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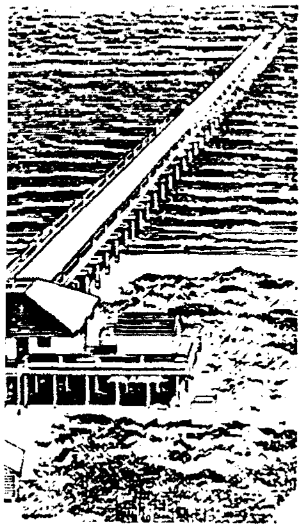

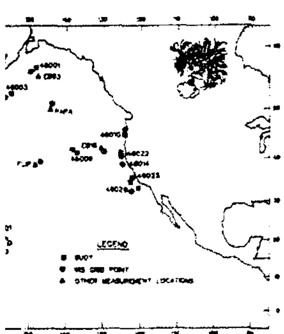

WAVE INFORMATION STUDIES
OF US COASTLINES

WIS REPORT 29

VERIFICATION OF PACIFIC OCEAN DEEPWATER HINDCAST WAVE INFORMATION

by

Jon M. Hubertz, Barbara A. Tracy, Jane B. Payne, Alan Cialone

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
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13. ABSTRACT (Maximum 200 words)

The Wave Information Study (WIS) for the Northern Pacific Ocean (WIS Reports 14 and 16) provides a wave climate for the US shorelines of the Northern Pacific based on simulation of 20 years of weather data from the period 1956-1975. During these years few wave data exist with which to evaluate the adequacy of the total hindcast procedure, which includes derivation of pressure charts, translation of these into wind estimates, and then calculation of wave conditions. In 1991, the Coastal Engineering Research Center conducted a 1-year hindcast of the Northern Pacific Ocean for the year 1988 and evaluated the model results against extensive wind and wave measurements now available in order to provide guidance on the quality of the previous hindcast work. This report provides a summary of that hindcast and guidance on the use of the earlier WIS study.

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Preface

In late 1976 a study to produce a wave climate for US coastal waters was initiated at the US Army Engineer Waterways Experiment Station (WES). The Wave Information Study (WIS) was authorized by Headquarters, US Army Corps of Engineers (HQUSACE) as part of the Coastal Field Data Collection Program, which is managed by the WES Coastal Engineering Research Center (CERC). Messrs. John H. Lockhart, Jr., John G. Housley, and Barry W. Holiday, HQUSACE, are Technical Monitors for the Coastal Field Data Collection Program; Ms. Carolyn M. Holmes, CERC, is Program Manager; and Dr. Jon M. Hubertz, CERC, is WIS Project Manager.

This report, the twenty-ninth in a series, provides information to verify the 20 years of hindcast deepwater wave information for the Pacific Ocean. The information is derived from an evaluation of the winds and the wave model used in the 20-year hindcast. The report was written by Dr. Jon M. Hubertz. Application of the model was done by Mses. Barbara Tracy and Jane Payne. Preparation of all of the comparison figures and statistical calculations was done by Ms. Payne and Mr. Alan Cialone.

The study was conducted under the direct supervision of Dr. Martin Miller, Chief, Coastal Oceanography Branch, CERC, and Mr. H. Lee Butler, Chief, Research Division, CERC; and under the general supervision of Dr. James Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director, CERC, respectively. Word processing of this report was done by Ms. Jane Stauble, Coastal Oceanography Branch, CERC. Editing was done by Ms. Janean Shirley, Information Technology Laboratory, WES.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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Contents

VERIFICATION OF PACIFIC OCEAN DEEPWATER HINDCAST WAVE INFORMATION

Introduction

1. The Wave Information Study (WIS) has hindcast deepwater wave conditions in the Pacific Ocean for the period 1956-1975 (Corson et al. 1986, 1987). There are no long-time series of measured wave conditions available in this time period to compare to the calculated results and thus verify them. Comparisons to measurements were done in a climatological sense using the shallow-water Phase III results (Jensen, Hubertz, and Payne 1989; Jensen et al., in preparation) and gage or buoy data at nearby model locations. Phase III results were calculated using Phase II results as input to the Phase III transformation process for locations along the coast north of Point Conception and to the hindcast model for locations along the coast to the south of Point Conception. The percent distributions of hindcast wave heights and periods for the 20-year period 1956-1975 were compared to those of measurements from buoys over time periods of 3-5 years, in the early 1980's. The assumption is made that the distributions should agree if the wave climate has not changed during the different time periods. Monthly means and maximums of wave height were also compared.

2. These comparisons, at similar locations, indicate that the distributions of hindcast and measured wave heights and periods are generally similar. Monthly means of wave height showed a slight (typically 0.5-m) bias, with the calculated results being higher than measured, especially in the winter months for the Phase III results north of Point Conception. This tendency for deepwater wave heights to be high (by about 0.5 m) was also noted in the southern California hindcast south of Point Conception. Thus, Phase II boundary input information was reduced by 0.5 m in this hindcast prior to calculation of the southern California results. It was also noted that there were fewer occurrences of periods greater than 15.5 sec in the model results than in the measurements.

3. The purpose of this study is to further verify the wave hindcast results and assign an accuracy to them. This is done by hindcasting deepwater wave conditions for a recent time period and comparing the time series of

calculated wave heights and periods to measurements at nearby locations. The time period chosen was January through December 1988, when measured data were available from a number of buoys in the Pacific Ocean. This type of study provides a statistical measure of model performance. This report expands on summary conclusions and recommendations in Coastal Engineering Technical Note I-49 (1991).

4. Wave model performance is dependent on the accuracy of the wind information that is put into it. Thus, conclusions on the accuracy of the 20 years of hindcast wave information have to be qualified by the accuracy of the 20 years of input winds. In the original 20-year hindcast for the Pacific, much time and effort were devoted to obtaining accurate wind fields. In order to apply the conclusions of the present study to the results of the 20-year hindcast, one has to assume that the wind fields used in the 20-year hindcast are equivalent in quality to those used in this 1-year hindcast. This is addressed in more detail in the section on wind data input to the models.

Wave Data Used for Verification

5. The National Oceanic and Atmospheric Administration (NOAA) operated 28 buoys in the North Pacific in 1988. In addition to these, the Scripps Institution of Oceanography made wave measurements at 28 additional sites as part of the Coastal Data Information Program. It was considered impractical, for the purposes of this study, to make time series comparisons to all 56 of these measurements throughout the year. Instead, six deepwater buoys were chosen, which were close to model grid points and located in different regions of the North Pacific Ocean. These are identified as buoys 46003, 46006, 46010, 51001, 46022, and 46028, and are shown in Figure 1, which includes sites of other gages used for comparisons. The locations of measurements and model stations are given in Table 1. Time series comparisons between measured and model results at these six sites are made for wind speed and direction and significant wave height and peak period every 12 hr from 1 January through 31 December 1988. These comparisons are then used for evaluation of model performance. Only selected plots typical of the comparisons are shown to keep the report to a reasonable size.

6. Wave height was calculated from the measured and hindcast spectra by multiplying the square root of the total energy under the spectrum by 4.0. Wave period was determined by taking the reciprocal of the wave frequency associated with the largest energy value. These values are referred to as significant wave height H_s and peak wave period T_p, respectively. The NOAA buoys also measured wind speed and direction. The wave model verification consists of comparing measured and modeled values of wind speed and direction to H_s and T_p values in a time sequence by months during 1988 and then calculating certain statistics to characterize the agreement.

Wind Data Used as Input to the Wave Model

Winds for the 20-year hindcast

7. The wind data used in the 20-year hindcast were calculated from US Weather Bureau maps of surface atmospheric pressure over the Pacific Ocean and from ship observations of wind speed using the procedures described in WIS Report 4 (Resio, Vincent, and Corson 1982). The wind data used as input to the wave model for the 1988 hindcast were obtained from the US Navy's Fleet Numerical Oceanographic Center (FNOC). This organization routinely estimates surface (19.5 m) wind speed and direction on a global basis at a resolution of 2.5 deg in space and 6 hr in time. Estimates are made using US Weather Service data, atmospheric numerical models, and observed data from ships, buoys, and satellites.

8. The accuracy of wave model results is dependent on the accuracy of the wind data input into the model. To verify the past hindcast results, one needs to judge the accuracy of the winds used as well as the wave model. Two comparisons are presented to verify the wind data used in the 20-year hindcast. The first is a comparison of the bias and root mean square (RMS) difference between measured and hindcast wind speeds and directions at four different sites for various times within the hindcast period. The second is a comparison of the distribution of wind speeds and directions using climatic summaries from NOAA buoys at four different locations. In order to compare them, the assumption is made that the distributions do not change with time, because the time periods of the hindcast and buoy measurements do not coincide.

9. Wind speeds and directions are available for NOAA buoys EB03, EB16, Ocean Station Vessel PAPA, and the platform FLIP for the periods shown in Table 2. These times are within the hindcast time period; therefore, wind speeds and directions can be compared to those at nearby WIS locations (see Figure 1 and Table 1 for the location of these sites). The bias of wind speeds (mean WIS value minus mean measured value) and RMS difference are also shown in Table 2. The average RMS difference for all observations is 7.4 knots* (range of 5.0 to 10.2 knots), and there is a slight bias (average -1.7 knots), with WIS being lower than measured values.

10. Time series plots of wind speed and direction at these locations and times are shown in Appendix A. In general, the time series plots of WIS wind speeds and directions are smoother than the observed, thus missing the measured peaks and valleys occurring over relatively short time periods, but generally tracking the longer term variations. More often than not, WIS underestimates peak wind speeds. The typical RMS difference in wind direction is 60 deg. At times, the directional traces agree well, but there are instances where they differ by more than 90 deg.

11. The distributions of WIS and measured wind speeds and directions for different speed and direction categories are shown in Appendix B (Plates B1-B8). The directions on the bottom axis need to be multiplied by 10 to give degrees; for example, 35-01 represents the band from 345 to 15 deg. The WIS values are taken from the Phase I hindcast for the 20-year period 1956 to 1975. Measured values are from NOAA buoys: 46001 (17), 51003 (7), 46014 (8), and 46025 (7). The numbers in parentheses are the years of record for each buoy, generally in the 1980's. Measurements are not continuous over these years. Speed and direction distributions match closely at 46001 and 51003. Generally, differences in categories are less than 10 percent. Calculated speeds at 46014 and 46025 are skewed toward higher values with respect to measurements, while directions are generally 10 percent of each other.

12. The plots in Appendix B indicate that the calculated 20 years of WIS winds represent the climatology of the winds at these Pacific Ocean locations, as far as having the same general distribution of speeds and

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* To convert knots to meters per second, multiply by 0.5144444.

directions. The plots and statistics from the data in Appendix A indicate that fairly large differences in wind speed (average, 7.4 knots) and direction (60 deg) can be expected at any given time. Differences in speed are almost evenly distributed about the mean so the bias is small (1.7 knots), with WIS being lower.

13. Calculated wind fields over the Pacific Ocean are expected to have relatively higher RMS differences of wind speed and direction versus measurements when compared to similar values over smaller water bodies such as the Gulf of Mexico and the Great Lakes. This is due to the lower density of observations over the Pacific, which contribute to the calculated winds. Recently calculated wind fields tend to be more accurate than earlier ones, since they are based on more measurements and better models and computers.

Input winds for 1988 simulation

14. A comparison is made between FNOC wind speeds and directions input to the model for the 1988 hindcast and those measured at the six buoys. The calculated and measured values are not independent, since measured wind information from buoys and ships is used by FNOC to calculate the global wind fields. However, this provides a quantitative measure of the agreement.

15. Table 3 is a summary of the biases of wind speeds, by month, at the different buoys. The biases are calculated by taking the monthly average calculated wind speed at the buoy location minus the monthly averaged wind speed from the buoy measurements. Calculated values are available every 6 hr. Buoy measurements are generally available every hour. Only values corresponding to the times from the calculated time series are used to calculate the statistics. Both sets of wind speeds are at an elevation of 19.5 m.

16. There is a tendency for the calculated values to be lower than the measured. Yearly averages of the biases range from -1.1 to -4.0 knots, with most being closer to -4 knots. Yearly averages of RMS differences range from 4.3 to 6.5 knots, with most closer to 6 knots. Corresponding average bias and RMS differences from available measurements during the 20-year hindcast are -1.7 and 7.4 knots, respectively.

17. In general, calculated wind speeds appear to be lower than those measured, based on the available comparisons in Table 2 and 3. The percent distributions of measured and calculated wind speed in Appendix C indicate

that the number of calculated wind speeds in the higher speed categories are generally less than the number of measured. Thus, it is concluded that calculated wind speeds for 1988 are lower, on the average, than measured speeds at the buoy locations.

18. The time series of calculated wind directions generally agree quite well with measurements at locations 46003, 46006, and 46028, which are close to the coast. The distribution of measured and calculated wind directions in 30-deg bands is shown in Appendix C. The distribution of directions agrees well at all sites. Most of the comparisons agree within 5 percent.

19. The FNOC wind speeds are considered an accurate representation of the wind speed during 1988, generally within ±6 knots. The bias of about 3-4 knots is considered small. Wind direction agrees well with measurements most of the time. Thus, these winds should produce unbiased wave heights and periods with relatively low RMS differences when used with an acceptable wave model.

20. Comparison of data from the 20-year hindcast with FNOC wind data for 1988 indicates that bias and RMS difference values are generally the same (Tables 2 and 3). The distributions of speeds and directions from both hindcasts generally agree with those of buoy measurements. The FNOC wind data used in the 1988 hindcast are thus judged to be equivalent in quality to those used in the 20-year hindcast. Therefore, wave information from the 1988 hindcast that was produced with the model used in the 20-year hindcast should be typical of wave data produced in the 20-year hindcast.

Wave Model

21. The wave model used to produce the Pacific Ocean Hindcast wave information for 1956-1975 is similar to that used for the Atlantic hindcast. It is described in WIS Report 12 (Resio and Tracy 1983). The model is forced by the input of wind speed and direction at each grid point over the modeled region as a function of time. Output results vary from summary information such as height, period, and direction at a point to directional wave spectra over the computational grid. It is a discrete spectral model, which means a wave energy spectrum is represented by a fixed number of frequency and direction bins. The number of frequency bins is variable, but is typically

set to 20. The number of direction bins is fixed at 16, so that each band represents 22.5 deg centered on 0 deg, 22.5 deg, 45 deg, etc.

22. A second-order propagation scheme is used to move wave energy over a spherical orthogonal grid of water points. Deep water is assumed at all points, so bathymetric effects such as refraction and shoaling are neglected.

Verification

23. Verification of the Pacific Ocean model consists of comparing wave height and peak period as calculated by the model to values measured at six different locations during 1988. Model results are compared to buoy measurements in three ways. Time series plots of hindcast and measured wave height and peak period were prepared for each month of the year. The bias and RMS difference were calculated by month from the time series of hindcast and measured wave height and peak period. These values, which are summarized in Table 4, provide a quantitative measure of model performance. The distributions of hindcast and measured wave heights and peak periods were prepared. These comparisons provide a qualitative measure of the performance of the model at the various measurement sites and are presented in Appendix C.

Wave heights

24. Selected plots of hindcast and measured wave height at the six buoy locations (46003, 46006, 46010, 46022, 46028, and 51001; Figure 1) are shown in Appendix D. A winter and summer month were chosen at each site. It is apparent from the plots that the hindcast wave heights tend to be larger than the measured heights at each site for summer and winter months. This is also apparent in the percent distribution plots of hindcast and measured wave height in Appendix C. The hindcast values are skewed toward higher values with respect to the measured. The time series plots for the other months of the year (not shown) show that this is true for all months. The biases of wave height are summarized, in Table 4, for each site by month. The bias is less in the summer months of June through September (typically 0.5 m or less). In the remaining months of the year, it is fairly constant at about 1.0 m. The best comparisons are at the Hawaiian Island site, where wind and, hence, wave conditions are fairly constant and thus easier to hindcast. This is also shown by the relatively low yearly average value of bias (0.3 m) compared to

the other sites whose values are similar and average 1.1 m.

25. The RMS differences of hindcast and measured wave height are also shown in Table 4 (by month, at each site). Again, the yearly value at the Hawaiian Islands site is lower (0.7 m) than values at the other sites, which range from 1.3 to 1.7 m. Values are also lower in the months of June through September (average 0.6 m) than for other months (average 1.5).

26. The time series plots of measured and hindcast wave height were examined to identify the causes of those cases where the results differed the most. Cases were identified where the disagreement could not be explained by the bias at a particular site and month. Most of the cases are attributed to excess wave energy characterized as swell. In these cases, wind speeds, directions, and wave periods agree well at the site, and the periods indicate wave energy is present as swell (14-16 sec). Other cases of hindcast wave heights being higher than measured values are explained by winds being overestimated in the area of generation.

Wave peak periods

27. Wave peak period is defined as the period associated with the frequency band in a spectrum that has the highest energy value. Thus, peak period represents a single point of a spectrum, while the significant height is derived from adding up energy in all frequency bands and represents an averaged or integrated value. The peak period comparisons are qualified by two aspects that make comparisons of wave period difficult. First, for spectra where energy peaks at nearly equal levels in two or more frequency bands, the choice of the peak value only may ignore the presence of significant energy at other periods. In these cases, comparisons may be misleading since buoy data may indicate a peak period in the swell region, while model results may indicate a peak period in the local wind generation part of the spectrum, or vice versa. In reality, the measured and modeled spectra may have two peaks which agree well in period, but the restriction of using only one period as the peak value may be misleading if the swell peak is chosen from the modeled spectrum and wind sea peak from the other. Secondly, in this hindcast, the numerical grid used does not cover the southern portion of the Pacific, where hurricanes can occur off the Mexican coast and large storms can occur in the Southern Hemisphere. These events can produce swell that propagates into the model region, but is not simulated in the model.

