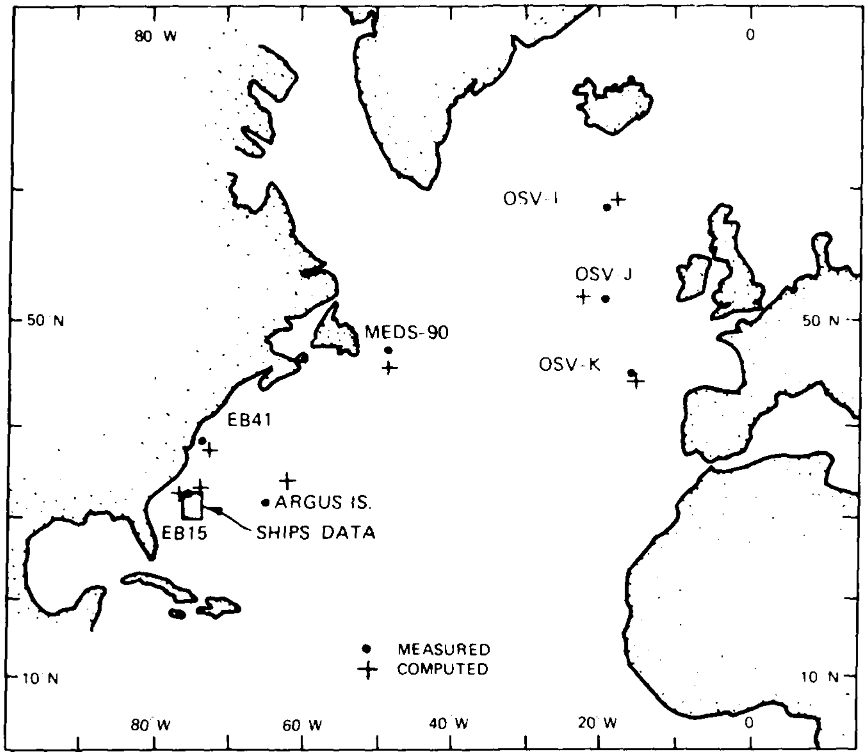

Figure 3. Location map of measured and computed data locations

ACWIS Computed Wave Data

5. For the comparisons in this report, computed wave heights are deepwater and significant (computed as $4*\sqrt{\text{wave energy}}$). Although computed significant wave height, period, and direction are available, comparisons here are restricted to significant wave height. Computed (hindcast) data are available for the 20-year period, 1956-1975, at 3-hr intervals (0000 GMT, 0300 GMT, 0600 GMT, etc.).

Measured Wave Data

6. Measured data were recorded with various instruments and the analyses that determined the wave heights also varied. Therefore, some differences are expected between records, but these differences are not expected to greatly affect the comparisons. For more information on the recording instruments, discussion of the shipborne wave recorder used

by the Ocean Station Vessels (OSV) can be found in Tucker (1956a), Tucker (1956b), and Tucker (1959); details of the Argus tower wave staff are given in Pickett (1964), Pickett (1962), Deleonibus and Simpson (1972), and Moskios and Deleonibus (1965); development and accuracy of the large discus buoys used by the National Oceanic and Atmospheric Administration Data Buoy Office (NDBO) are discussed in Michelena et al. (1974); and the accuracy of the Waverider buoy similar to the one used by the Marine Environmental Data Service (MEDS)* is discussed in Pitt, Driver, and Ewing (1978), while details of the buoy are given in the Datawell Waverider specification sheet.**

7. The various sources, dates, locations, and types of measuring devices for the recorded wave heights are presented in Table 1. The comparisons performed for selected intervals at the OSV locations and the MEDS buoy were done to determine how well the computed data represent severe storm intervals.†

8. The records used from the NDBO buoys (EB15 and EB41) and the Argus tower wave staff contain all wave heights available from the source, and comparisons of computed data with these records should show how well computed wave data represent various wave climates.

9. Since sufficient wave period and direction recordings were not available from all measured-data sources, no attempt was made to compare the measured and computed wave periods and directions.

Comparisons

10. Simple, yet descriptive, techniques were employed for the comparisons: time series plots, cross plots, difference of the means and mean absolute difference computations, and percent occurrence

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* Data for MEDS Station 90 were supplied by Marine Environmental Data Service, Canada.

** Datawell, Laboratory for Instrumentation, Zomerluststraat 4, Haarlem, Netherland.

† Although they are not from severe storm intervals, the November 1966 wave heights are included since they were recorded at OSV locations and they contain some relatively large wave heights.

computations and plots. The last of these types of comparisons is probably the most indicative of the ability of the hindcast wave data to represent a wave climate accurately. For the time series plots, cross plots, and the mean absolute difference computations, the significant wave heights (H_s) were paired as a function of time. These paired-data techniques are used to describe the random error of the hindcast model. However, much of the random error in these comparisons is attributable to shifts in time between the wave hindcasts and observed wave height. Although this type of error, which is typically associated with a storm displacement, can be an important consideration in forecasting wave conditions, it is not a major consideration in the estimation of climatological wave characteristics. Consequently, for the evaluation of these hindcast data relative to wave climate representations, major emphasis is centered on the long-term comparisons of means and probability distributions in which the time factor has been removed. The difference of the mean was computed and tabulated for each event, and the percent occurrence of H_s was computed for all events and combined into one graph each for the EB15 and ships data with the time factor removed. These parameters are a means of describing the bias of the hindcast model.

11. Although the time series comparisons shown in Appendix A do not provide a numerical value for difference or similarity, they are qualitative descriptors of the response of the model. In general, all of the time series plots show that the hindcast H_s are distributed through time similar to the distribution of the measured H_s (Figures A1-A15). Some intervals show the computed waves to be "out of phase" with respect to the measured data. However, this out-of-phase characteristic is probably due to the difference in locations between the computed and measured sites. Slight storm displacement on the National Weather Service (NWS) surface charts or from the Meteorological International Inc. (MII) data tapes would also cause some phase shifts (Corson, Resio, and Vincent, 1980).*

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* Corson, Resio, and Vincent, WIS Report 1, discusses the use of NWS and MII data in the preparation of pressure fields which were used to generate the wind fields--the basic input to the wave model.

12. The first set of time series plots represent comparisons during severe storm intervals (Figures A1-A8). Although some of the plots show the out-of-phase characteristics, the magnitudes and distributions of the computed waves appear very similar to those of the recorded waves.

13. The time series plots for the two NDBO buoys (EB15 and EB40, Figures A9-A12 and A13-A15, respectively) indicate more difference between the measured and computed waves than the previous time series plots. Although the "signals" of the two data sets are very similar (computed wave heights increased when buoy wave heights increased), the computed significant wave heights are generally smaller than measured EB15 significant wave heights and generally larger than measured EB41 wave heights. However, the validity of the wave data from the early NDBO buoys has been questioned by those processing the buoy data tapes. In fact, buoy data from 1973 and 1974 were disregarded on instructions from NSTL (NDBO) personnel. As seen in Figures A11 and A12 the EB15 wave heights peak higher than the computed wave heights when storms pass through the area. Also, the distribution of significant waves greater than 4.9 m for EB15 is quite different from the distribution of ACWIS waves (Figure 4). EB15 recorded a relatively high percentage of waves occurring greater than 4.9 m, and up to approximately 8 m, yet review of weather charts and records shows this interval in 1975 to be relatively mild compared with other years. The buoy error is presumed to have not affected the time parameter in the recordings; therefore, the comparisons were retained to investigate the synchroneity of the computed and measured data sets.

14. The time series plots of computed data and EB41 data show a different trend than the comparisons to EB15. Comparisons to EB41 show computed wave heights to be generally greater than EB41 recorded wave heights (Figures A13-A15).

15. Since EB41 is closer to shore and in shallower water than model location "4" (Figure 5), the difference between model location 4 data and EB41 data is probably related to the difference in the physical parameters (deep ocean and shelf zone, respectively) at the different

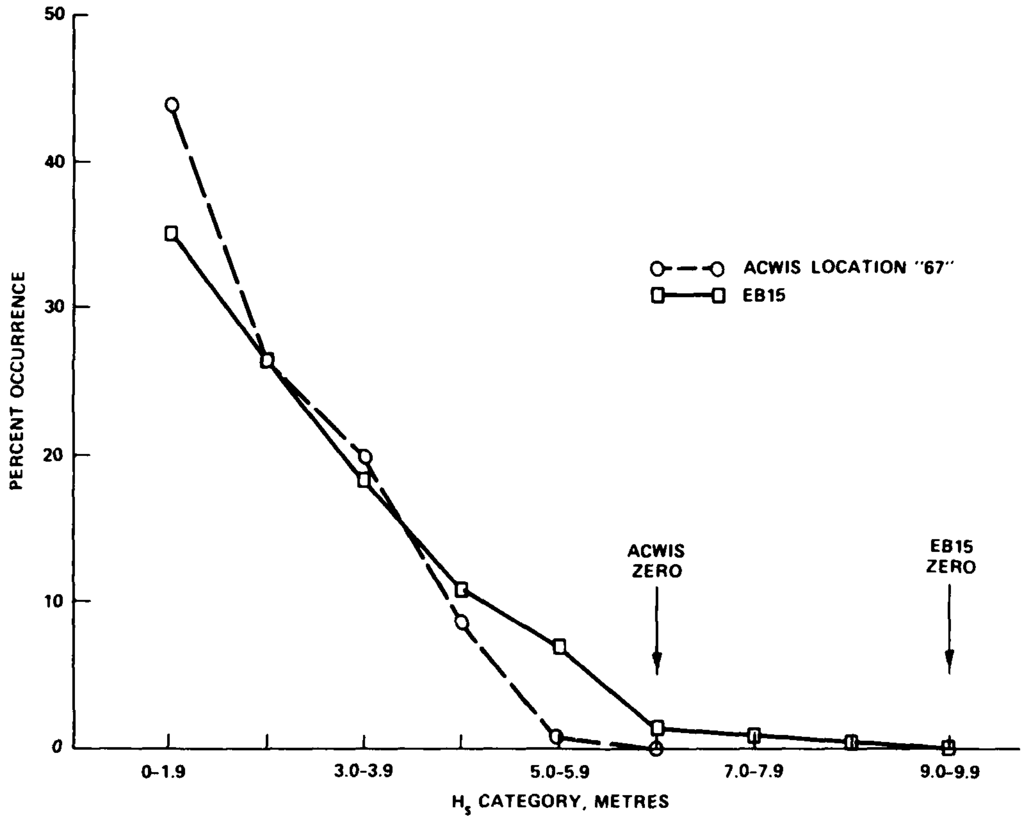

Figure 4. Plot of percent occurrence versus H_s for measured (buoy) data and computed data. Notice the ACWIS computed no waves over 6 m (ACWIS zero); yet EB15 recorded some waves above 8 m

sites.* However, if there were problems with EB15 processing in 1975, then it is likely that EB41 processing has similar problems.

16. In any event, the time series plots show the ACWIS data to be in phase with the buoy data, and the magnitude differences are probably due to data processing errors of the early NDBO buoy tapes which may have biased the measured data. However, the errors in the wave heights of the buoy data cannot be definitively assessed at this time; therefore, computations of error between the buoy wave heights and the computed wave heights are included in this report, but should be

* When ACWIS Phase II data become available, the NDBO buoy data and the Phase II computed data will be compared.

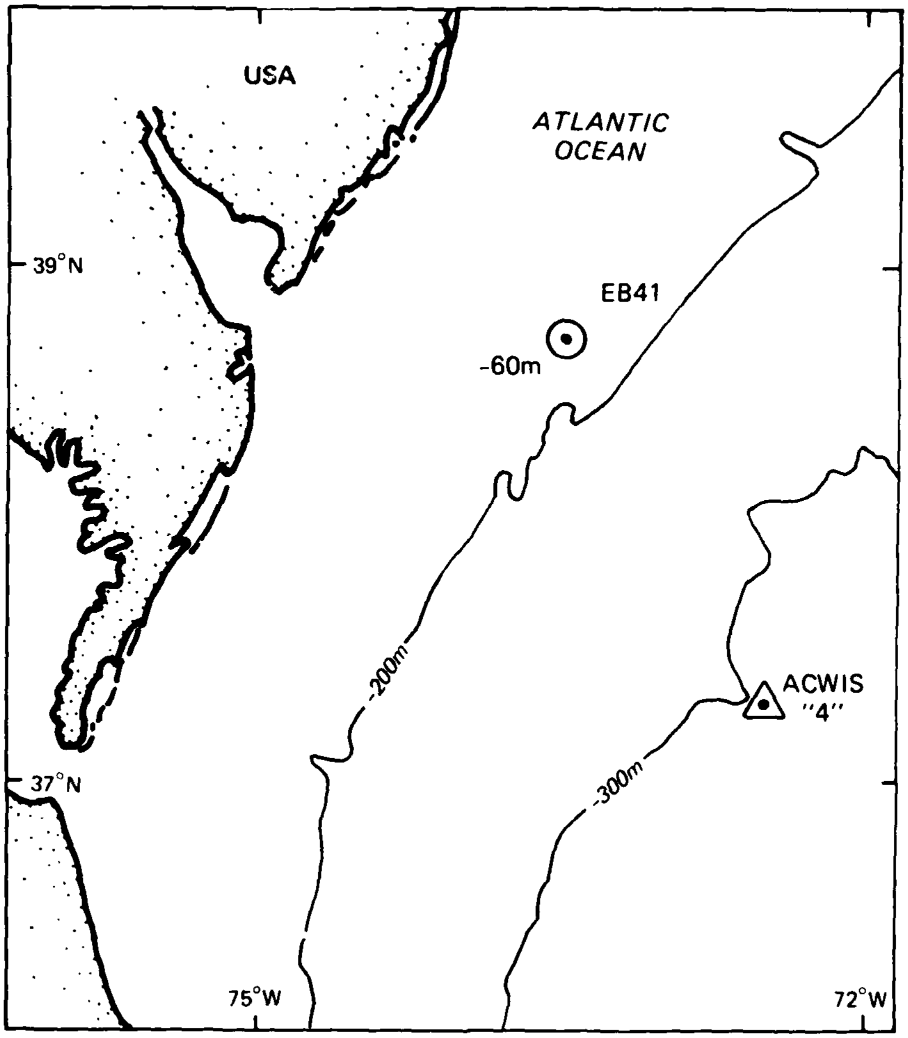

Figure 5. Map showing physiographic differences between the locations of EB41 and ACWIS 4

studied with the understanding that a relatively large amount of error (especially in the larger wave categories) is derived from the buoy data.

17. Cross plots were prepared for three combinations of the measured and computed data sets: one plot was drawn from all paired significant wave heights (excluding the NDBO buoy data) (Figure 6); another plot was prepared for only the NDBO buoy and ACWIS paired data (Figure 7); and one plot was constructed from the largest

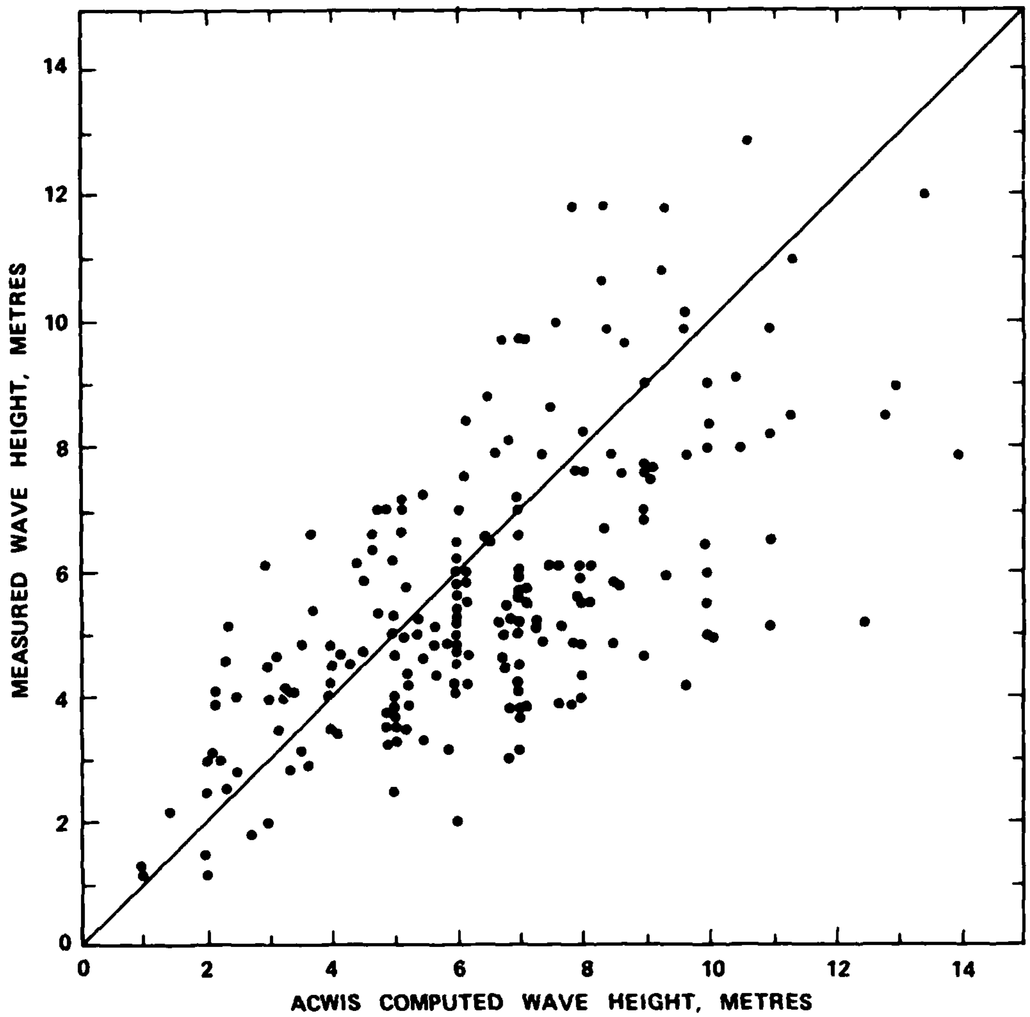

Figure 6. Measured H_s versus computed H_s cross plot for paired data (excluding NDBO buoy data)

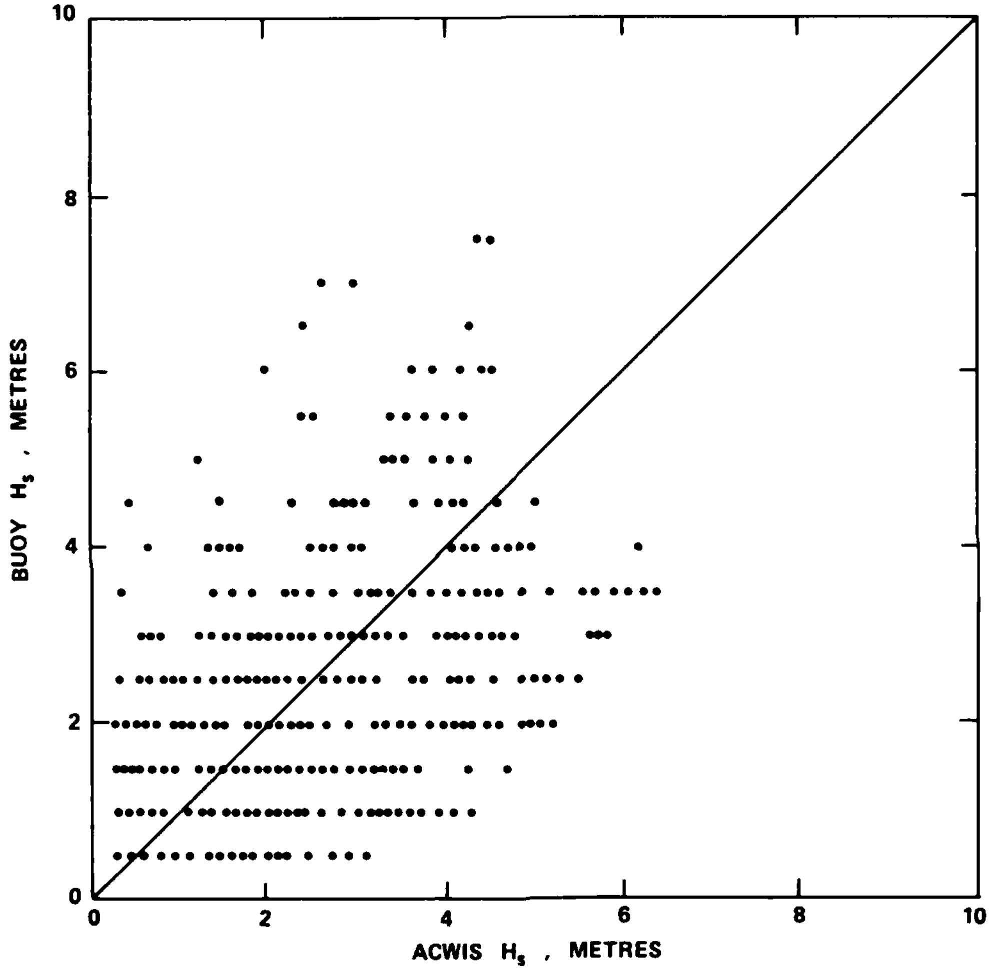

Figure 7. Measured H_s versus computed H_s cross plot for paired NDBO buoy data

H_s * of the computed and measured data sets (Figure 8). The data in Figure 6 are slightly scattered with most of the scatter in the larger wave-height categories. However, the scattering is probably due to the two data sets being out of phase, and as can be seen in Figure 8, with the time parameter removed, the scatter is greatly reduced for extreme wave-height comparisons. The cross plot of the buoy data displays more scatter than the other plots, but possible difficulties with buoy data have already been discussed which probably explains some of the scatter (Figure 7). The cross plot of the largest H_s has less scatter than the other plots and indicates that the wave hindcast model produces extreme wave heights similar to those recorded by the instruments (Figure 8).