Usually this energy is quite small, so wave height comparisons are not affected. However, in cases of low winds and waves, swell energy propagating into the model region can be equivalent in magnitude to locally generated wave energy, but periods can be distinctly different. This is more likely in the Northern Hemisphere summer months when hurricanes are likely north of the equator and major storms are likely in the Southern Hemisphere, where it is the winter season.

28. Measured and modeled wave peak periods are compared in the same way as the wave heights, namely using time series plots in Appendix D, percent distribution plots in Appendix C, and in Table 5, where bias and RMS values are summarized by site and month. No obvious biases are evident in the plots of measured and modeled periods shown in Appendix D, as were evident for wave heights.

29. The percent distribution plots in Appendix C indicate that the number of hindcast periods less than about 10 to 12 sec are generally less than the number from measurements. There are more hindcast values in the bands from 12 to 15 sec than measured, and generally no hindcast values above 18 sec. The percent difference in each band is typically less than 5 percent. The general lack of modeled periods above 18 sec, which is the significant difference shown by the these plots, may be due in part to the causes discussed in paragraph 27.

30. The biases shown in Table 5 indicate that the model neither consistently over- or under-estimates the measured peak periods as a function of month or location. The large values of bias are correlated with a smaller number of cases each month, and thus are not as reliable as those where the sample population is larger. The RMS differences in Table 5 indicate that typical differences in hindcast and measured peak periods are about 3 sec.

31. The time series plots for all months comparing measured and modeled peak periods show 5 to 15 occurrences at each site where peak period values differ by 5 to 10 sec. Hindcast values tend to be lower twice as often as they are higher for these cases. Wind and wave energy tend to be low during these times when the model estimates a period lower than that measured by the buoy. These cases may be due to the causes discussed in paragraph 27. For the cases when the model overestimates the peak period with respect to the buoy, it also overestimates the wave height. This could be caused by the

generation of excess wave energy, which becomes swell and propagates to the site.

32. The tendency for hindcast wave heights to be high with respect to buoy measurements would indicate that swell energy should be higher also. The time series plots of wave height indicate that in high-energy events, model wave heights do not dissipate as rapidly as is indicated by the buoy data. Note, as an example, the events at buoy 46003 in January (Appendix D). Thus, wave energy may remain higher in the grid and propagate to other points, giving high values of swell energy.

Conclusions

WIS winds

33. Comparison of the WIS wind data used in the 20-year hindcast with measured data coincident in time indicates relatively large RMS differences (average 7.4 knots) and a slight bias to be low (average 1.7 knots). The low bias is not significant, but the expectation that wind speeds could differ from reality at any time by about 7.4 knots automatically introduces potential error in wave estimates. The RMS differences using FNOC winds for 1988 are typically 6 knots. The FNOC winds are considered among the best archived oceanic winds available today. Thus, any attempt to improve the 20 years of WIS winds probably has little chance of reducing the random error in the 20-year wind fields.

34. Buoy data on the distribution of wind speeds and directions (mainly from the 1980's) were compared to the 20-year results at four sites. The distribution of WIS speeds compares well at two offshore sites, but is skewed toward higher values at the two coastal sites. Directions compare favorably at all sites. It is concluded that the WIS 20-year wind data are as accurate a representation of the wind climatology over the Pacific as was possible to obtain at the time that they were generated, and are nearly equivalent to similar present-day products. Attempts to improve the 20 years of WIS Pacific wind data are not recommended.

FNOC winds for 1988

35. Wind speeds used in the verification tended to be lower (by about 3 knots) than those measured by the buoys. The RMS difference between FNOC

wind data and measurements was about 6 knots. There are more occurrences of calculated wind speeds in the lower speed categories than measured, and fewer in the higher speed categories. However, percent differences in categories are small, generally being about 5 percent. Calculated and measured wind directions generally agree well in time, and are distributed in direction categories equally, with differences within categories being about 5 percent. It is concluded that the FNOC wind data from 1988 are an accurate representation of actual winds during that period to within ± 6 knots. The FNOC data are considered acceptable for testing the performance of the wave model that was used to produce the Phase I and II wave information for the Pacific, and to judge the accuracy of those results.

Wave results

36. Hindcast wave heights are biased high with respect to measurements, by about 1.0 m. The average RMS difference between hindcast and measured values is 1.3 m. This value is high, due to the bias, and would be within an acceptable range if the bias were removed. The large bias is attributed to the wave model since, in general, the input winds are biased low.

37. There is no indication of bias in wave peak periods, and the RMS difference between calculated and measured values is about 3 sec. These statistics are considered acceptable. However there is a lack, in the model results, of any waves longer than 18 sec, both in the winter months when swell from outside the model region should be absent, and in the summer. There is also a persistence of swell energy in the model, which appears in the time series plots, but is not seen in the buoy data.

38. It is recommended that the present WIS wave model be applied in the same way as this verification study to assess the accuracy of present hindcast model results. Based on those results, a decision will be made on revising the original hindcast results. Based on the 1988 hindcast, users of the WIS deepwater Pacific Ocean results for the period 1956-1975 should interpret the data to have the following accuracies:

a. Wind speed: low in the mean by 3.0 knots; RMS difference, 5.5 knots.

b. Significant wave height: high in the mean by 1.0 m; RMS difference, 1.5 m.

_c._ Peak period: high in the mean by 1 sec; RMS difference, 3.5 sec.

Additionally, when designs involve long period swell, consideration should be given to lengthening the period to account for the underestimation. Adjustment of results in WIS Reports 14, 16, 17, and 20 to account for these biases is a difficult problem. It is believed that the tendency to overpredict wave height exists in the basic hindcast and is passed to other hindcasts, which use these results as input. Procedures to account for the biases should be considered on a site-by-site basis. The WIS staff may be contacted for assistance.

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Table 1

Locations of Measurements and Model Results

Buoy ID	Latitude Deg. N	Longitude Deg. W	Model Latitude Deg. N	Model Longitude Deg. W
46001	56.3	148.3	57.5	148.8
46003	51.9	155.7	52.0	156.8
46006	40.7	137.7	41.9	138.3
46010	46.2	124.2	46.0	125.0
46014	39.2	124.0	38.6	125.9
46022	40.8	124.5	40.3	124.9
46025	33.6	119.0	33.0	120.8
46028	35.8	121.7	35.4	122.2
51001	23.4	162.3	24.0	162.2
51003	19.2	160.8	20.0	160.0
PAPA	50.0	145.0	50.5	144.0
FLIP	39.5	148.0	39.5	147.0
EB03	56.0	147.0	55.0	146.0
EB16	42.5	130.0	41.0	130.0

Table 2

Comparison of WIS Wind Speeds to Measurements

Month/Year	Site	Number of Values	Bias (knots)	RMS. (knots)
Feb. 60	PAPA	111	-3.2	7.8
Nov. 60	PAPA	119	-6.0	10.2
Jan. 63	PAPA	124	-0.2	7.4
Oct. 65	PAPA	123	-3.2	9.4
Nov. 66	PAPA	120	-2.4	7.4
Feb. 69	PAPA	107	-4.0	9.6
Nov. 69	PAPA	120	0.4	7.2
Dec. 69	PAPA	124	2.6	8.2
Sep. 63	FLIP	51	-1.2	5.0
Dec. 75	EB03	123	2.8	7.8
Sep. 75	EB16	118	-3.6	5.2
Oct. 75	EB16	124	-3.8	6.8
Nov. 75	EB16	103	-1.2	5.8
Dec. 75	EB16	83	-0.6	6.4

*Bias = Monthly average calculated wind speed minus measured monthly average.

Table 3

Wind Speed Bias, RMS Difference, and Number of Cases Compared for NOAA Buoys

Bias* (knots) of FNOC Wind Speeds to Measured at Buoy Locations

1988

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	-5.1		-3.9	-3.1	-4.6					-4.6	-3.3	-2.7
46022	-5.6	-4.1		-3.4	-3.8	-3.5			-3.5			-1.7
46028	-2.5	-2.5	-5.4		-5.3	-4.1			-3.8	-2.6		-3.3
46003	-2.2	-3.0	-2.2	-2.8	-3.0	-1.5	-3.2		-2.8	-2.9	-2.4	-2.4
46006	-0.8	-0.8	-1.0						-1.7	-1.1	-1.0	-1.2
51001			-4.3	-4.6	-4.0	-4.5	-4.5		-2.7	-3.3	-4.1	-3.8

RMS Difference (knots) of FNOC Wind Speeds from Buoy

1988

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	7.2		6.3	5.8	6.8					6.3	6.1	6.3
46022	7.7	5.9		5.8	6.8	6.5			6.8			6.1
46028	4.8	5.4	6.3		6.6	6.9			5.7	4.1		5.5
46003	5.4	7.9	8.8	5.0	4.9	4.0	4.6		6.2	6.1	6.3	5.9
46006	5.4	4.7	3.8						3.8	3.9	4.4	3.9
51001			5.0	5.1	4.7	4.9	5.0		4.3	4.2	4.8	5.0

Number of Cases Compared

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	119		71	120	78					124	120	123
46022	124	116		120	123	120			100			124
46028	123	116	124		123	120			119	124		123
46003	124	116	124	119	124	120	124		120	124	119	123
46006	123	116	60						120	123	119	122
51001			86	120	124	120	123		119	117	120	124

Bias* = Calculated monthly average minus measured monthly average.

Table 4

Wave Height Bias,* RMS Difference, and Number of Cases Compared for NOAA Buoys

Bias* (m) of Wave Height from Measurements

1988

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	1.2		1.2	1.3	1.5					0.7	1.6	2.8
46022	0.9	1.1		0.9	1.0	0.7			-0.1			2.0
46028	0.8	1.0	1.1		0.7	0.6			0.2	1.6		1.8
46003	1.1	1.3	1.4	1.2	1.4	0.8	0.4		0.8	0.7	1.1	1.1
46006	0.8	1.2	2.0						0.5	1.0	1.8	1.2
51001			0.6	0.2	0.1	0.1	-0.3		0.3	0.3	0.2	0.6

RMS Difference (m) of Wave Height

1988

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	1.6		1.5	1.5	1.6					0.8	2.0	3.3
46022	1.5	1.4		1.1	1.1	0.8			0.7			2.7
46028	1.3	1.2	1.5		0.9	0.8			0.5	1.8		2.4
46003	1.8	1.7	1.8	1.5	1.6	0.9	0.5		1.4	1.2	1.6	1.6
46006	1.5	1.5	2.3						0.6	1.3	2.3	1.5
51001			1.3	0.7	0.4	0.6	0.4		0.6	0.5	0.8	1.0

Number of Cases Compared

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	119		71	120	78					124	120	74
46022	124	116		119	123	120			100			52
46028	119	113	123		119	118			112	51		45
46003	124	116	124	118	124	120	124		120	124	119	122
46006	122	114	55						120	120	115	121
51001			85	118	124	119	123		119	117	120	124

*Bias = Calculated monthly average minus measured monthly average.

Table 5

Wave peak Period Bias,* RMS Difference, and Number of Cases Compared

Bias (s) of Wave Peak Period from Measurements

1988

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	-0.3		1.9	1.0	2.2					0.2	1.3	5.6
46022	-1.3	-0.6		0.6	1.1	0.9			-0.2			7.5
46028	-1.6	-0.8	-0.4		-0.4	-0.2			-0.7	6.6		7.2
46003	-0.2	0.5	1.5	0.4	1.4	0.3	0.1		0.3	0.4	0.8	0.3
46006	-0.8	-0.9	1.2						-0.5	1.0	0.7	0.3
51001			-0.8	0.2	0.2	-1.3	-1.6		-0.2	-0.9	0.2	-0.4

RMS Difference (s) of Peak Period

1988

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	3.6		3.9	2.7	3.2					1.6	3.0	8.7
46022	4.4	2.5		2.6	2.7	2.6			2.2			10.2
46028	4.7	4.0	3.4		3.8	3.2			3.7	8.3		10.1
46003	3.2	2.1	3.1	2.2	2.4	2.5	0.5		2.2	2.2	2.7	2.4
46006	3.3	3.6	4.1						2.4	2.8	3.1	2.6
51001			3.7	2.9	2.8	4.1	2.3		2.7	2.6	2.7	2.3

Number of Cases Compared

Buoy	J	F	M	A	M	J	J	A	S	O	N	D
46010	119		71	120	78					124	120	74
46022	124	116		119	123	120			100			52
46028	119	113	123		119	118			112	51		45
46003	124	116	124	118	124	120	124		120	124	119	122
46006	122	114	55						120	120	115	121
51001			85	118	124	119	123		119	117	120	124

*Bias = Calculated monthly average minus measured monthly average.