18. For each of the events the absolute differences between paired significant wave heights were calculated, and from these values a mean absolute difference for each event was computed (Table 2). These values, which are descriptors of the random error of the hindcast model, range from 2.7 m for comparison of the severe storm of March 1968, in which the computed data are out-of-phase by about 10 to 15 hr, to 0.5 m for the summer months of May and June 1975 NDBO buoy comparison.**

19. The mean computed and measured H_s are also calculated for each event,† and from these values the difference of the means is computed (Table 2). The difference of the means (mean computed H_s minus mean measured H_s) is a measure of the bias of the model for each event. The difference of the means ranges from 0.1 to 1.9 m. Table 2 indicates that the model does not consistently overhindcast or underhindcast; for some of the comparisons the computed mean H_s is larger than the measured mean H_s, and in others it is smaller.

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* These wave heights are not time-paired. The largest computed H_s for a specific event is plotted against the largest H_s measured for the event. The cross plot is intended as another descriptor of the random error of the hindcast model. By selecting the largest H_s for a specified event, the out-of-phase characteristic has been removed.

** Since buoy data are categorized into 1/2-m increments when processed originally, some differences are inevitable.

† Mean H_s was computed from all recordings within the specified interval, not just data used in the paired wave-height comparisons.

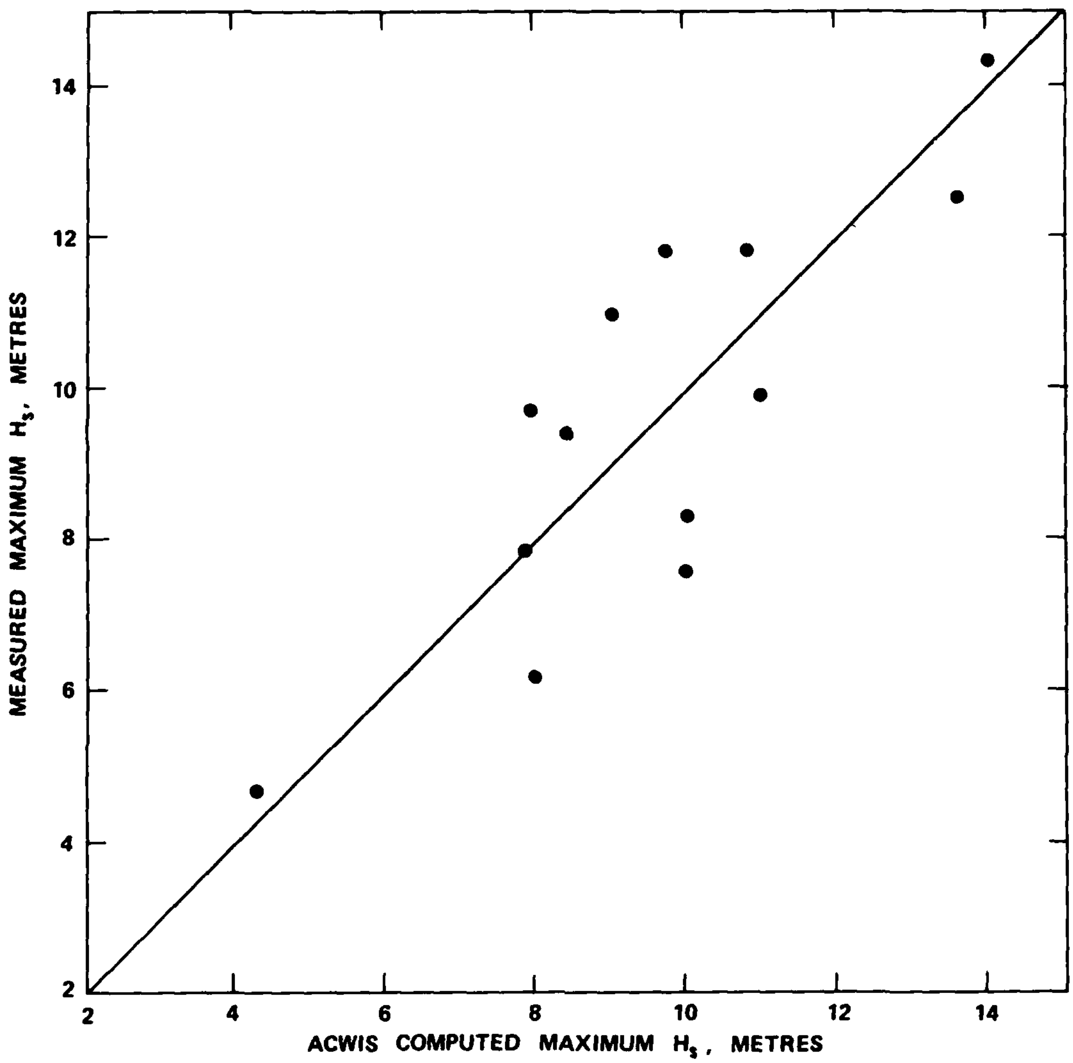

Figure 8. Cross plot of measured maximum H_s versus ACWIS computed maximum H_s. Maximum H_s is the largest H_s for a specific event

20. The comparisons thus far have covered relatively short (with respect to a 20-year hindcast) intervals of time. In order to further investigate the bias of the hindcast model, a comparison to a long interval data set was employed. The only long-term data set available is the ships observations stored on magnetic tapes by NOAA, which include visually observed data.

21. The ships data in an area (30°N to 33°N; 74°W to 76°W) surrounding model locations 6 and 7 (which have been averaged to yield location "67") were selected for comparison. The ships data and computed data were categorized, and the percent occurrence of each category was calculated. As shown in Figure 9, distribution of waves within the two data sets is extremely similar. It was also determined that the ACWIS 20-year hindcast yielded a maximum significant wave height of 10.7 m for the area and the ships reported a maximum significant wave height of 11 m* for approximately the same interval of time.

22. Ships records were also used to compare return periods of significant waves from ships wave records to return periods of ACWIS computed significant waves (Figure 10). The largest H_s for each year from 1965 through 1974 was ranked by size, divided into the total number plus one, and plotted with the relative H_s.** This procedure allows the extreme characteristics of the two data sets to be analyzed and compared in a consistent manner. Considering that the ships data are coded into 1/2-m increments, the extremes of the two data sets appear very similar (Figure 10).†

23. A percent occurrence comparison was also employed using all of the time-paired data (Figure 11). Distribution of the two data sets is again remarkably similar, with a maximum difference of only 7 percent. Also, the mean H_s of the measured waves was 3.67 m, while the mean H_s of the computed waves was 3.63 m, a difference (bias) of only 0.04 m.

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* The ships recorded significant wave heights are coded into 1/2-m increments; when recorded, therefore, only 0.0 or 0.5 fractions are reported.

** A coding error in the ships records did not allow the use of ships information on extreme waves prior to 1965.

† Since ships data are not spaced (in time) at consistent intervals, it was not possible to define specific events for extreme wave-height analyses; and the technique used for extreme analyses allows the same H_s to represent different years. This explains why some wave-height categories represent different return intervals in Figure 10.

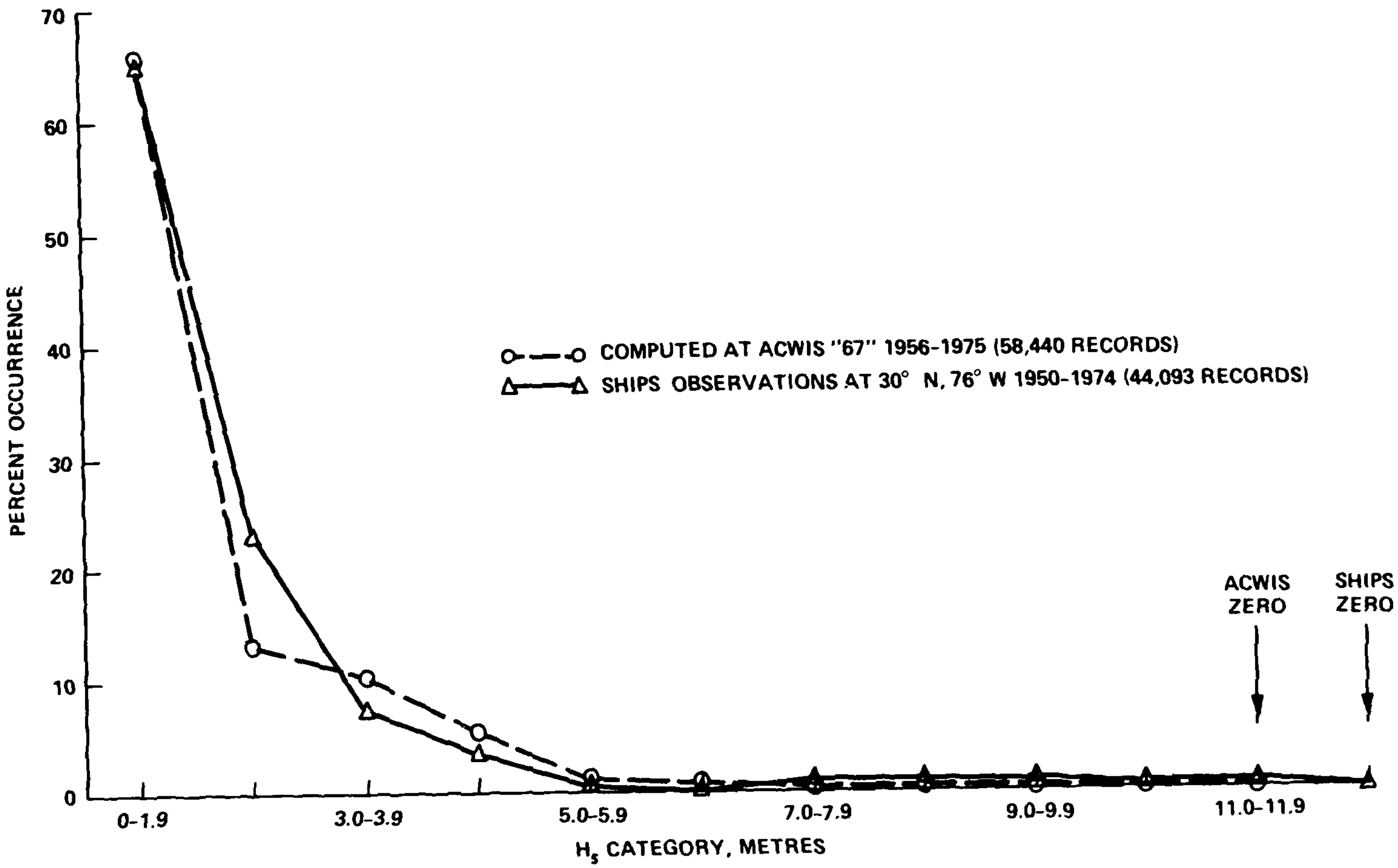

Figure 9. Plot of percent occurrence versus H_s for ships records and computed data. Notice both data sets "zero-out" (no waves recorded in the category or greater) at nearly the same category

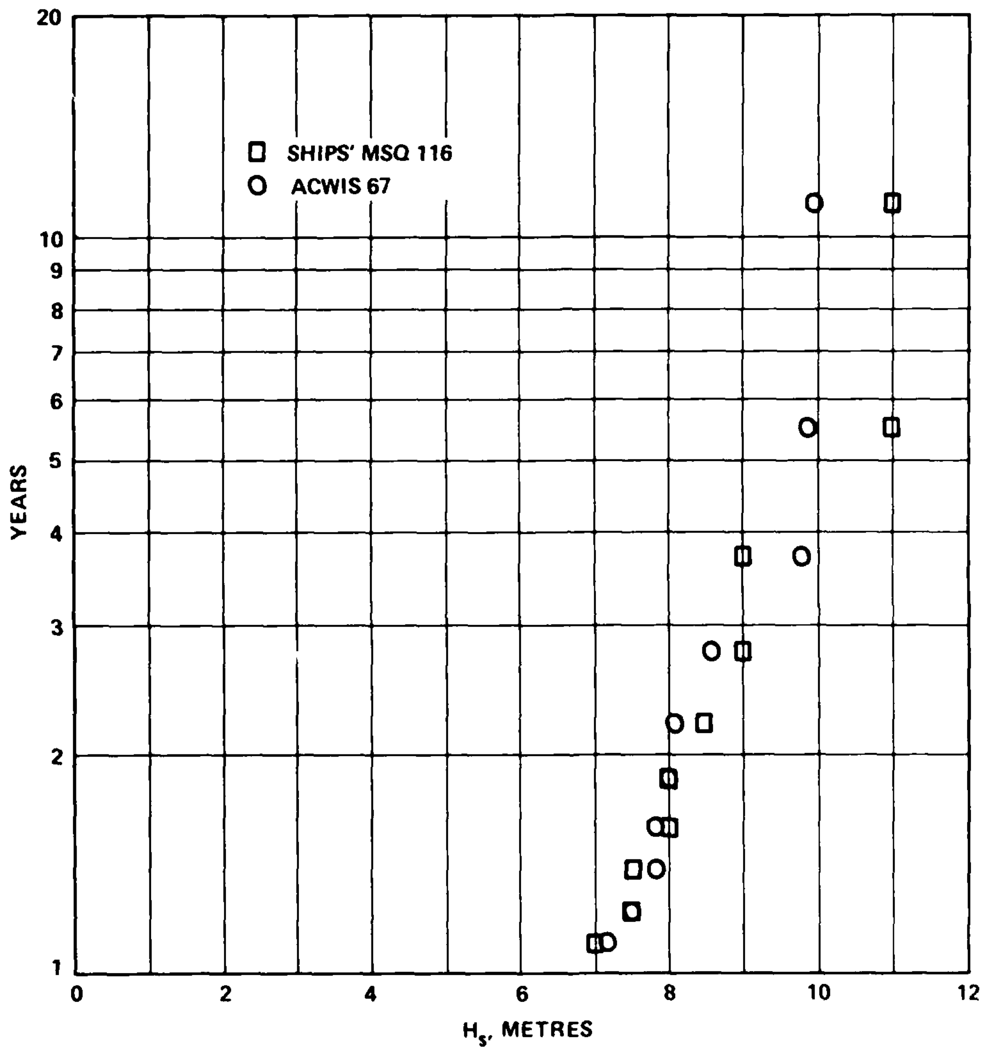

Figure 10. Plot of extremes from ships records and computed information

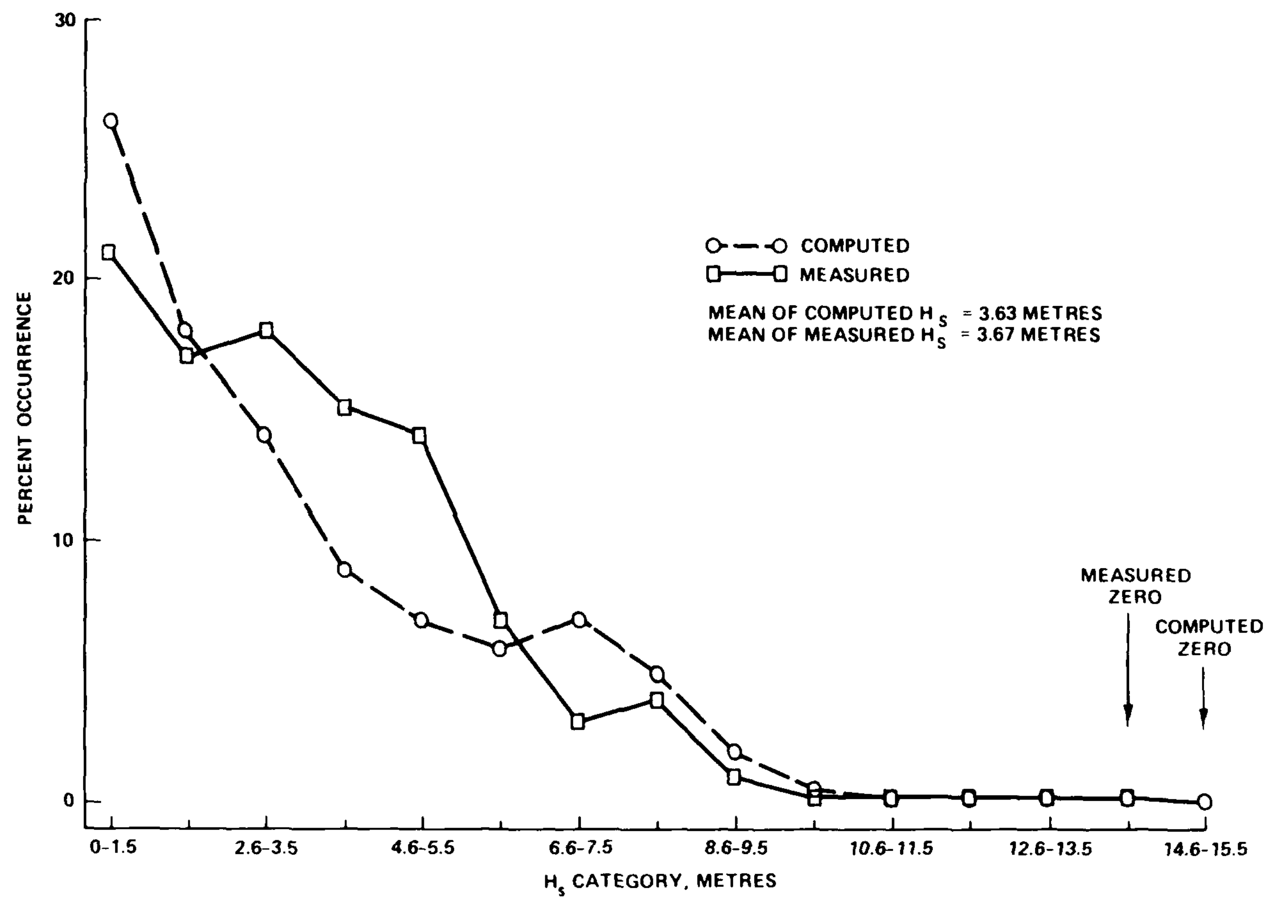

Figure 11. Plot of percent occurrence versus H_s for time-paired measured and computed data sets. Notice the similiarity of distribution of waves even in extreme categories (measured data set "zeros-out" near computed data set)

Conclusions

24. The remarkable similarity between the computed and measured time-series plots is the most visible indication of how well ACWIS data represent various wave climates. The mean of all the absolute differences (random error) between the two data sets (measured and computed) is relatively small (~1.0 m) and the overall bias is extremely small (0.04 m). Obviously, the computed data are not exact copies of the measured data, nor are the measured data true representations of the actual wave climate. However, comparisons indicate that the methods used to develop Phase I ACWIS wave data produce valid wave climates over a wide range of conditions in the Atlantic Ocean. Measured data will contain uncertainties and errors of comparable magnitude to those inherent in the computed data. Consequently, application of an alteration factor to the computed data cannot be justified; and the Phase I wave data should be used "as is" for ocean engineering projects. As a result of the accuracy of the Phase I wave information, Phase II and III wave climatologies are expected to provide an excellent data base for the planning, design, operation, and maintenance function of coastal engineering activities of the Corps of Engineers.

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Table 1

Comparison Site Information (SBWR = Shipborne Wave Recorder, WS = Wavestaff, LDB = Large Discus Buoy, WAB = Waverider Accelerometer Buoy)

Measured Site Name and Location	Computed Site Name and Location	Source of Measured Data	Instrument Type
OSV-J (52.5°N, 20°W)	7,22 (51.9°N, 22.7°W)	USACERC (1977) after Inoue (1967)	SBWR
OSV-J	7,22	Chakrabarti and Cooley (1977)	SBWR
Argus Tower (32°N, 65°W)	19,10 (33.9°N, 62.4°W)	Pickett (1962)	WS
OSV-I (59°N, 19°W)	3,21 (59.2°N, 18.2°W)	Ewing (1971)	SBWR
OSV-J	7,22	Ewing (1971)	SBWR
OSV-J	7,22	Snider and Chakrabarti (1973)	SBWR
MEDS - 90 (47.1°N, 48.8°W)	13,14 (45.7°N, 51.4°W)	MEDS	WAB
OSV-K (45°N, 16°W)	9,26 (44.5°N, 15.5°W)	Gelci and Chavy (1977)	SBWR
EB15 (32.3°N, 75.2°W)	"67" (32.9°N, 76.7°W) and (33.2°N, 74.4°W)	NDBO, NOAA	LDB
EB41 (38.7°N, 73.6°W)	"4" (37.3°N, 72.6°W)	NDBO, NOAA	LDB

Table 2

Comparison Information for Hindcast and Measured Wave Data

Date and Locations	Computed Mean H_s m	Measured Mean H_s m	Mean Absolute Difference m	Difference of the Means	Number of Paired Readings
15-27 Dec '59 ACWIS (7,22)/OSV-J	6.5	6.4	1.6	0.1	52
12-15 Sep '61 ACWIS (7,22)/OSV-J	7.8	6.1	1.8	1.7	17
20-30 Nov '61 ACWIS (19,10)/Argus Tower	4.6	5.2	1.2	-0.6	38
21-24 Nov '66 ACWIS (3,21)/OSV-I	5.0	4.7	0.8	0.3	16
21-24 Nov '66 ACWIS (7,22)/OSV-J	3.7	3.2	0.9	0.5	16
15-19 Mar '68 ACWIS (7,22)/OSV-J	8.3	6.4	2.7	1.9	18
26-31 Oct '73 ACWIS (13,14)/MEDS-90	4.0	4.4	0.9	-0.4	12
1-18 Jan '74 ACWIS (9,26)/OSV-K	6.8	5.4	1.9	1.7	70
14-31 May '75 ACWIS "67"/EB15	0.6	1.1	0.5	-0.5	123
1-28 Jun '75 ACWIS "67"/EB15	0.9	1.3	0.5	-0.4	213
23-31 Oct '75 ACWIS "4"/EB41	2.1	2.2	0.6	-0.1	59
20-30 Nov '75 ACWIS "67"/EB15	1.7	2.6	0.8	-0.9	75
1-30 Nov '75 ACWIS "4"/EB41	1.9	1.4	0.8	0.5	235
1-31 Dec '75 ACWIS "67"/EB15	1.9	2.6	1.1	-0.7	240
1-31 Dec '75 ACWIS "4"/EB41	2.9	1.7	1.2	1.2	236
					1420