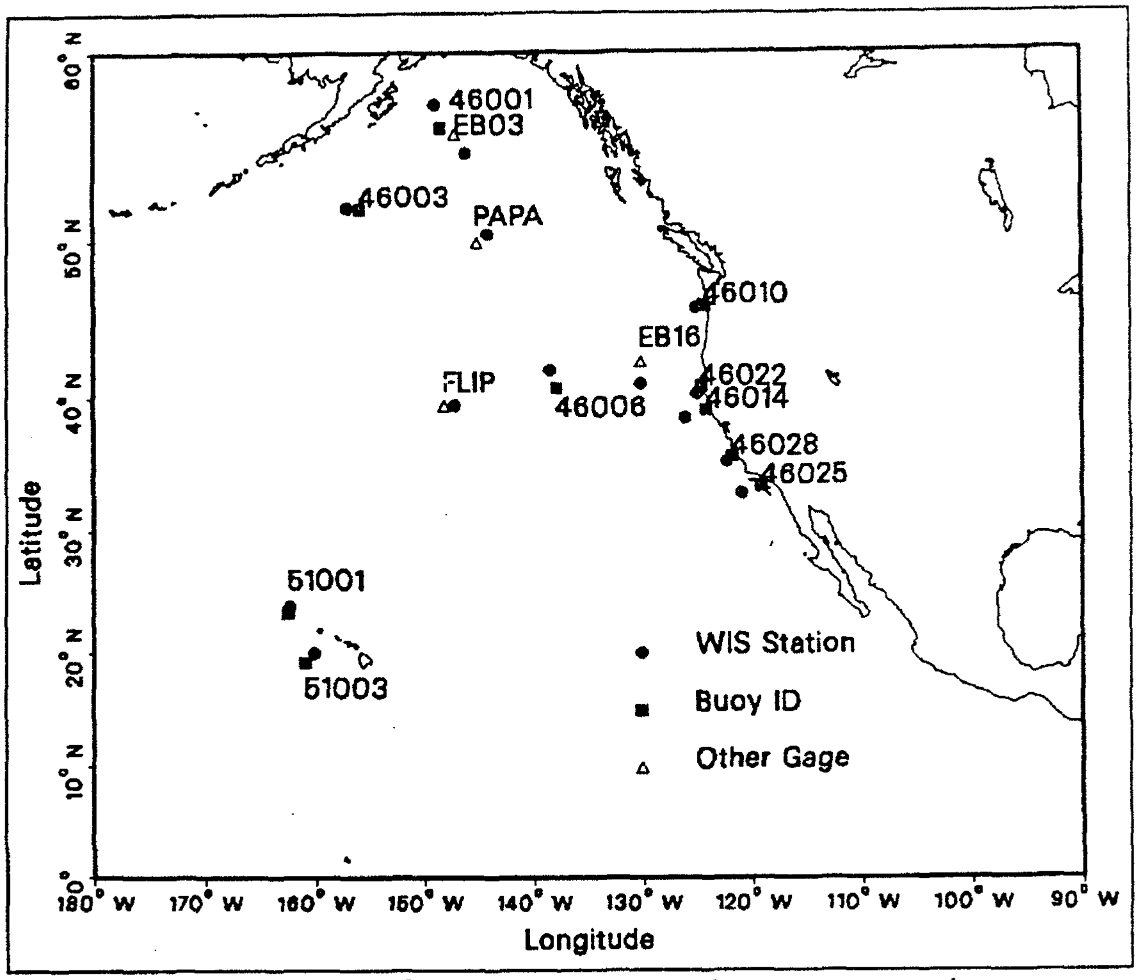
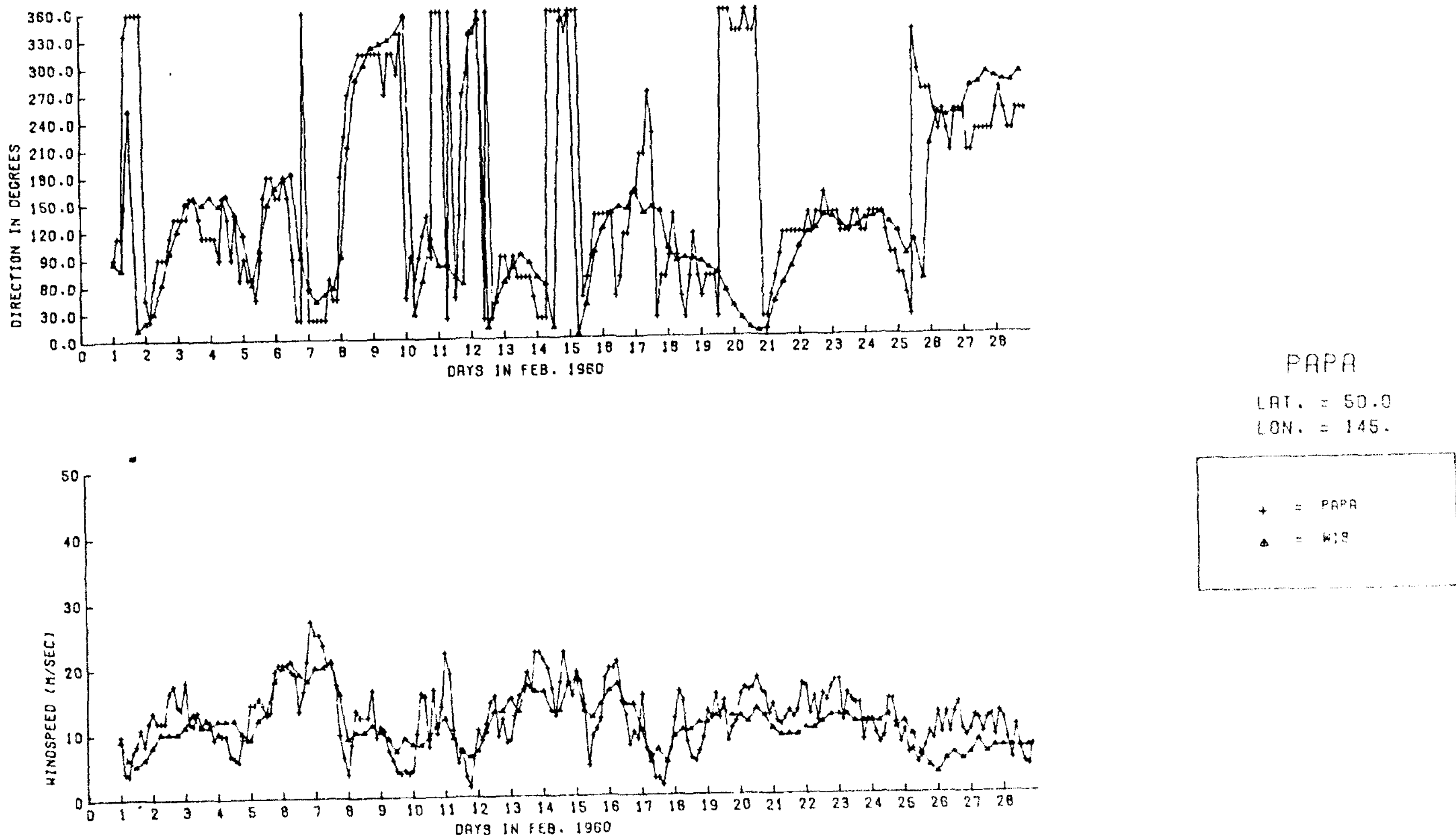
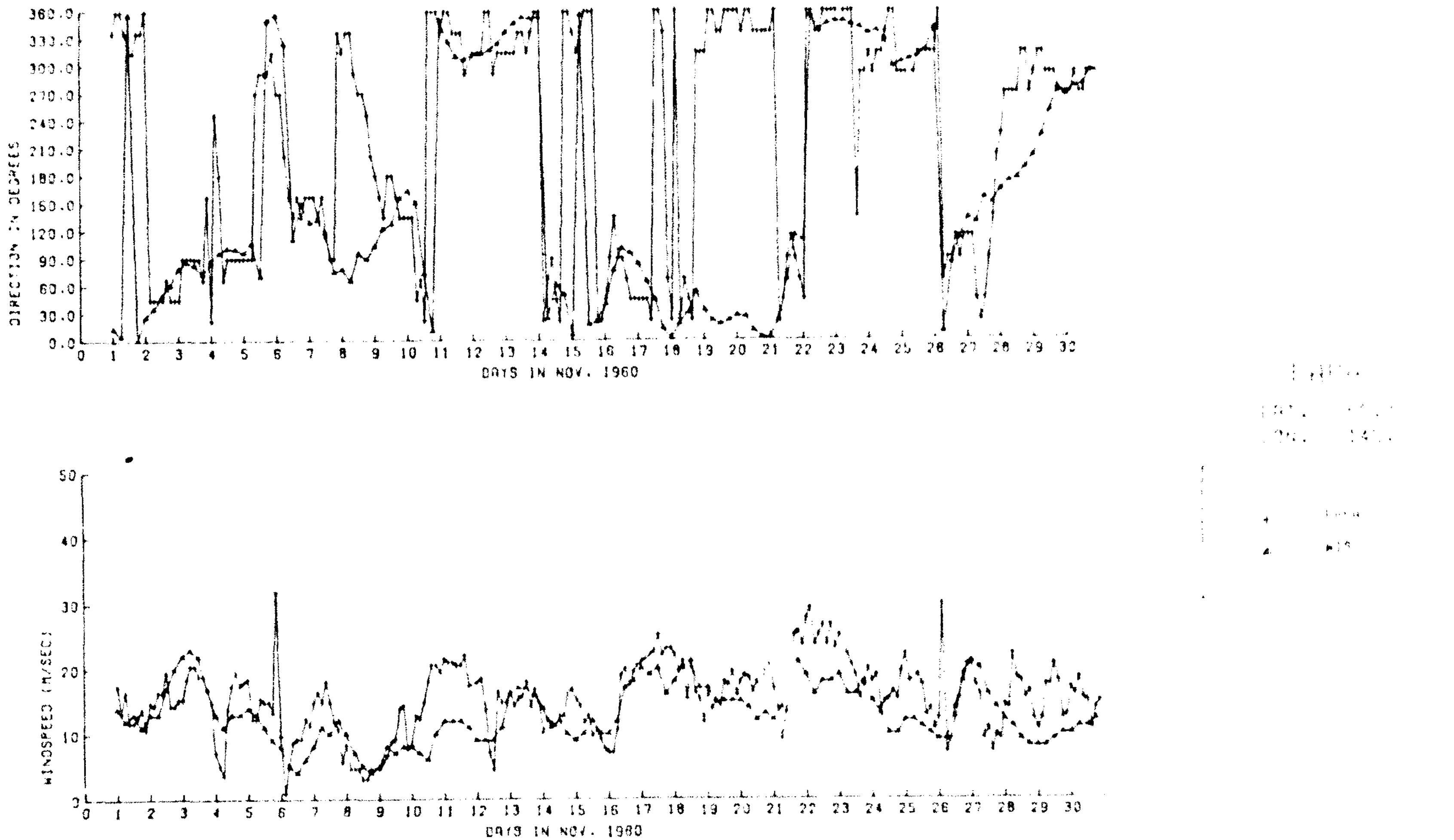
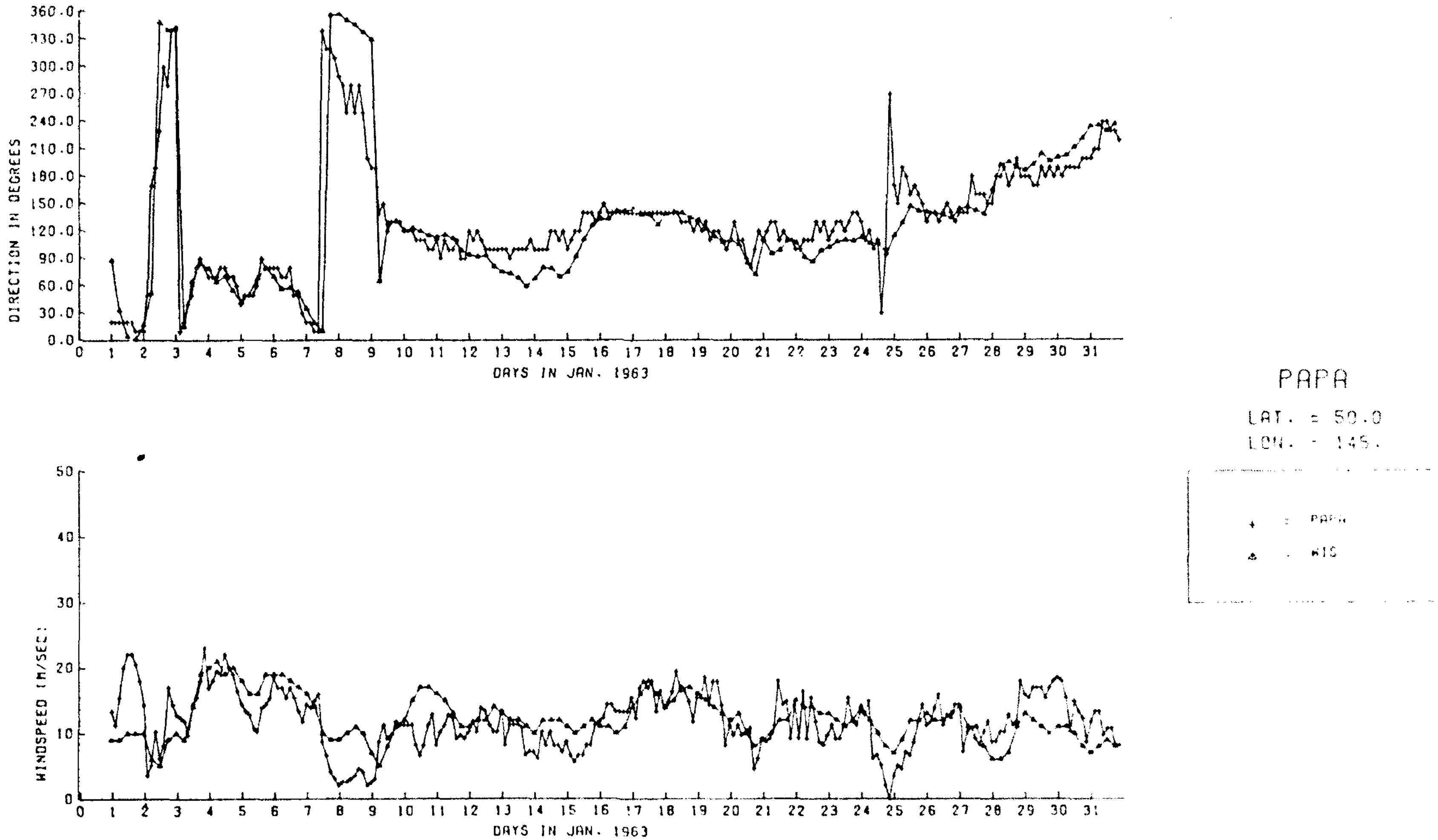


Figure 1. Location map for WIS stations and measurement sites

APPENDIX A: TIME SERIES PLOTS OF WIS AND MEASURED WIND SPEED AND DIRECTION


PAPA
LAT. = 50.0
LON. = 145.
+ = PAPA
△ = WIS
DIRECTION IN DEGREES
DAYS IN FEB. 1960
WINDSPEED (M/SEC)
DAYS IN FEB. 1960


DIRECTION IN DEGREES
DAYS IN NOV. 1960
WINDSPEED (M/SEC)
DAYS IN NOV. 1960



DIRECTION IN DEGREES
360.0
330.0
300.0
270.0
240.0
210.0
180.0
150.0
120.0
90.0
60.0
30.0
0.0
0 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 26 27 28 29 30 31
DAYS IN JAN. 1963
WINDSPEED (M/SEC)
50
40
30
20
10
0
0 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 26 27 28 29 30 31
DAYS IN JAN. 1963
PAPA
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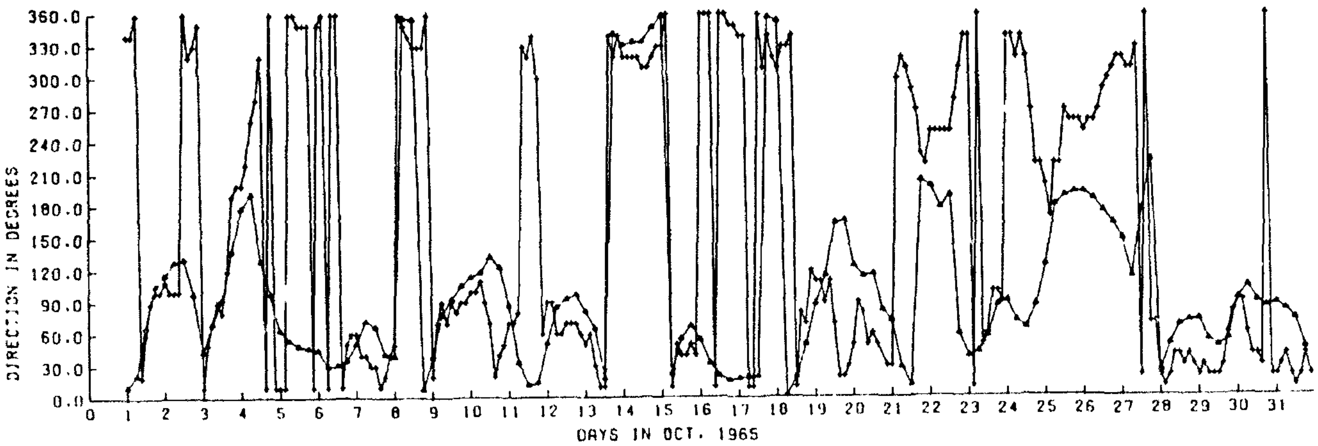
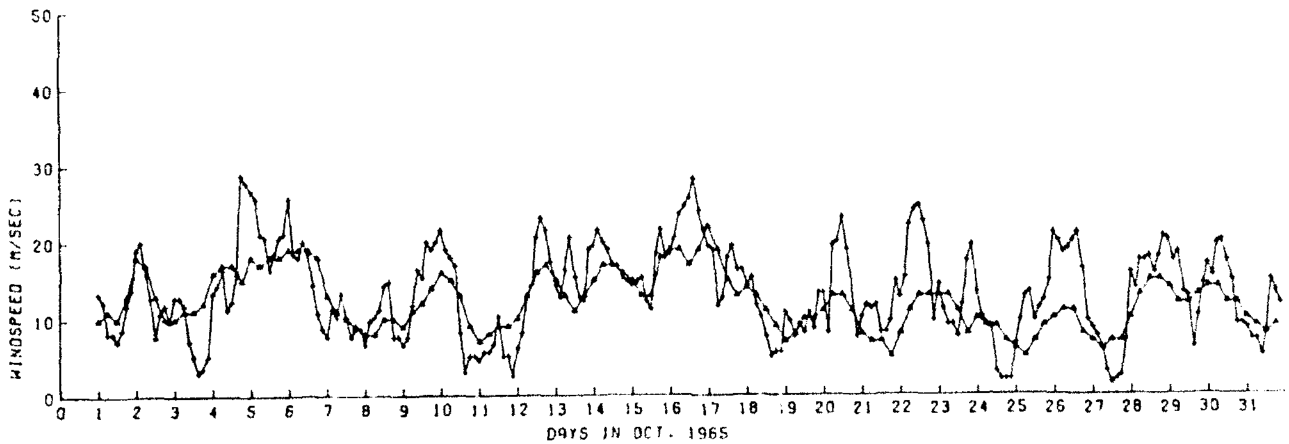
LON. = 145.
= PAPA
= WIS





PAPA

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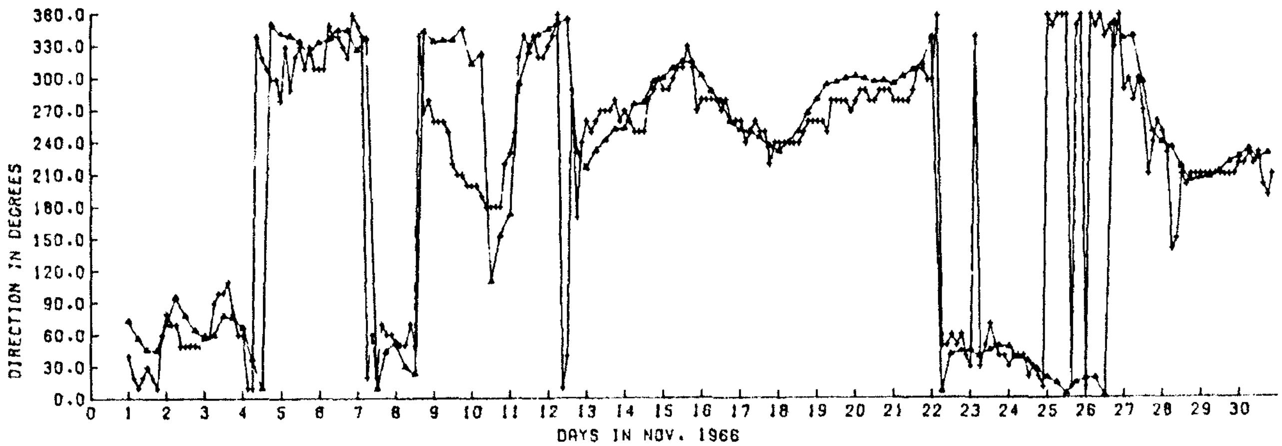
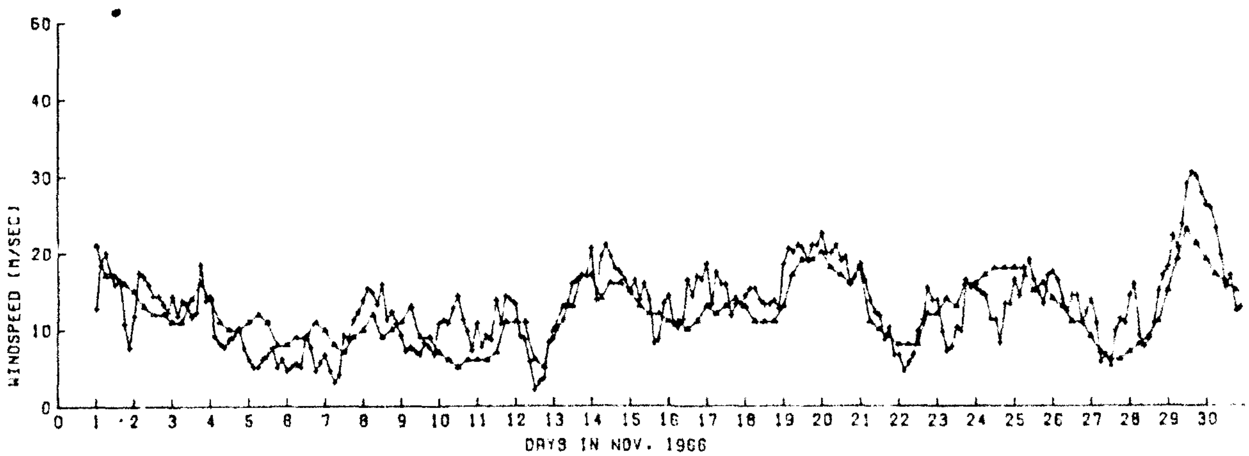
+ = PAPA
▲ = WIS





PAPA

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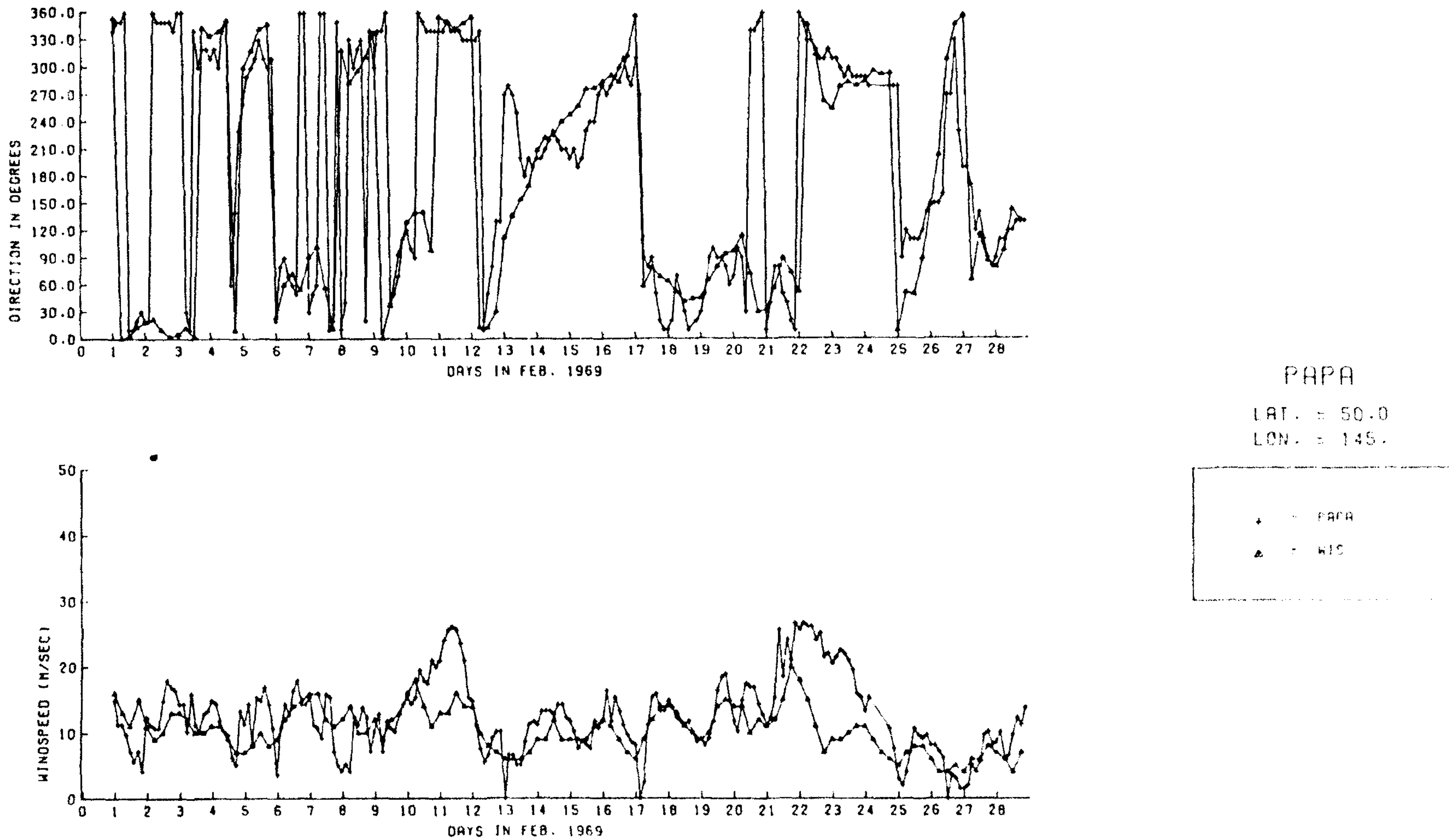
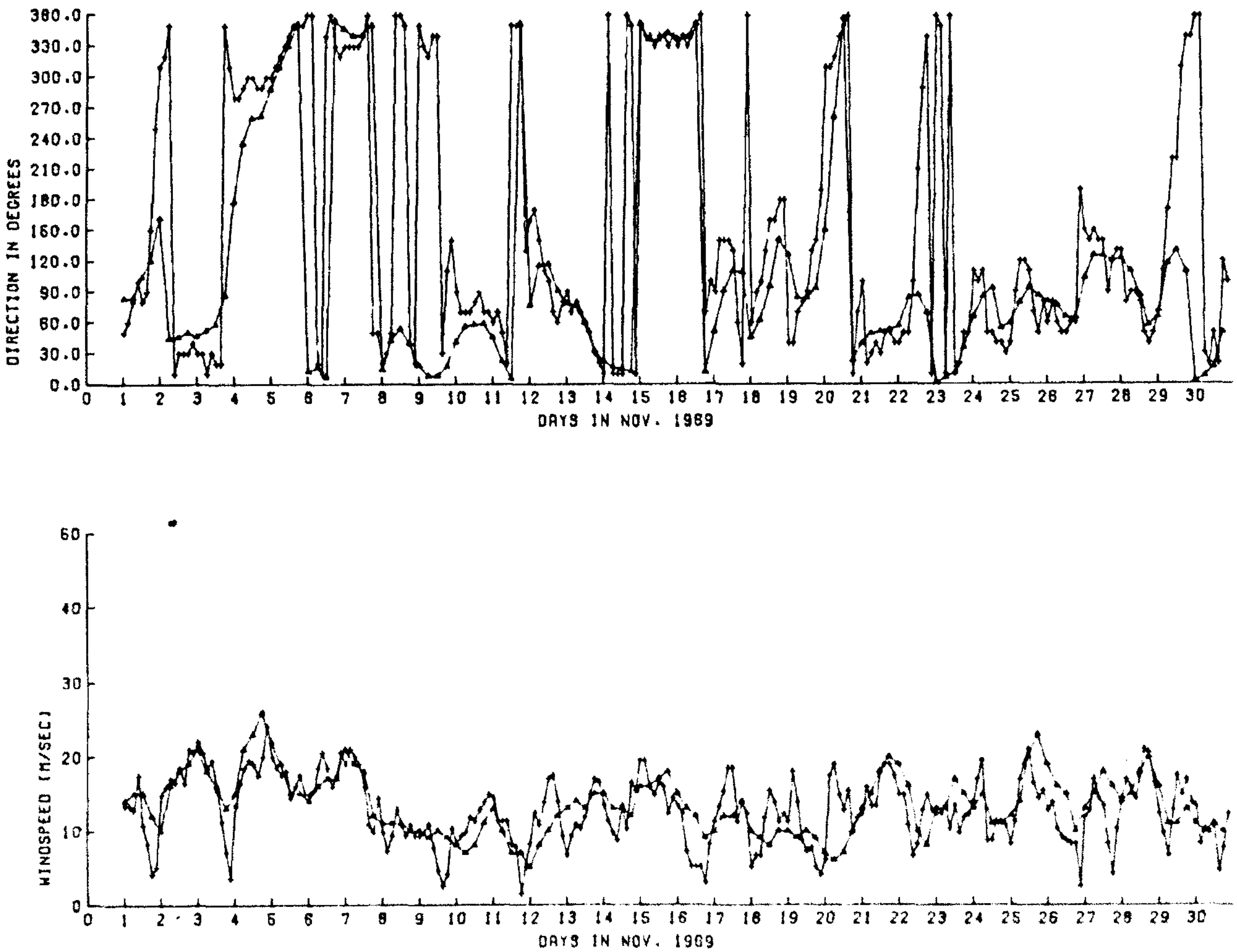
+ : PAPA
▲ : WIS

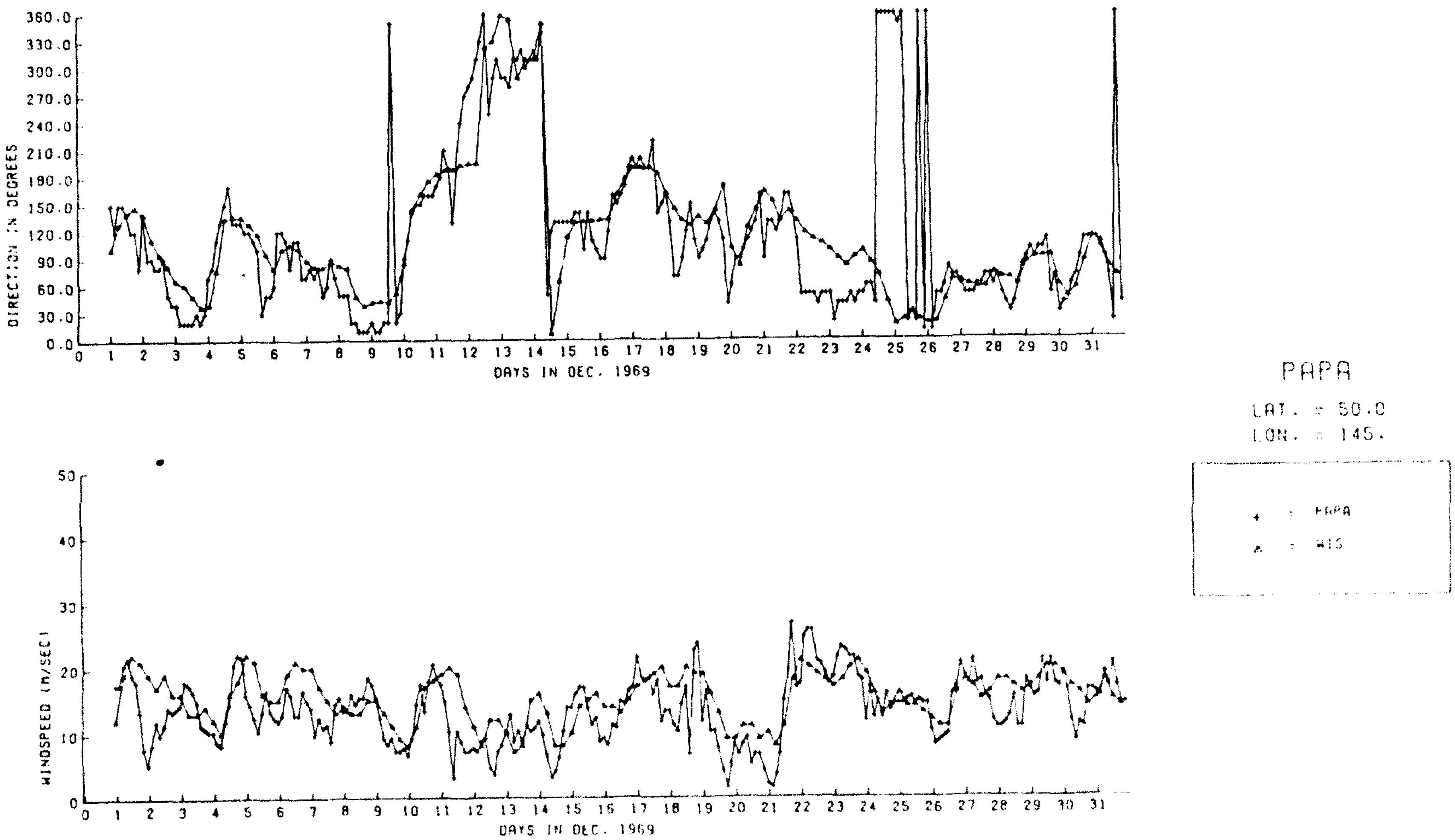

PAPA
LAT. = 50.0
LON. = 145.
+ = PAPA
▲ = WIS
DIRECTION IN DEGREES
360.0
330.0
300.0
270.0
240.0
210.0
180.0
150.0
120.0
90.0
60.0
30.0
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
DAYS IN FEB. 1969
WINDSPEED (M/SEC)
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
DAYS IN FEB. 1969

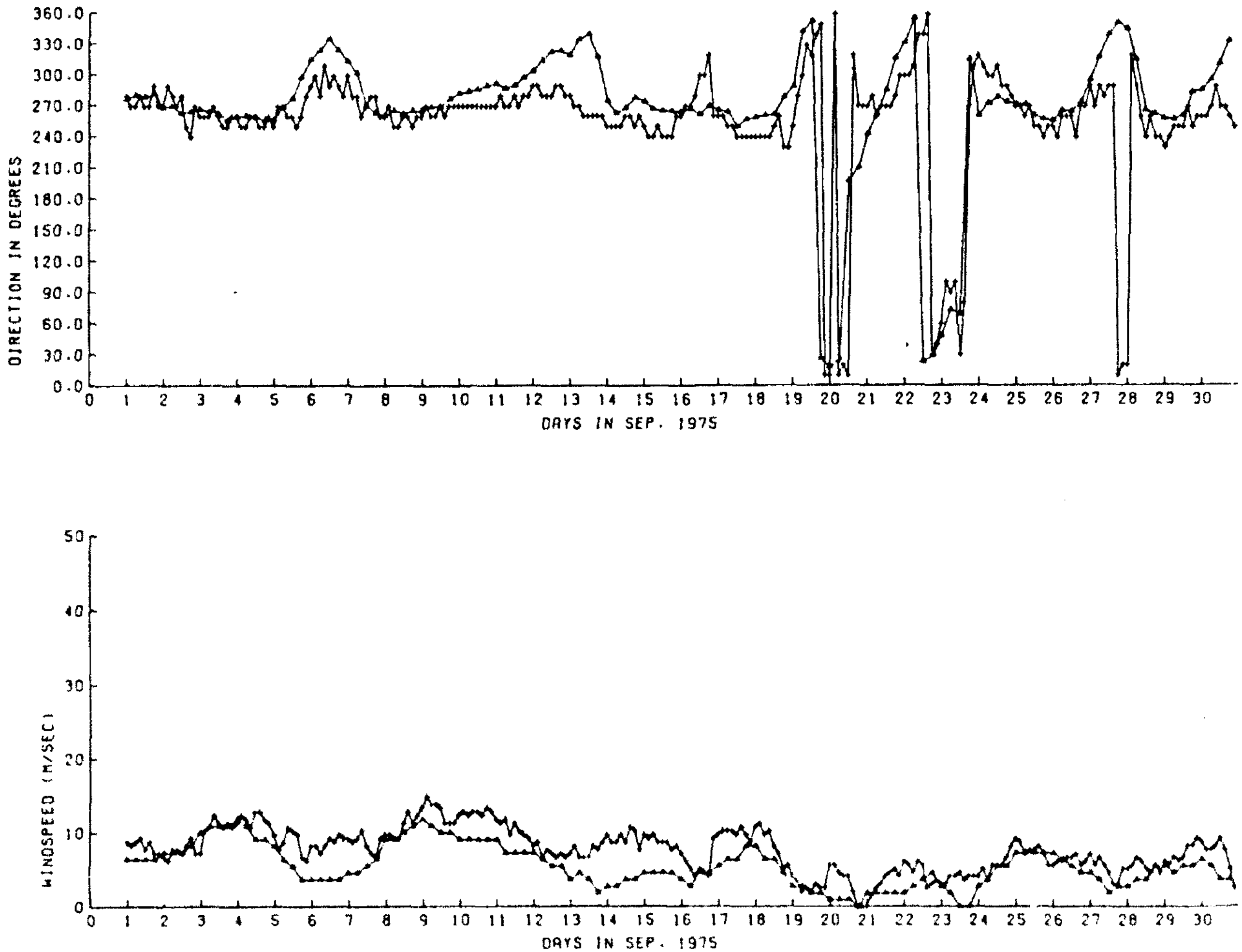


PAPA

LAT. = 50.0
LON. = 145.