Appendix A: Time Plots

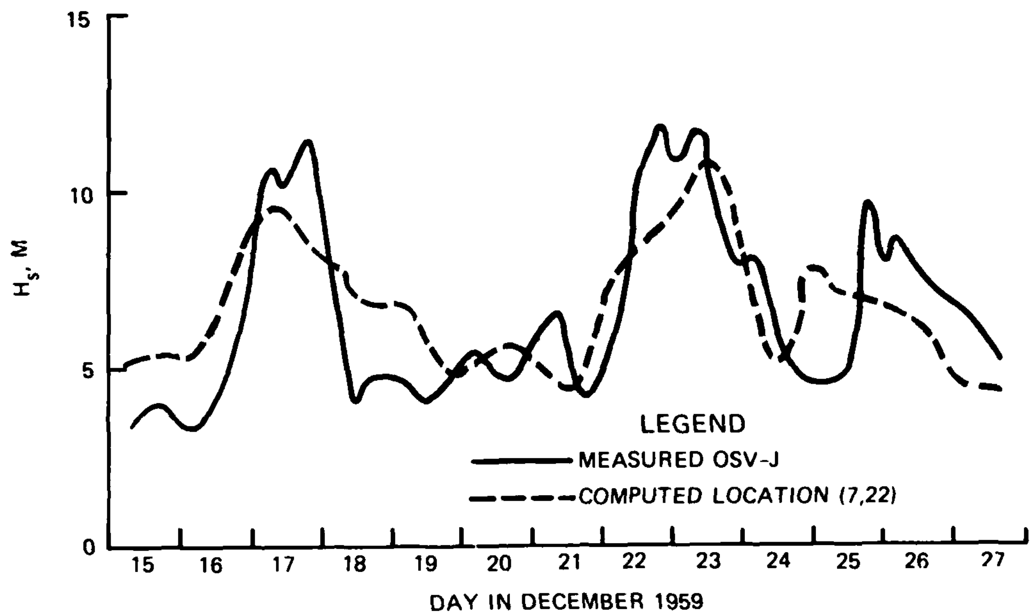

Figure A1. Comparison plot of H_s versus time for a period in December 1959 at OSV-J

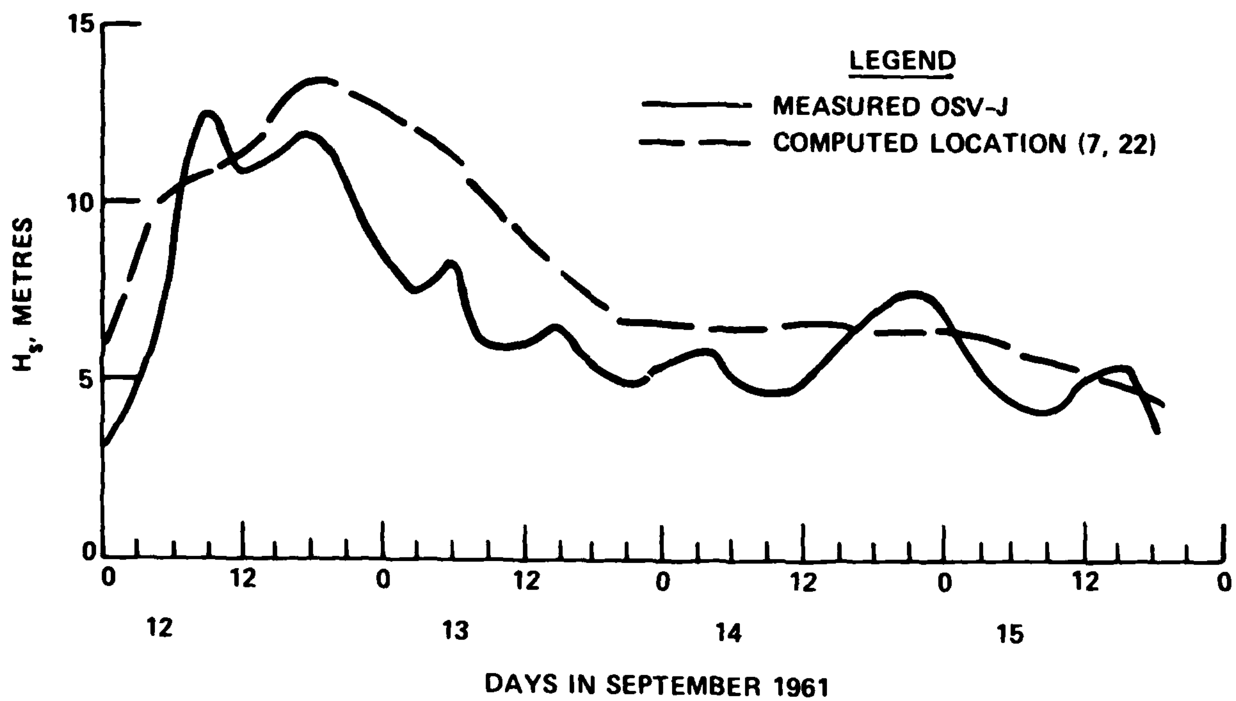

Figure A2. Comparison plot of H_s versus time for a period in September 1961 at OSV-J

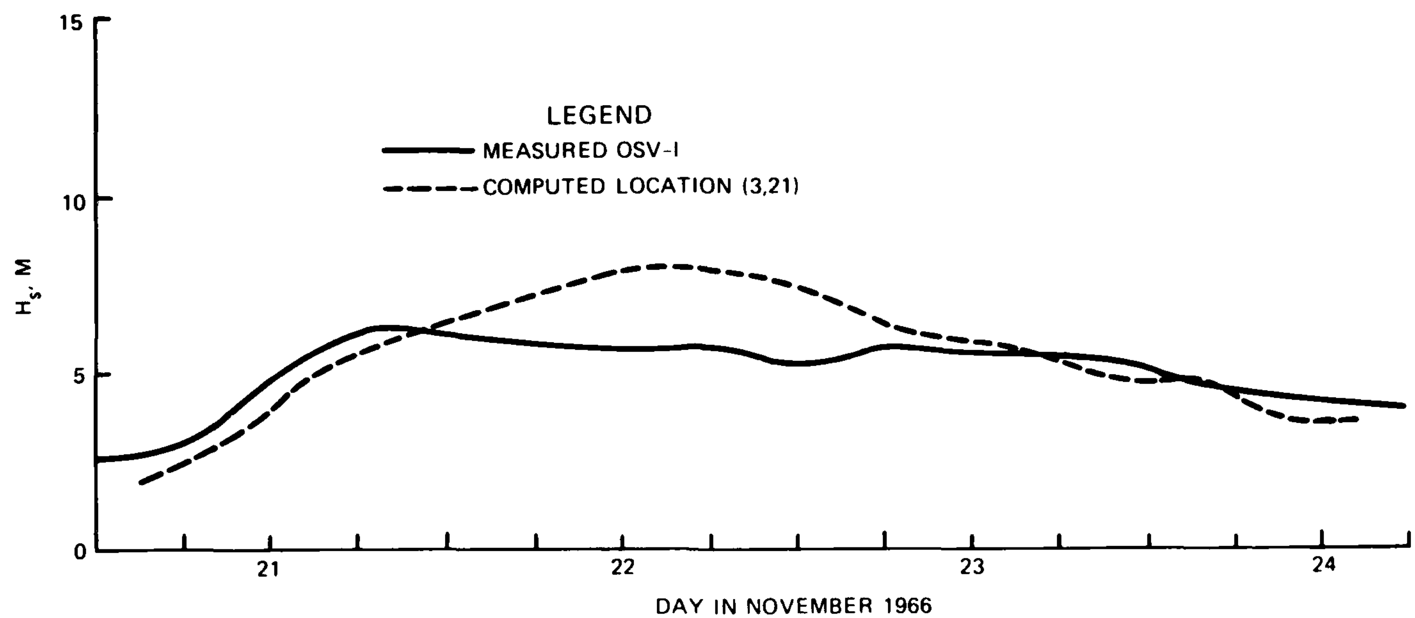

Figure A3. Comparison plot of H_s versus time for a period in November 1966 at OSV-I

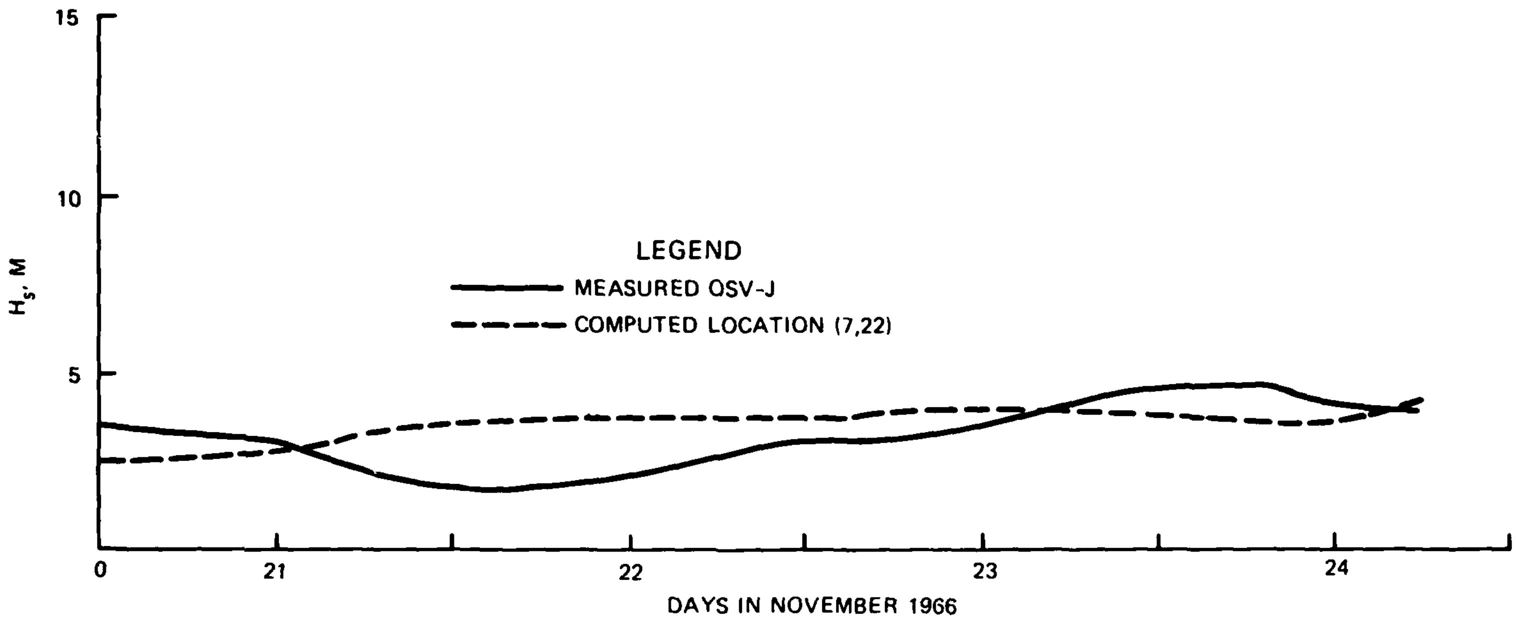

Figure A4. Comparison plot of H_s versus time for a period in November 1966 at OSV-J