+ = PAPA
▲ = WIS

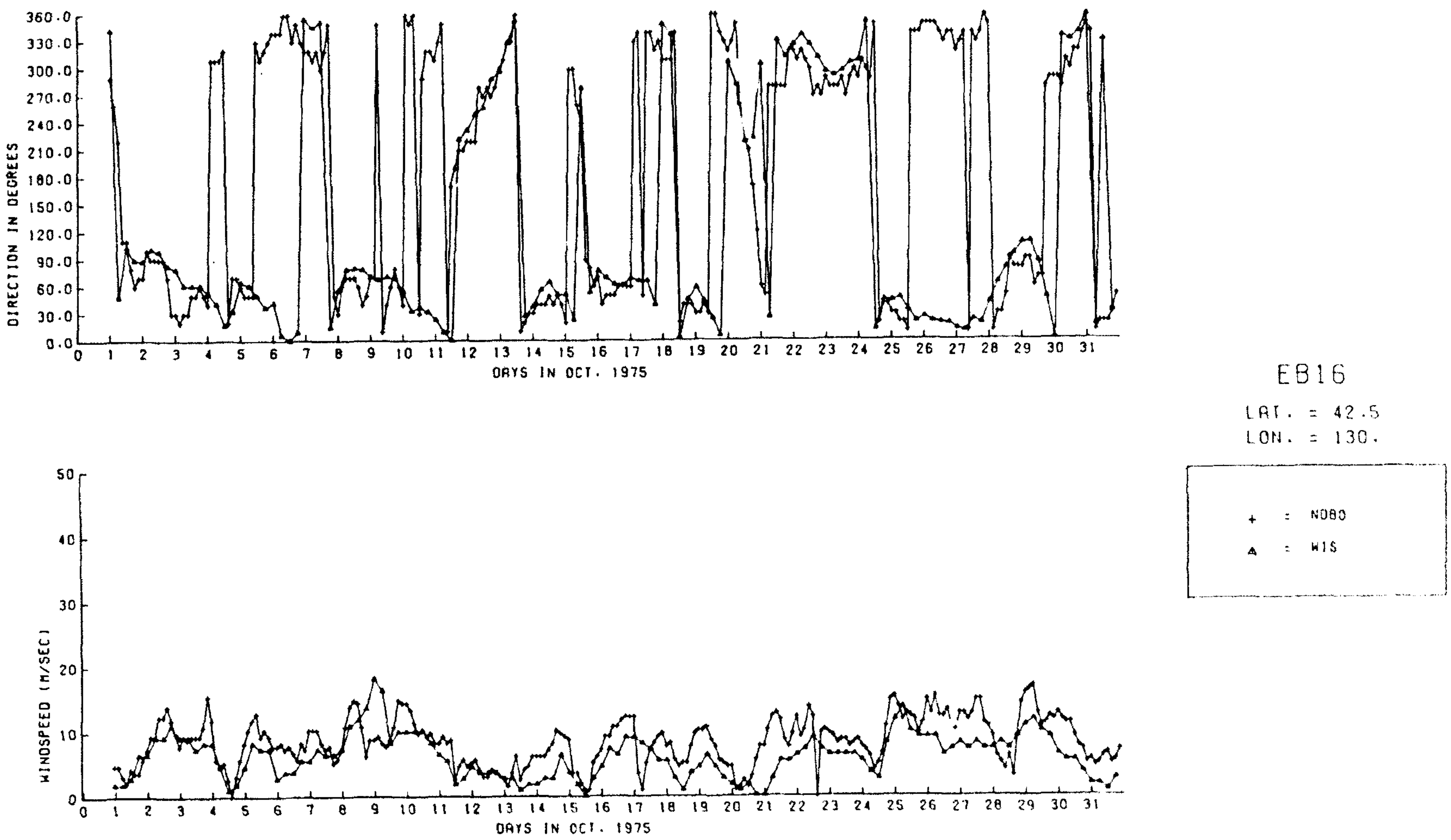

PAPA
LAT. = 50.0
LON. = 145.
+ = PAPA
A = WIS
DIRECTION IN DEGREES
DAYS IN DEC. 1969
WINDSPEED (M/SEC)
DAYS IN DEC. 1969



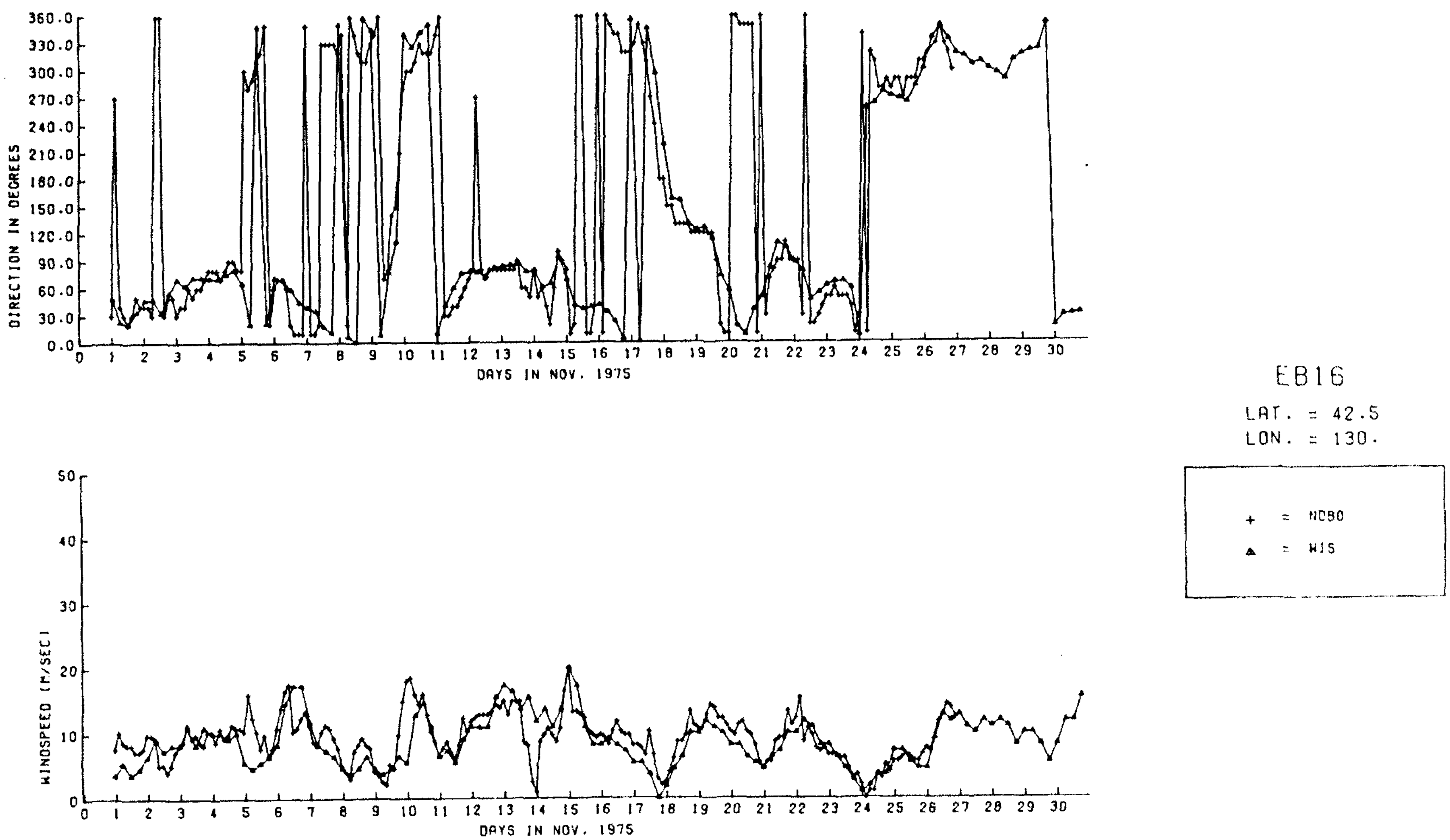
EB16

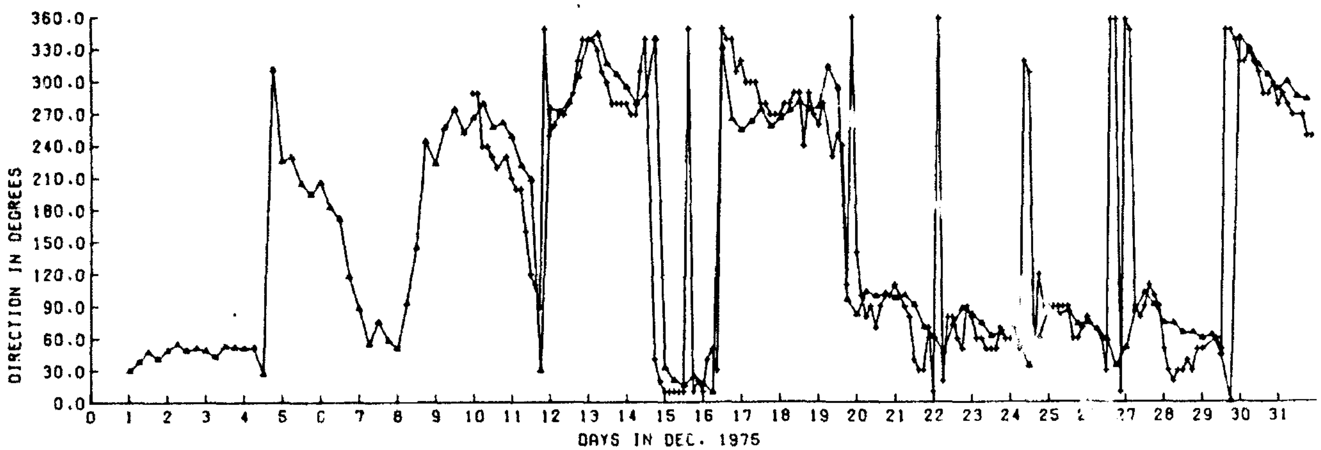
LAT. = 42.5
LON. = 130.

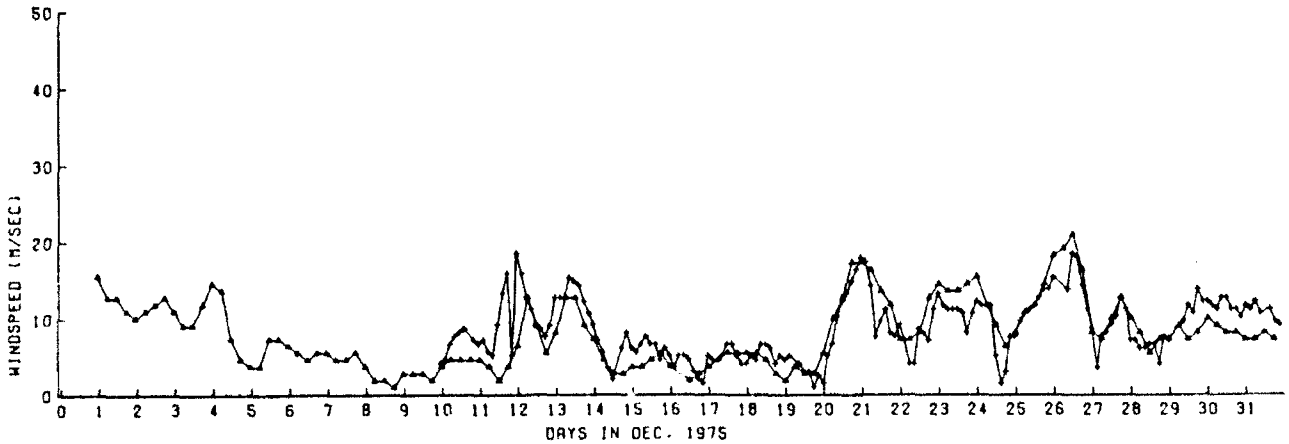
+ = NOBO
△ = WIS



EB16
LAT. = 42.5
LON. = 130.
+ = NDBO
▲ = WIS
DIRECTION IN DEGREES
DAYS IN OCT. 1975
WINDSPEED (M/SEC)
DAYS IN OCT. 1975


DIRECTION IN DEGREES
DAYS IN NOV. 1975
WINDSPEED (M/SEC)
DAYS IN NOV. 1975
EB16
LAT. = 42.5
LON. = 130.
+ = NDBO
▲ = WIS

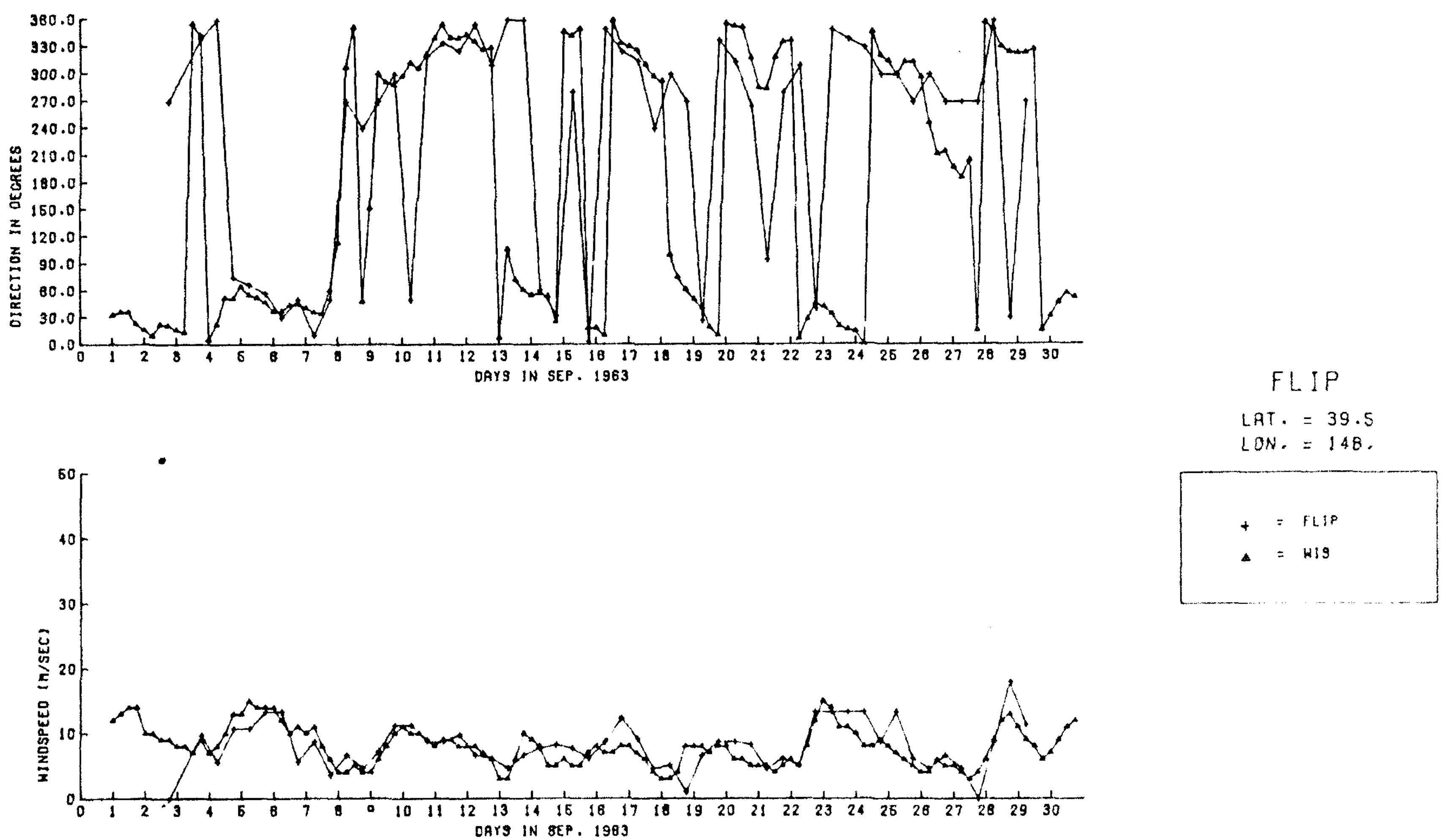


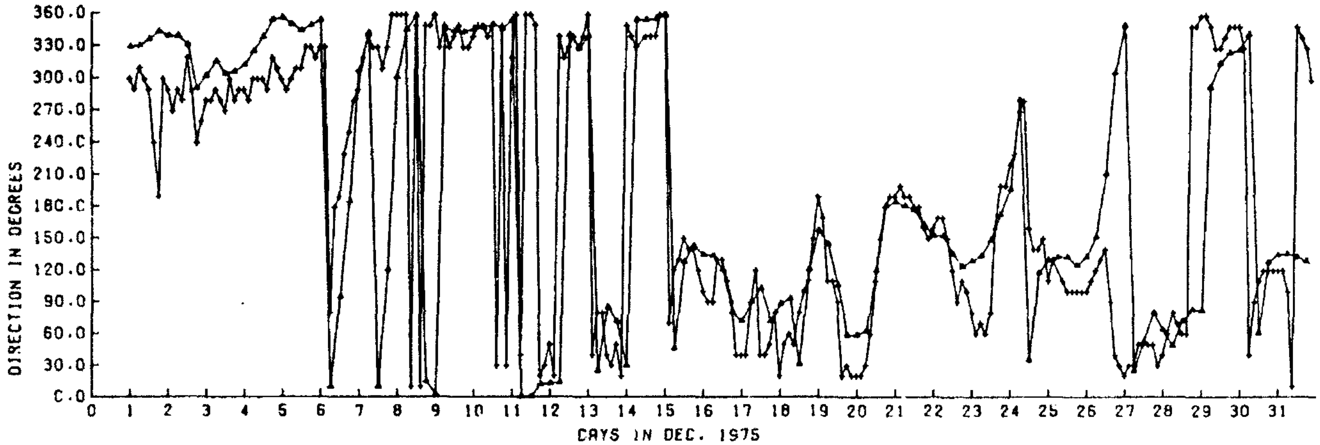


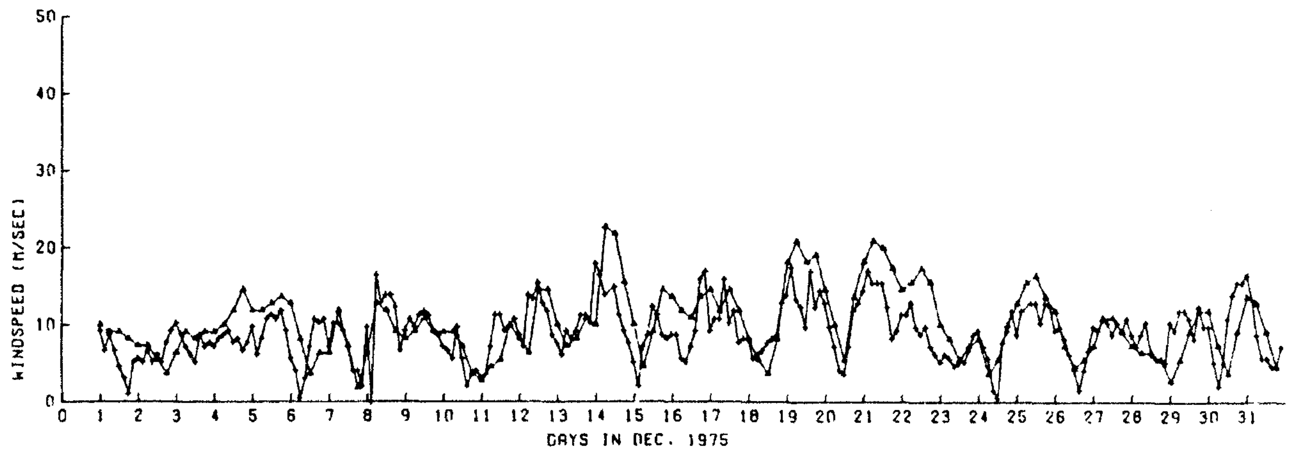
EB16

LAT. = 42.5
LON. = 130.

+ = NOBO
△ = WIS


FLIP
LAT. = 39.5
LON. = 148.
+ = FLIP
▲ = WIS
DIRECTION IN DEGREES
DAYS IN SEP. 1983
WINDSPEED (M/SEC)
DAYS IN SEP. 1983





EB03

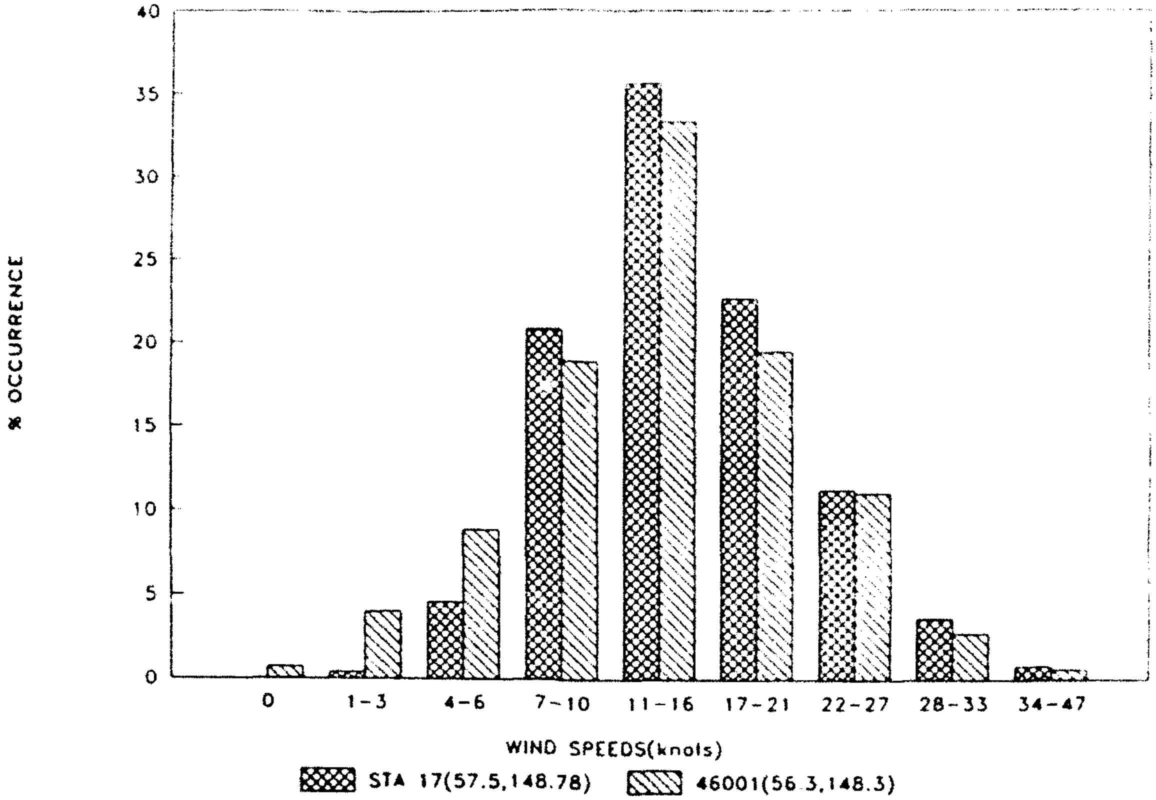
LAT. = 56.0
LON. = 147.