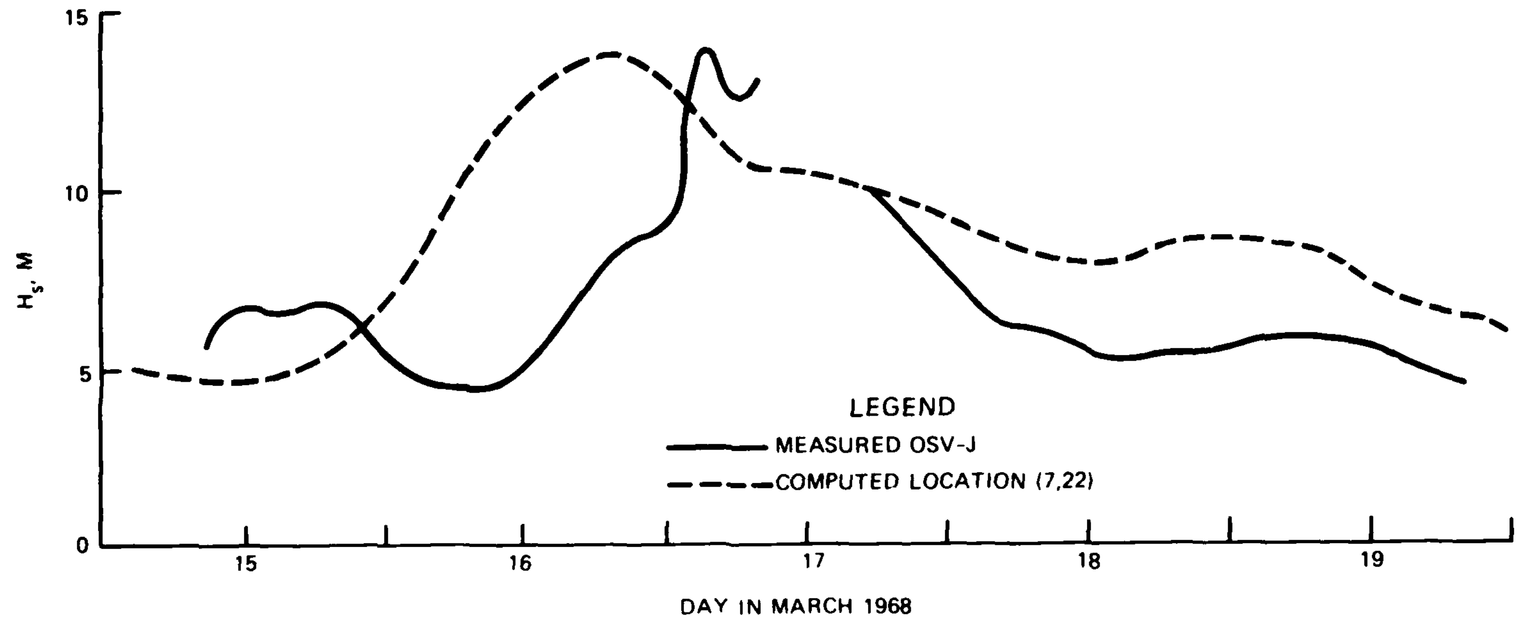

Figure A5. Comparison plot of H_s versus time for a period in March 1968 at OSV-J

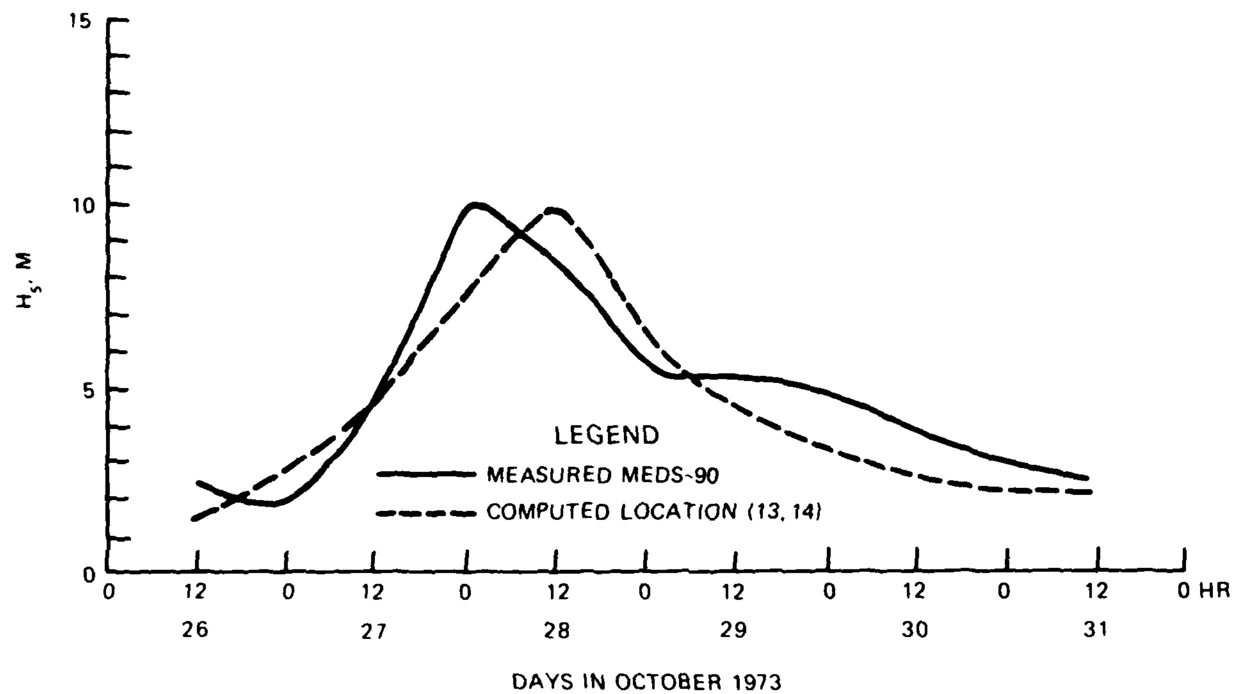

Figure A6. Comparison plot of H_s versus time for a period in October 1973 at MEDS-90

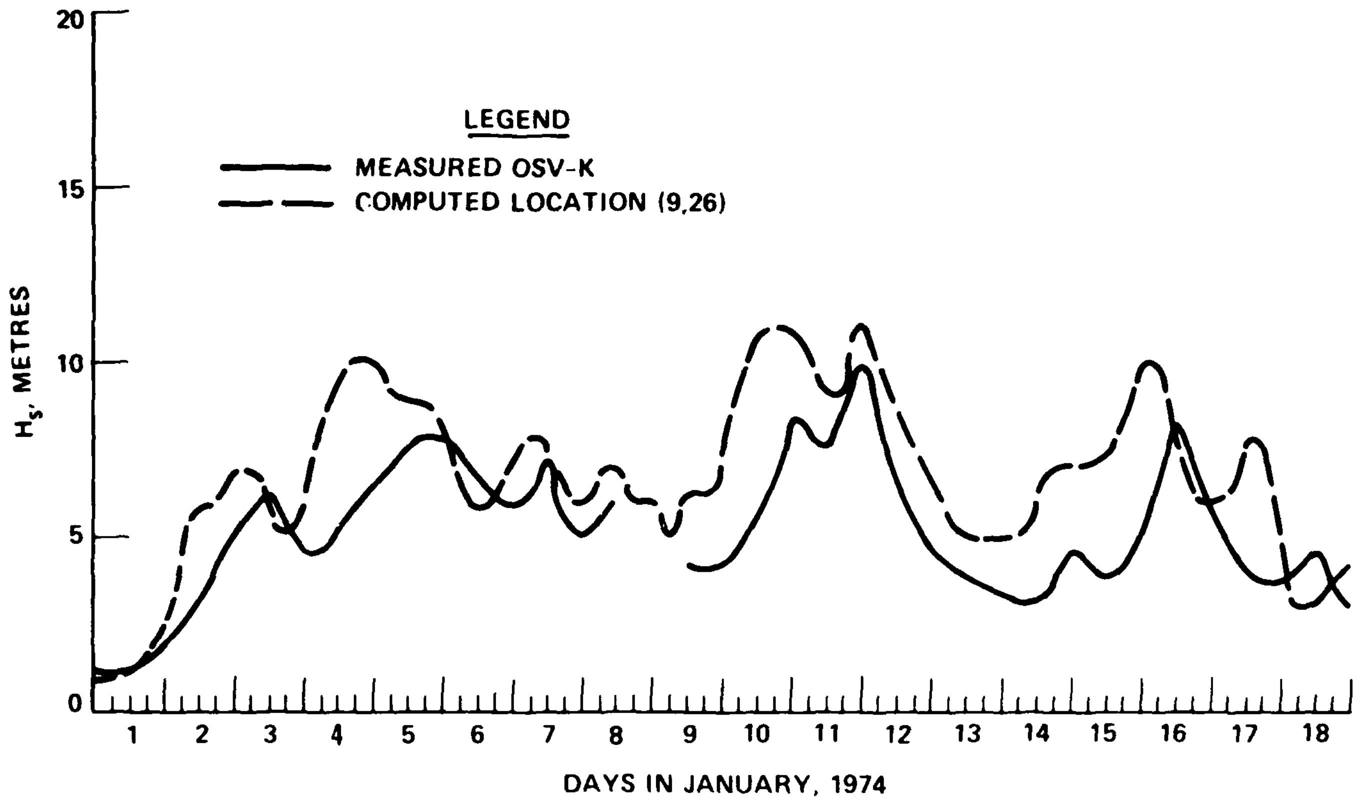

Figure A7. Comparison plot of H_s versus time for a period in January 1974 at OSV-K