+ = NOBO
▲ = WIS

APPENDIX B: DISTRIBUTIONS OF WIS AND MEASURED WIND SPEEDS AND DIRECTIONS

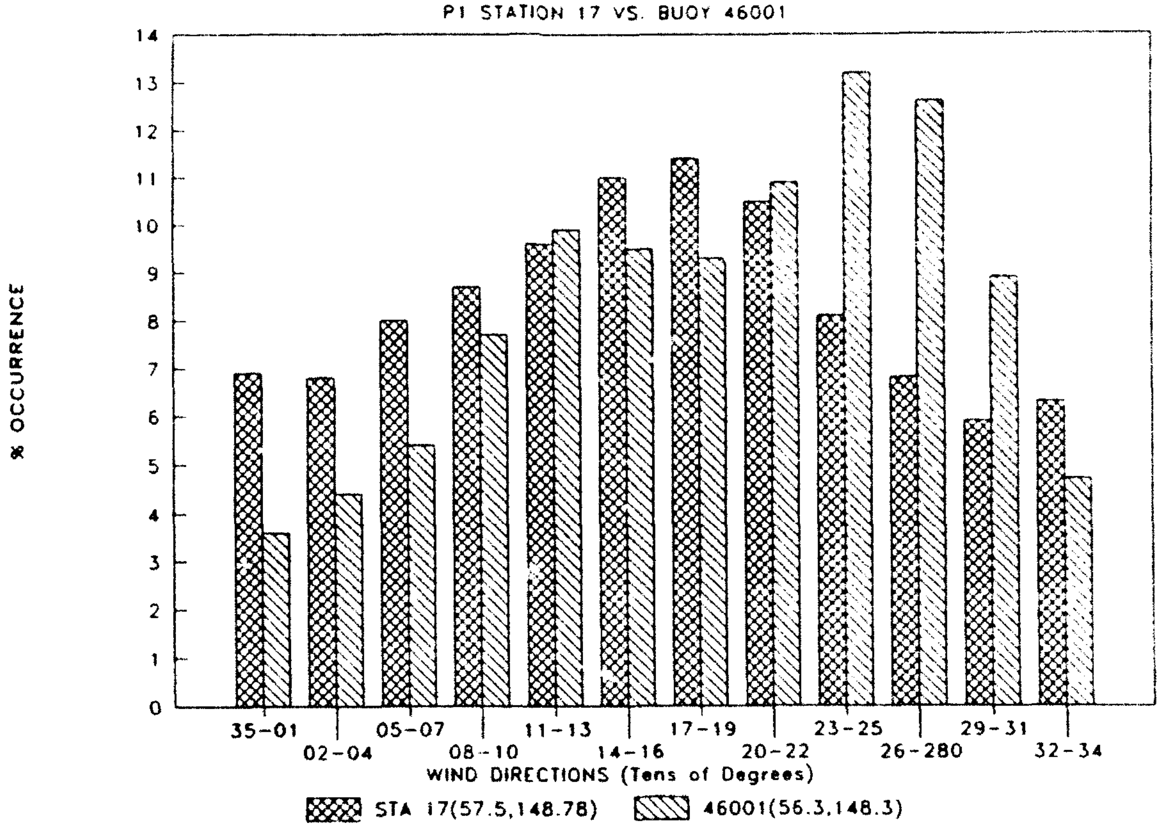
PERCENT OCCURRENCE WIND SPEEDS

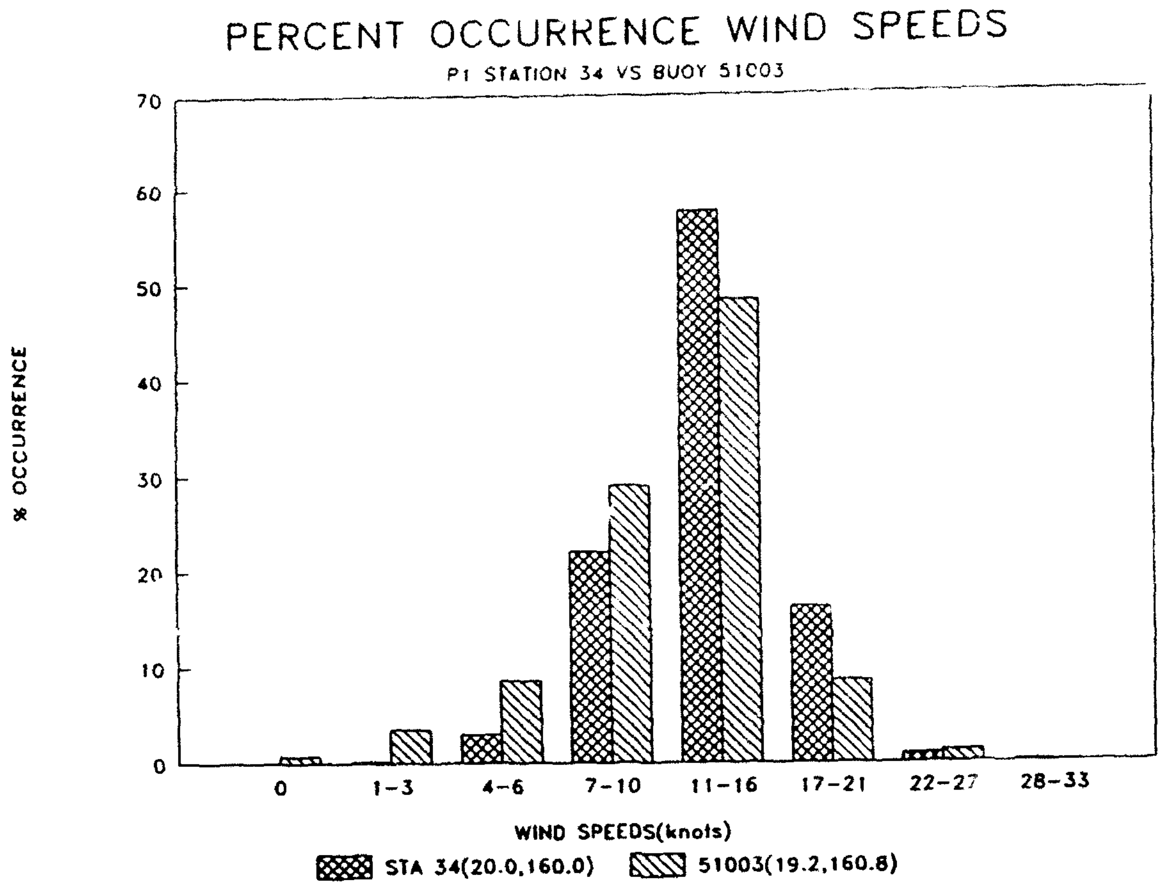
P1 STATION 17 VS. BUOY 46001

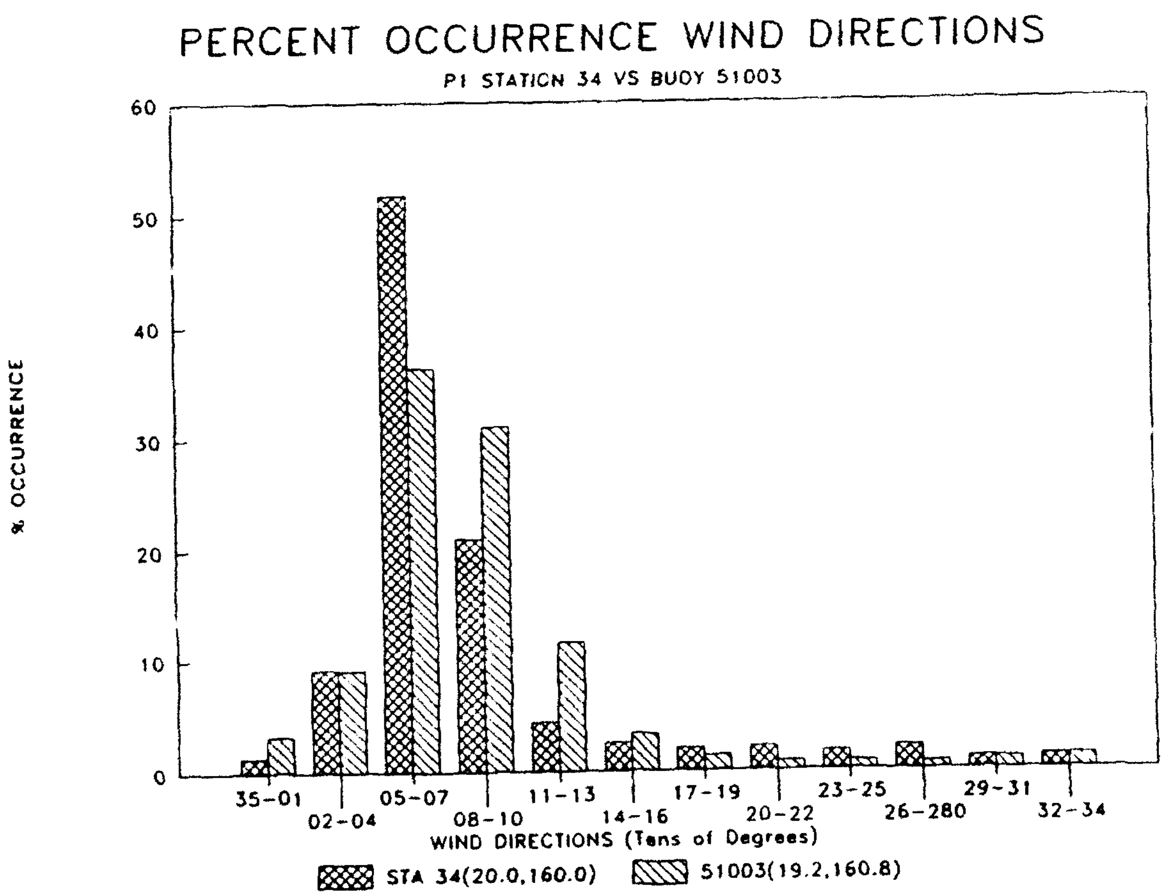


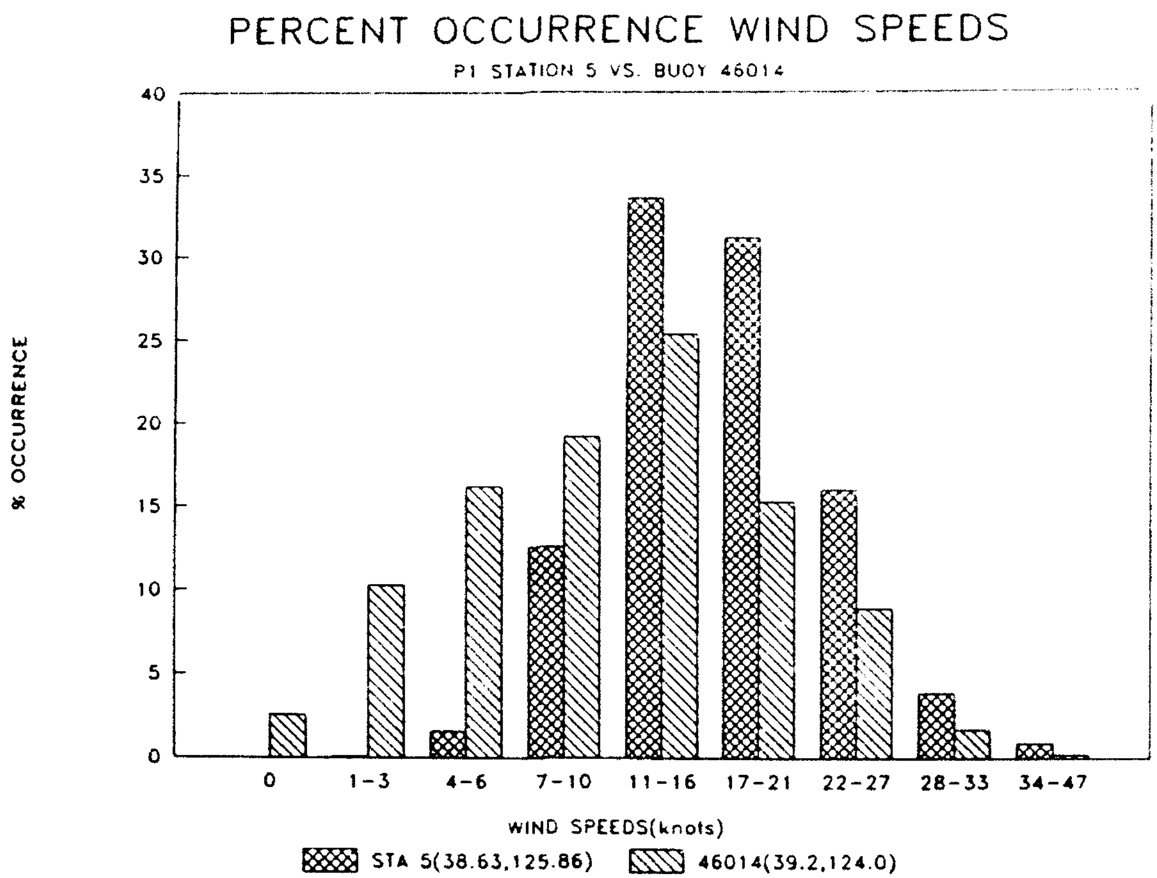
PERCENT OCCURRENCE WIND DIRECTIONS

P1 STATION 17 VS. BUOY 46001

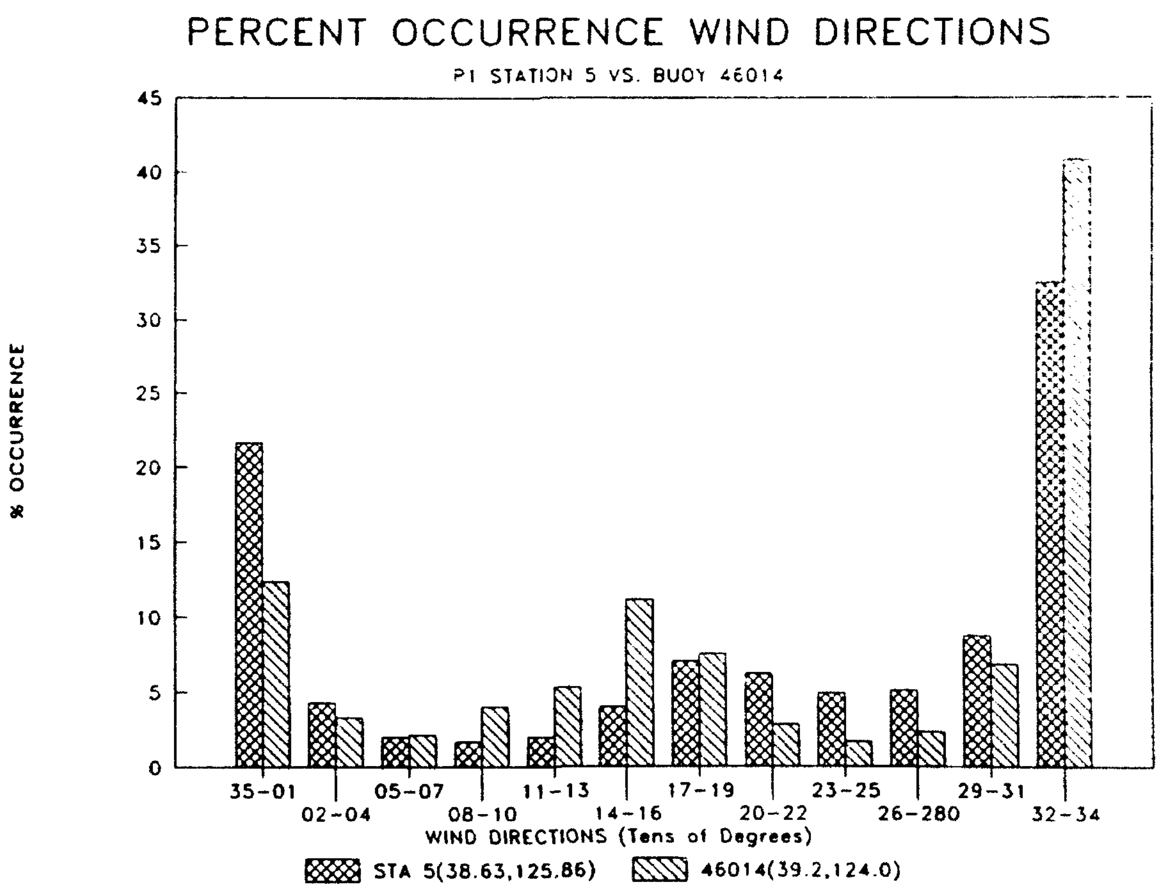



PERCENT OCCURRENCE WIND SPEEDS
P1 STATION 34 VS BUOY 51003
% OCCURRENCE
70
60
50
40
30
20
10
0
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
WIND SPEEDS(knots)
STA 34(20.0,160.0)
51003(19.2,160.8)

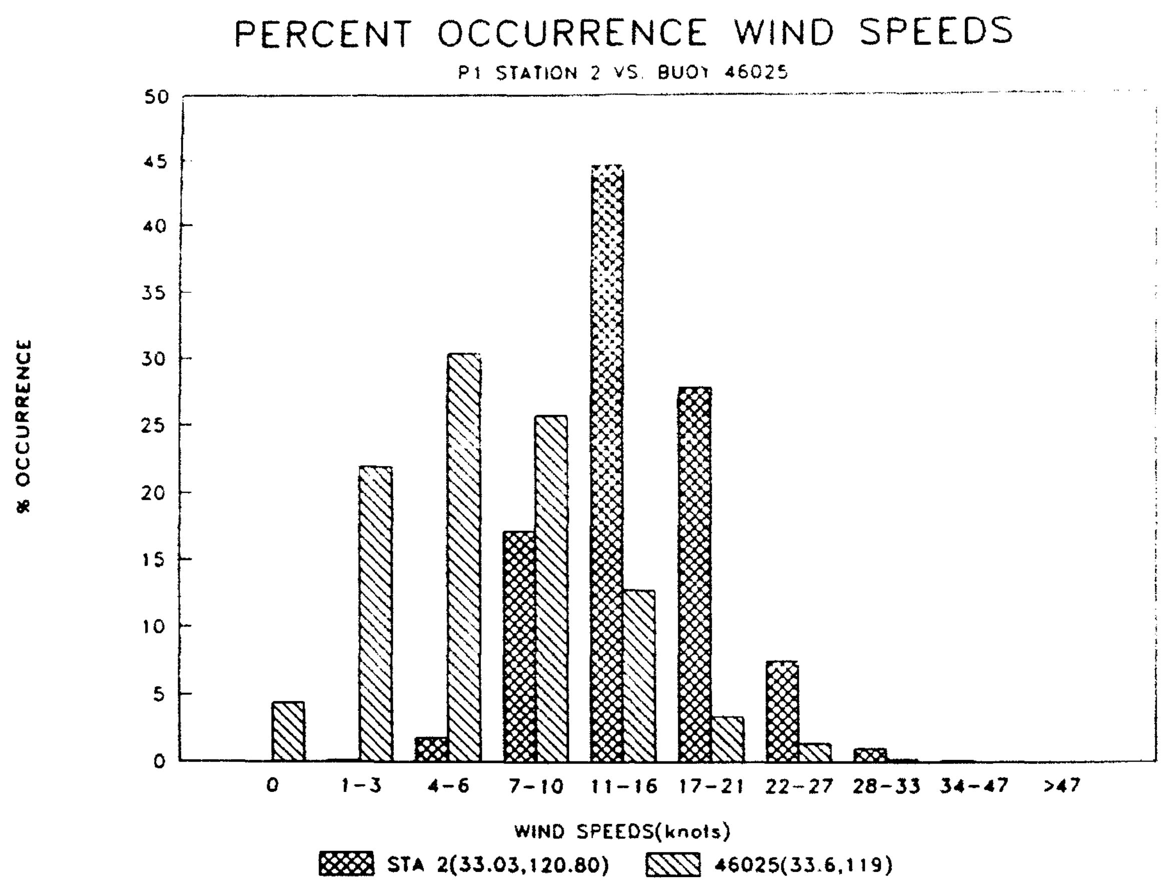

PERCENT OCCURRENCE WIND DIRECTIONS
P1 STATION 34 VS BUOY 51003
% OCCURRENCE
60
50
40
30
20
10
0
35-01
02-04
05-07
08-10
11-13
14-16
17-19
20-22
23-25
26-280
29-31
32-34
WIND DIRECTIONS (Tens of Degrees)
STA 34(20.0,160.0)
51003(19.2,160.8)

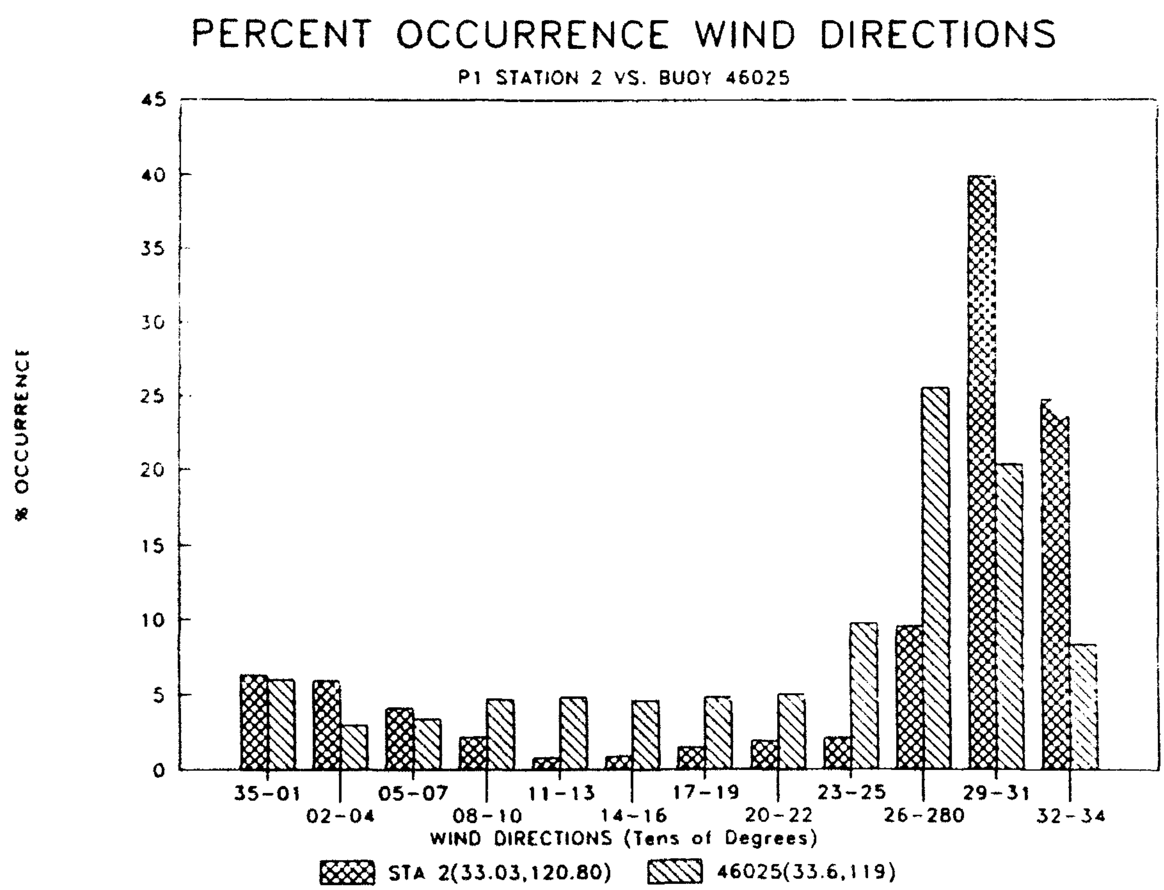


PERCENT OCCURRENCE WIND SPEEDS
P1 STATION 5 VS. BUOY 46014
% OCCURRENCE
40
35
30
25
20
15
10
5
0
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
WIND SPEEDS(knots)
STA 5(38.63,125.86)
46014(39.2,124.0)

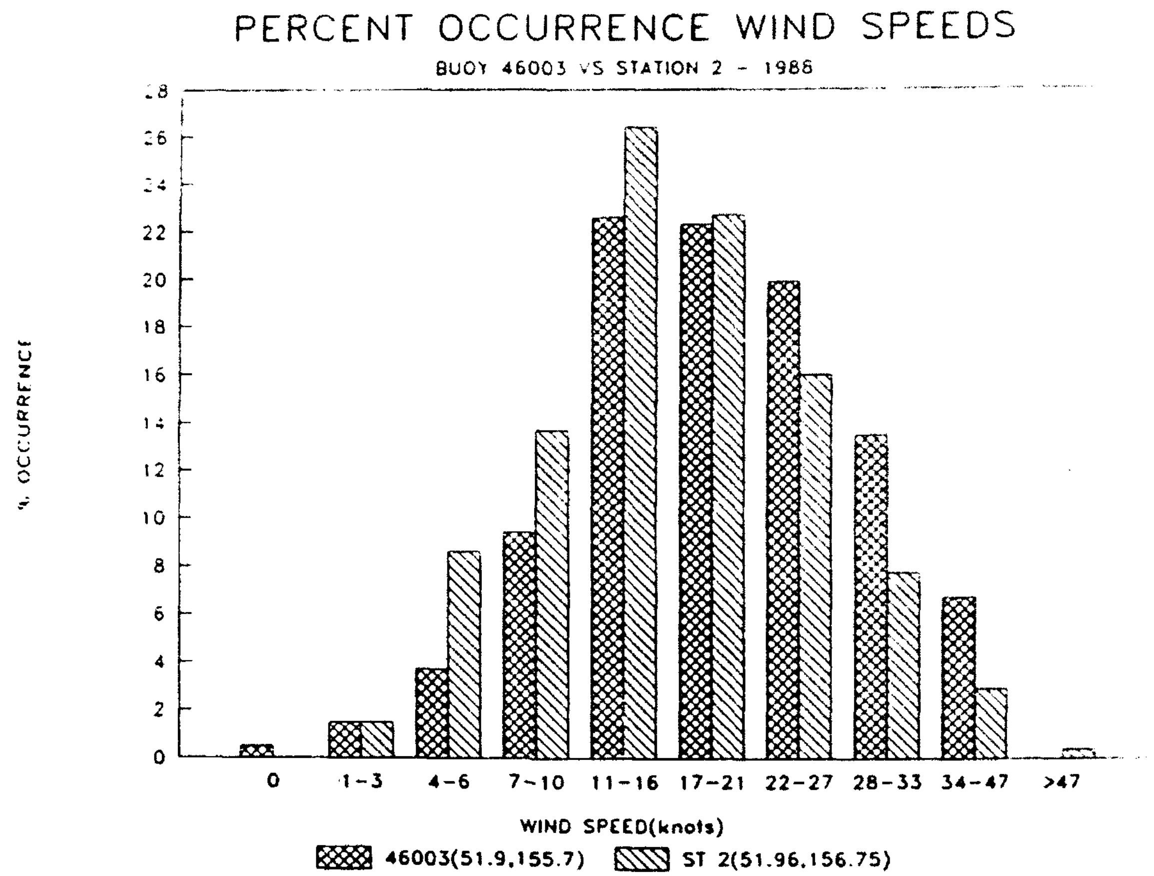


PERCENT OCCURRENCE WIND DIRECTIONS
P1 STATION 5 VS. BUOY 46014
% OCCURRENCE
45
40
35
30
25
20
15
10
5
0
35-01
02-04
05-07
08-10
11-13
14-16
17-19
20-22
23-25
26-280
29-31
32-34
WIND DIRECTIONS (Tens of Degrees)
STA 5(38.63,125.86)
46014(39.2,124.0)

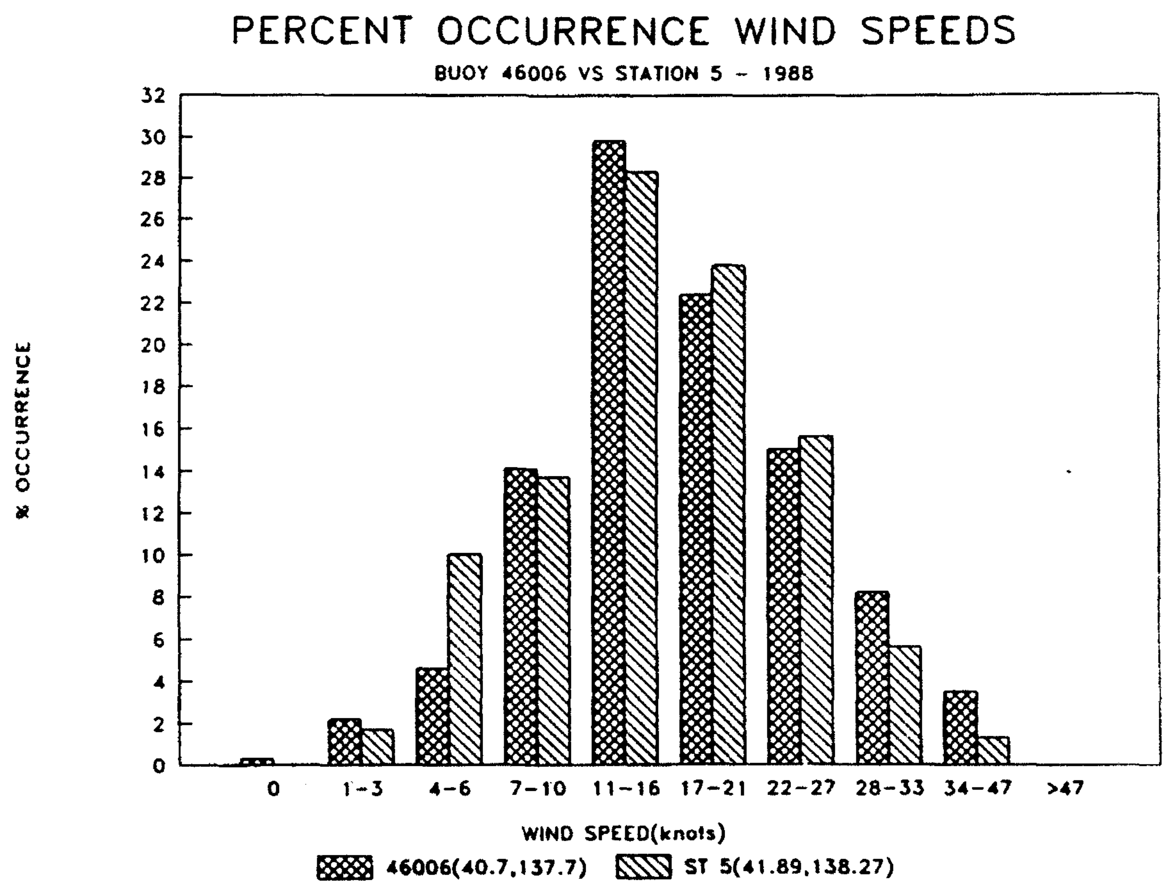

PERCENT OCCURRENCE WIND SPEEDS
P1 STATION 2 VS. BUOY 46025
% OCCURRENCE
50
45
40
35
30
25
20
15
10
5
0
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
>47
WIND SPEEDS(knots)
STA 2(33.03,120.80)
46025(33.6,119)


PERCENT OCCURRENCE WIND DIRECTIONS
P1 STATION 2 VS. BUOY 46025
% OCCURRENCE
45
40
35
30
25
20
15
10
5
0
35-01
02-04
05-07
08-10
11-13
14-16
17-19
20-22
23-25
26-280
29-31
32-34
WIND DIRECTIONS (Tens of Degrees)
STA 2(33.03,120.80)
46025(33.6,119)