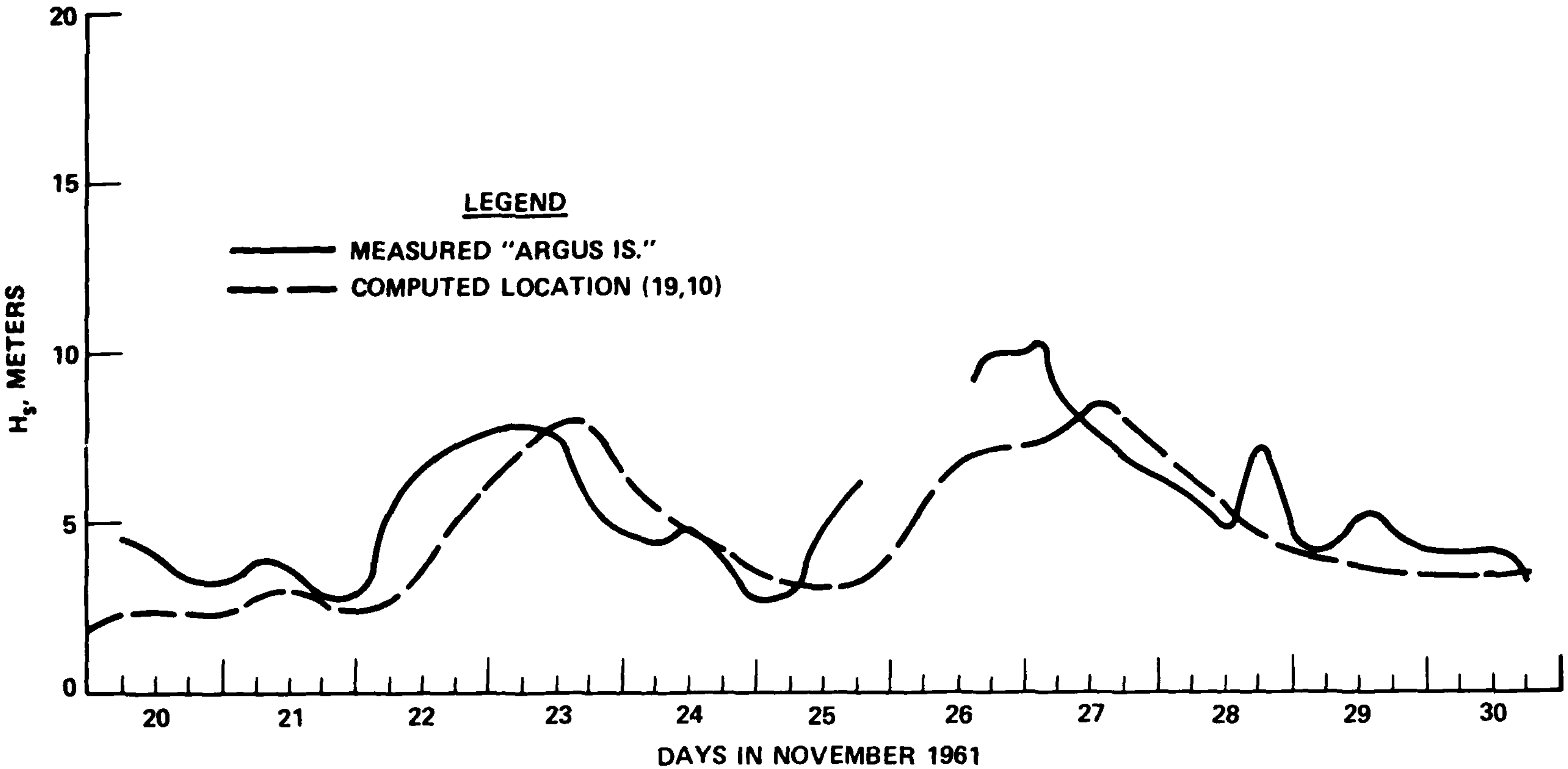

Figure A8. Comparison plot of H_s versus time for a period in November 1961 at Argus Island

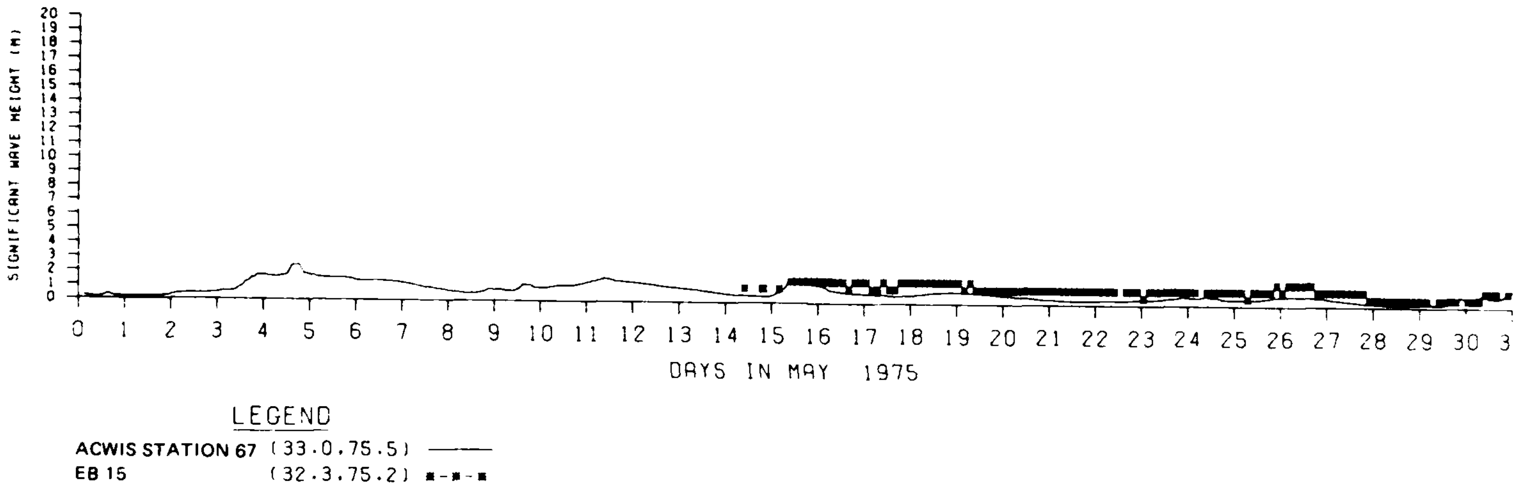

Figure A9. Plot of H_s versus time for a period in May 1975 for buoy EB15

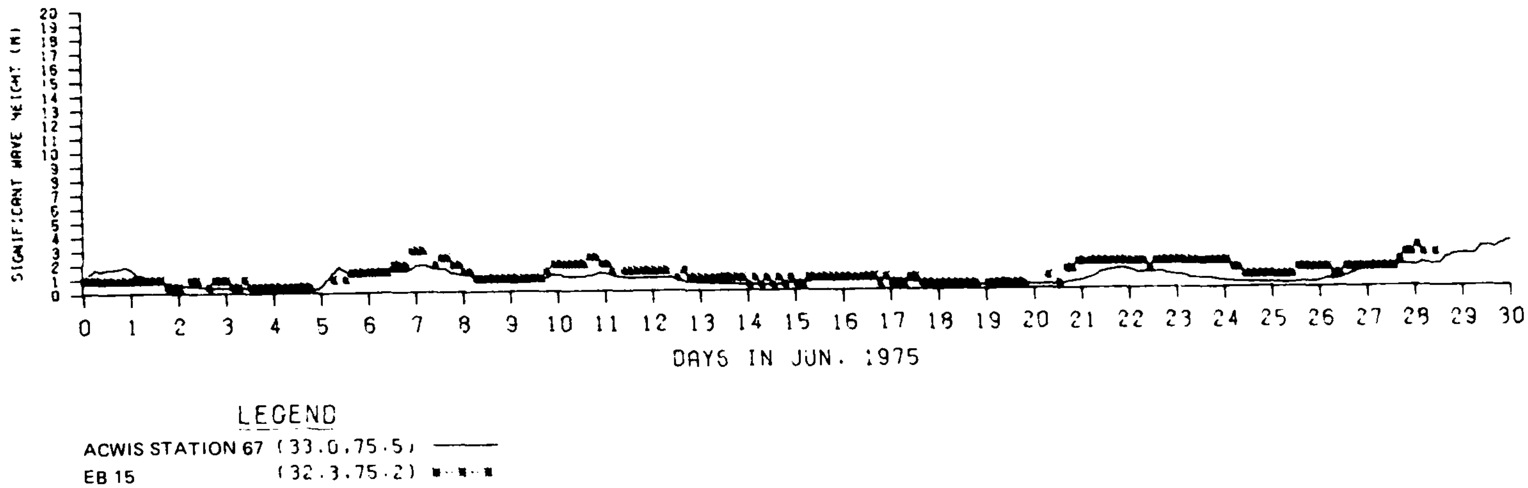

Figure A10. Plot of H_s versus time for a period in June 1975 for buoy EB15

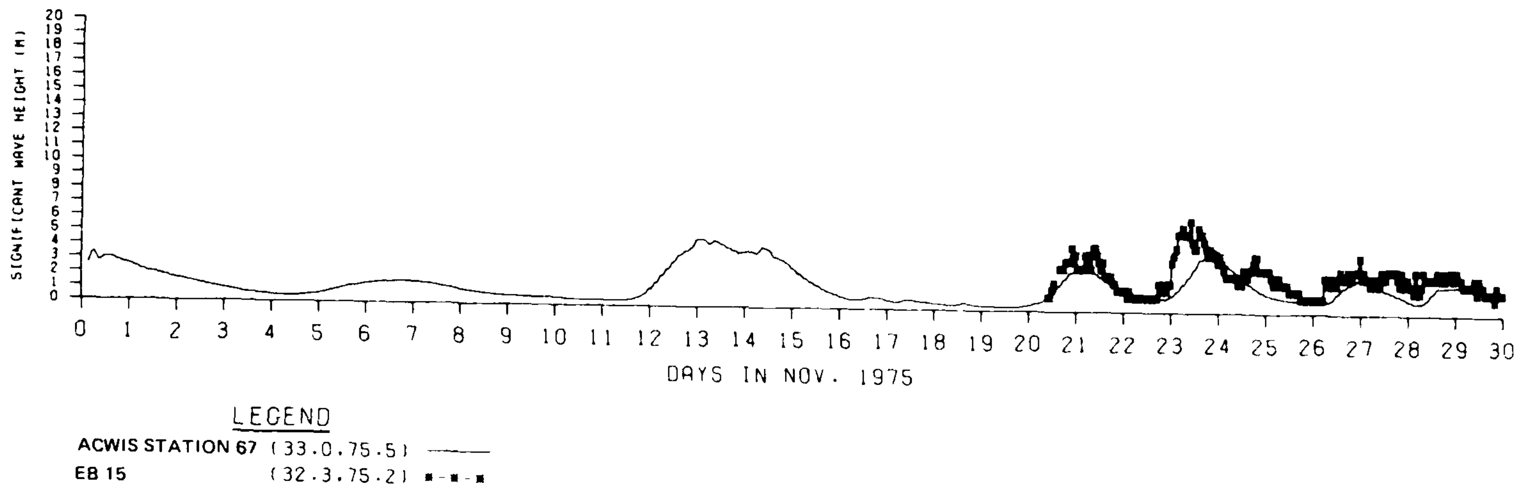

Figure A11. Plot of H_s versus time for a period in November 1975 for buoy EB15

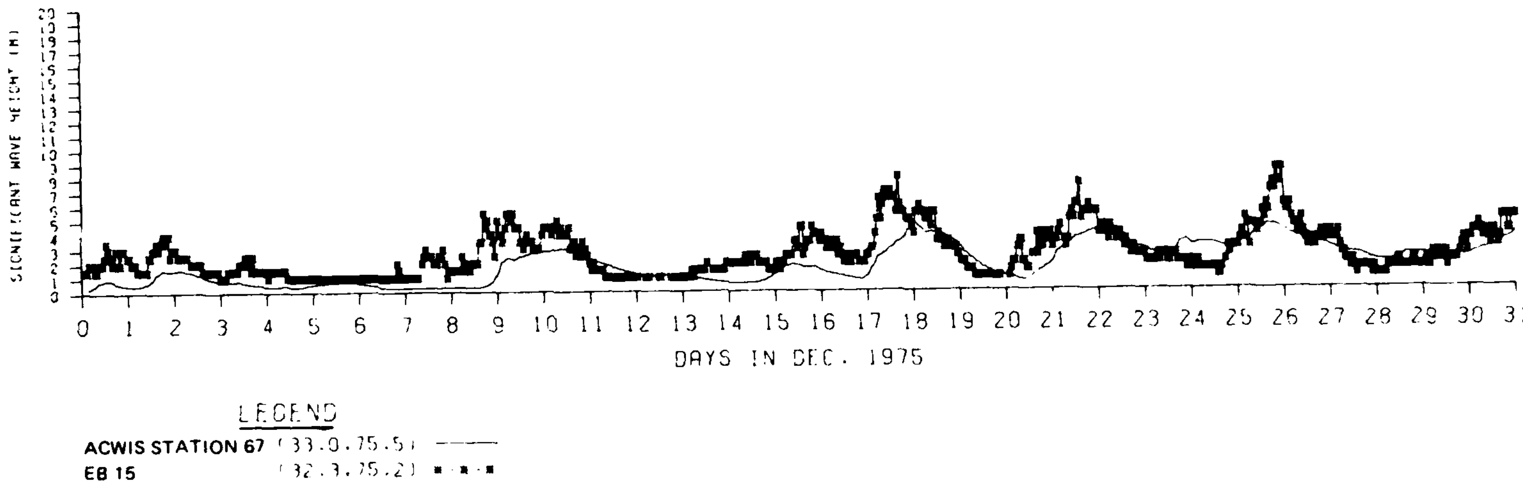

Figure A.2. Plot of H_s versus time for a period in December 1975 for buoy EB15

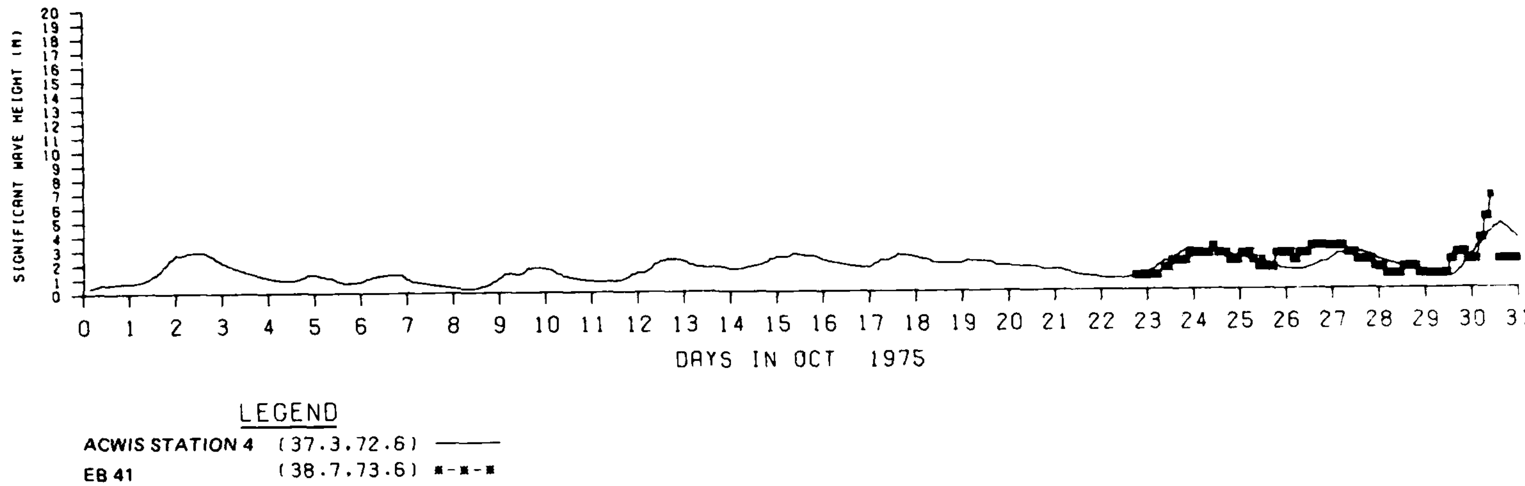

Figure A13. Plot of H_s versus time for a period in October 1975 for buoy EB41

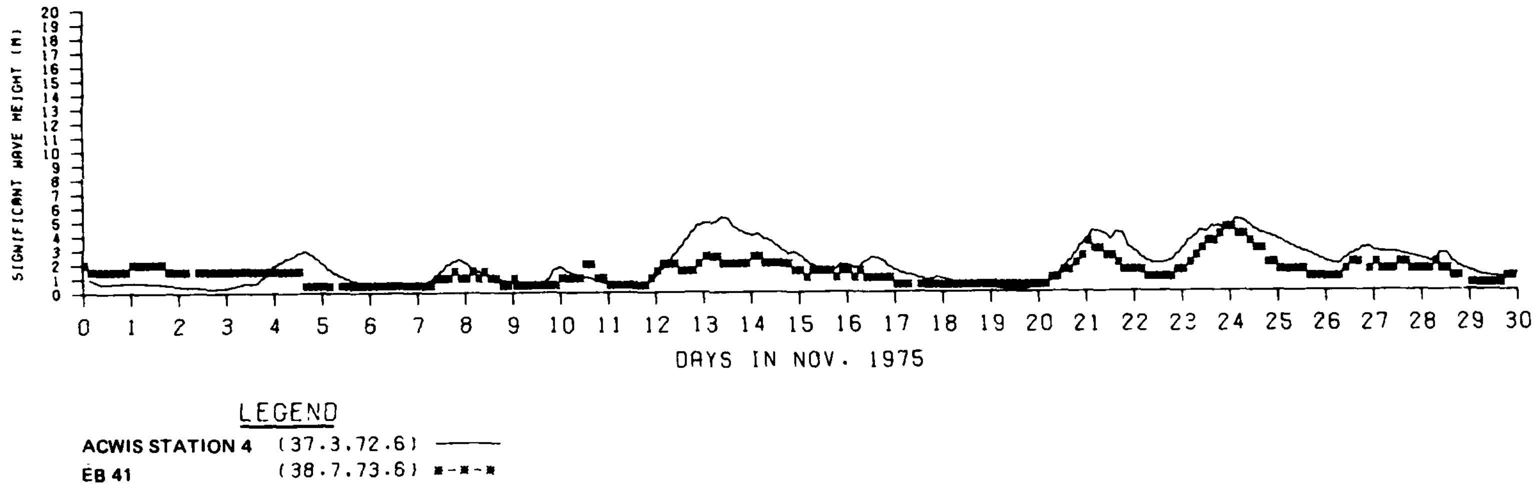

Figure A14. Plot of H_s versus time for a period in November 1975 for buoy EB41

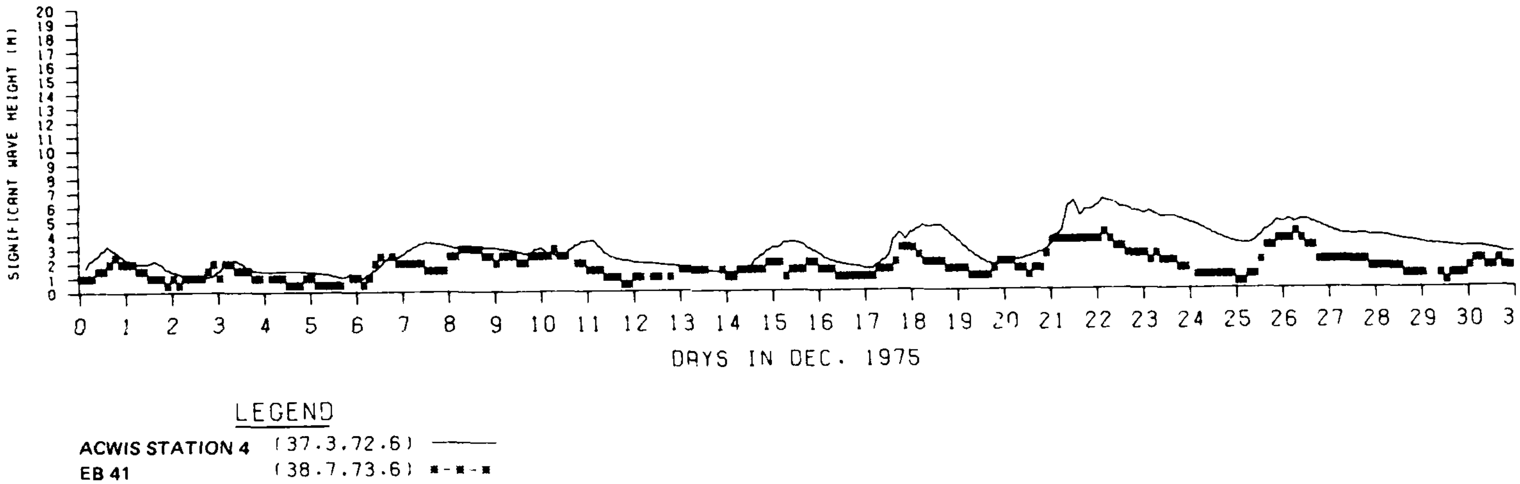

Figure A15. Plot of H_s versus time for a period in December 1975 for buoy EB41

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Corson, William D.
Comparisons of hindcast and measured deepwater, significant wave heights / by William D. Corson, Donald T. Resio (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station, [1981].
41 p. in various pagings : ill. ; 27 cm. -- (WIS report / U.S. Army Engineer Waterways Experiment Station ; 3)
Cover title.
"May 1981."
"Wave information studies of U.S. coastlines."
"Prepared for Office, Chief of Engineers, U.S. Army."
Bibliography: p. 23.

1. Water waves. 2. Ocean waves--Atlantic Ocean. I. Resio, Donald T. II. United States. Army. Corps of Engineers. Office of the Chief of Engineers. III. U.S. Army Engineer Waterways Experiment Station. Hydraulics Laboratory. VI. Title VII. Series: WIS report (U.S. Army Engineer Waterways Experiment Station) ; 3.
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