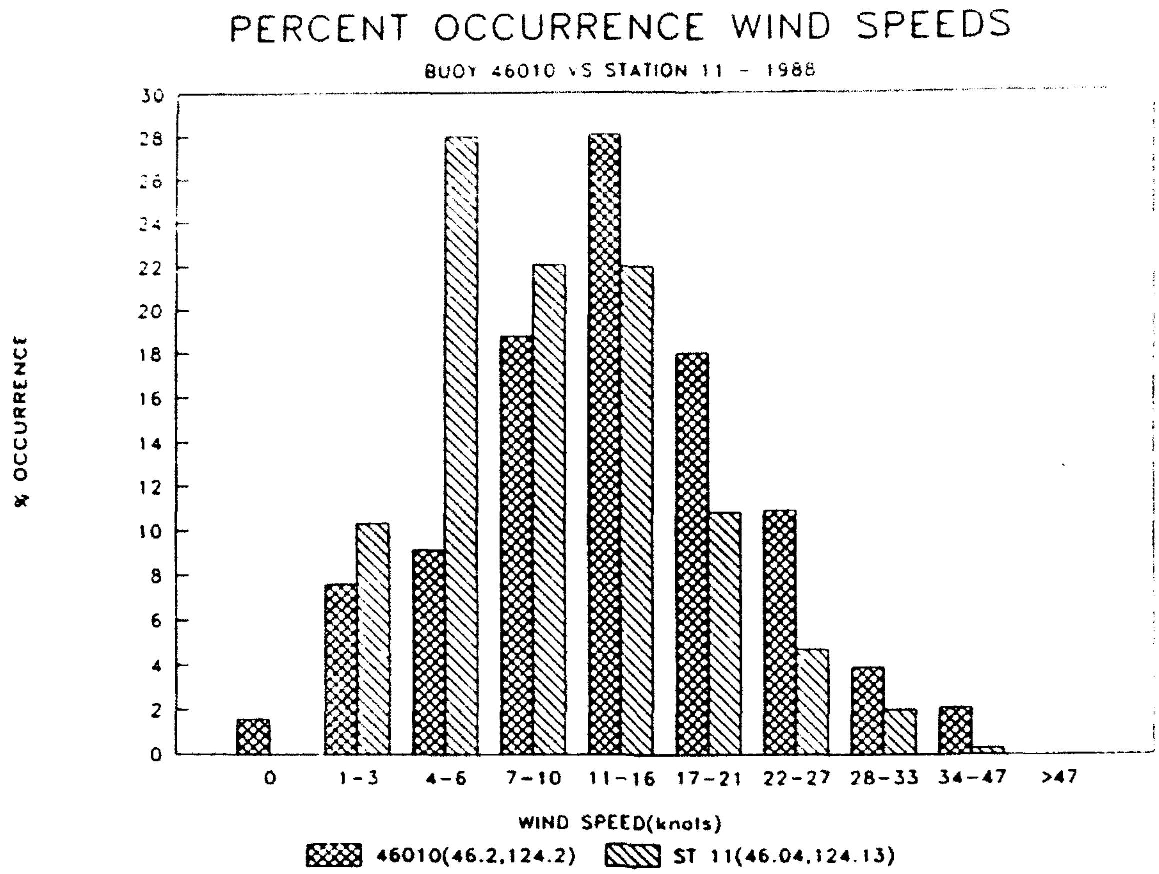
APPENDIX C: DISTRIBUTIONS OF WIS AND MEASURED WIND SPEED, DIRECTION, WAVE HEIGHT, AND PEAK PERIOD AT SELECTED BUOY SITES FOR 1988

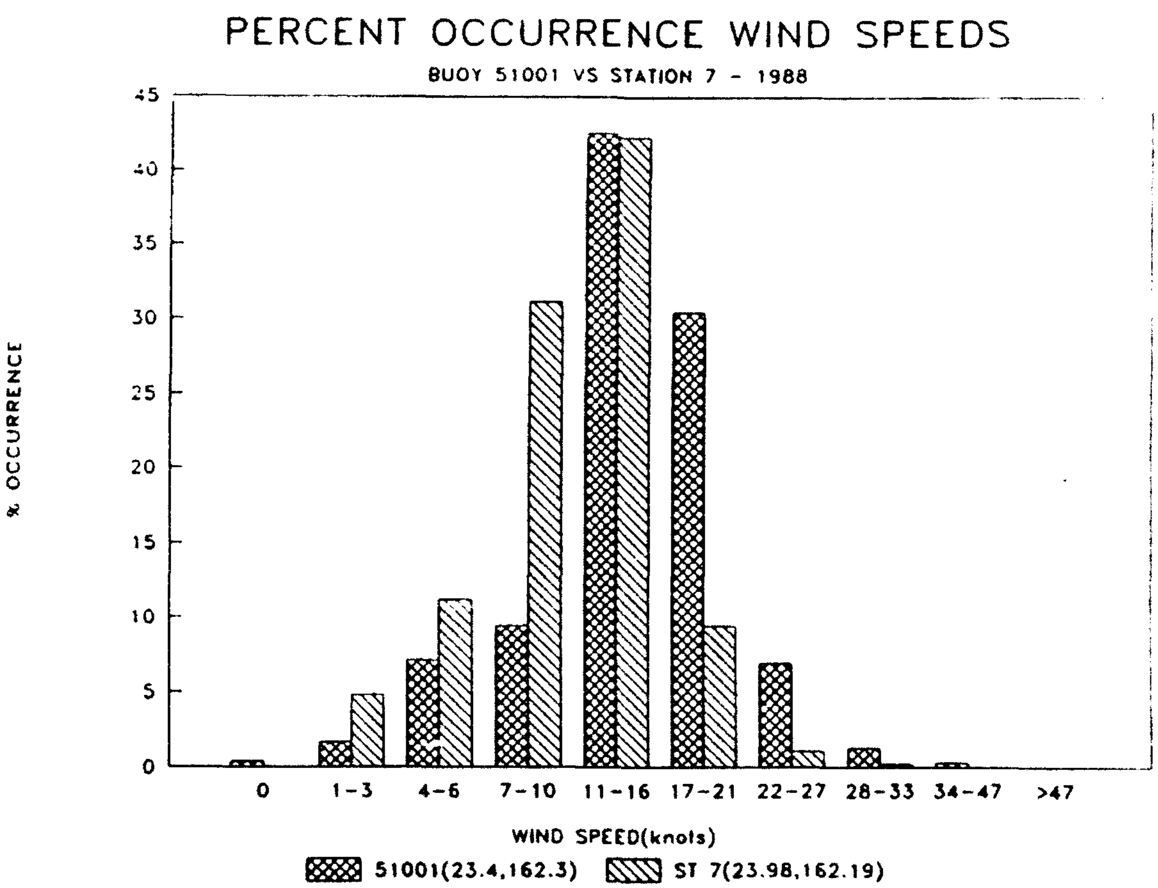


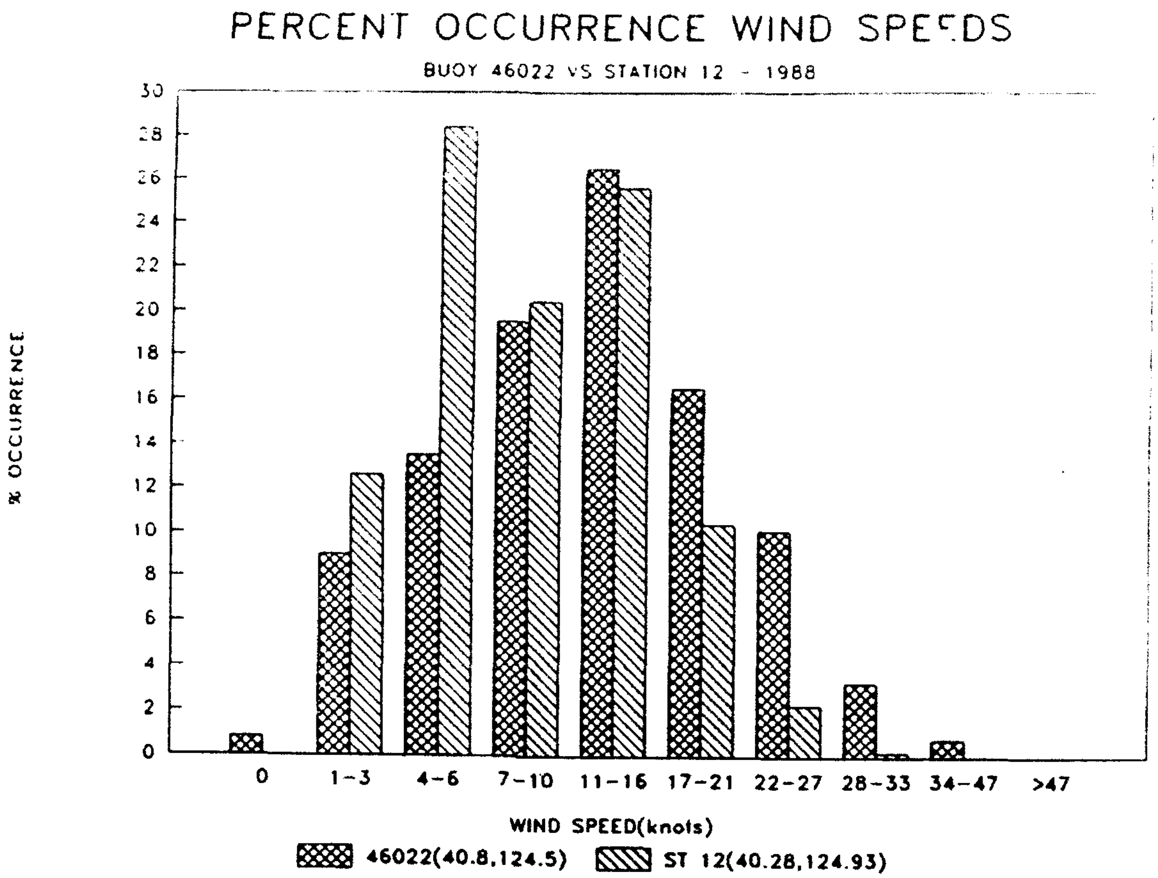
PERCENT OCCURRENCE WIND SPEEDS
BUOY 46003 VS STATION 2 - 1988
% OCCURRENCE
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
>47
WIND SPEED(knots)
46003(51.9,155.7)
ST 2(51.96,156.75)

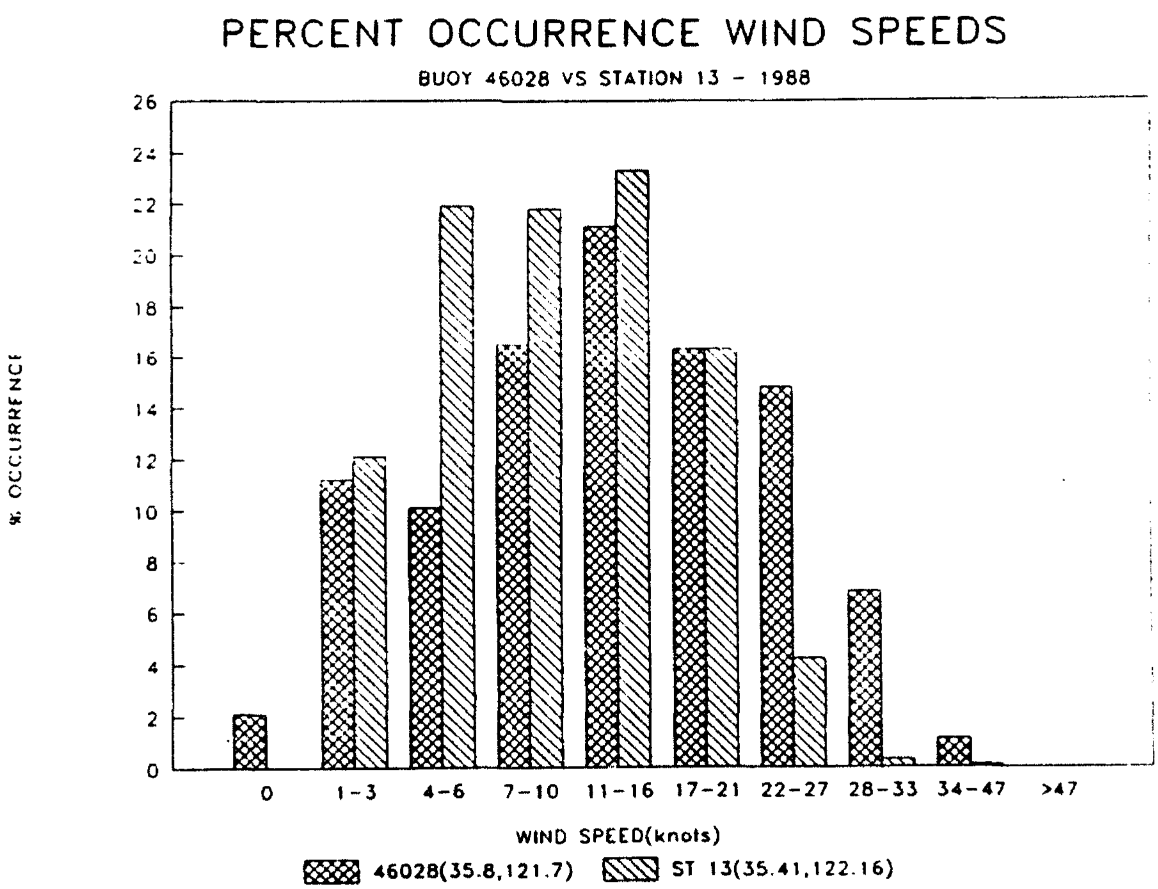


PERCENT OCCURRENCE WIND SPEEDS
BUOY 46006 VS STATION 5 - 1988
% OCCURRENCE
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
>47
WIND SPEED(knots)
46006(40.7,137.7)
ST 5(41.89,138.27)


PERCENT OCCURRENCE WIND SPEEDS
BUOY 46010 VS STATION 11 - 1988
% OCCURRENCE
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
>47
WIND SPEED(knots)
46010(46.2,124.2)
ST 11(46.04,124.13)

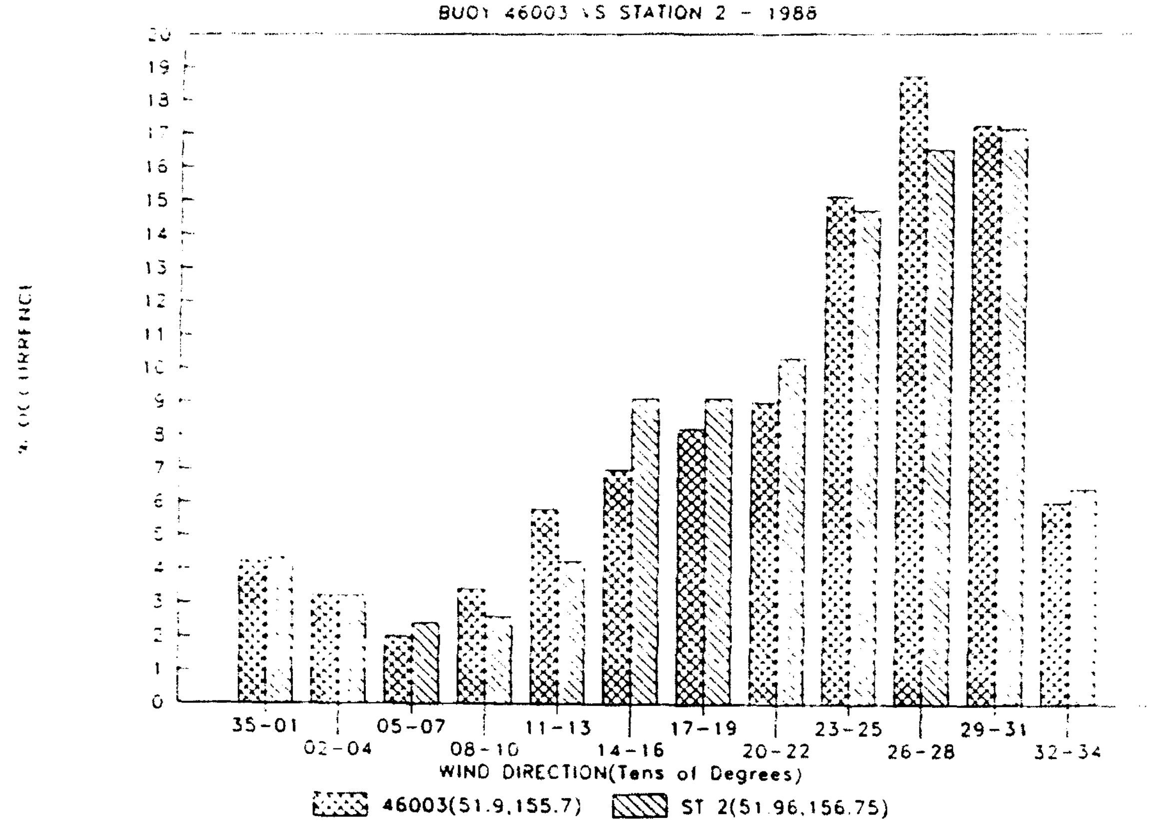

PERCENT OCCURRENCE WIND SPEEDS
BUOY 51001 VS STATION 7 - 1988
% OCCURRENCE
45
40
35
30
25
20
15
10
5
0
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
>47
WIND SPEED(knots)
51001(23.4,162.3)
ST 7(23.98,162.19)


PERCENT OCCURRENCE WIND SPEEDS
BUOY 46022 VS STATION 12 - 1988
% OCCURRENCE
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
>47
WIND SPEED(knots)
46022(40.8,124.5)
ST 12(40.28,124.93)


PERCENT OCCURRENCE WIND SPEEDS
BUOY 46028 VS STATION 13 - 1988
% OCCURRENCE
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1-3
4-6
7-10
11-16
17-21
22-27
28-33
34-47
>47
WIND SPEED(knots)
46028(35.8,121.7)
ST 13(35.41,122.16)

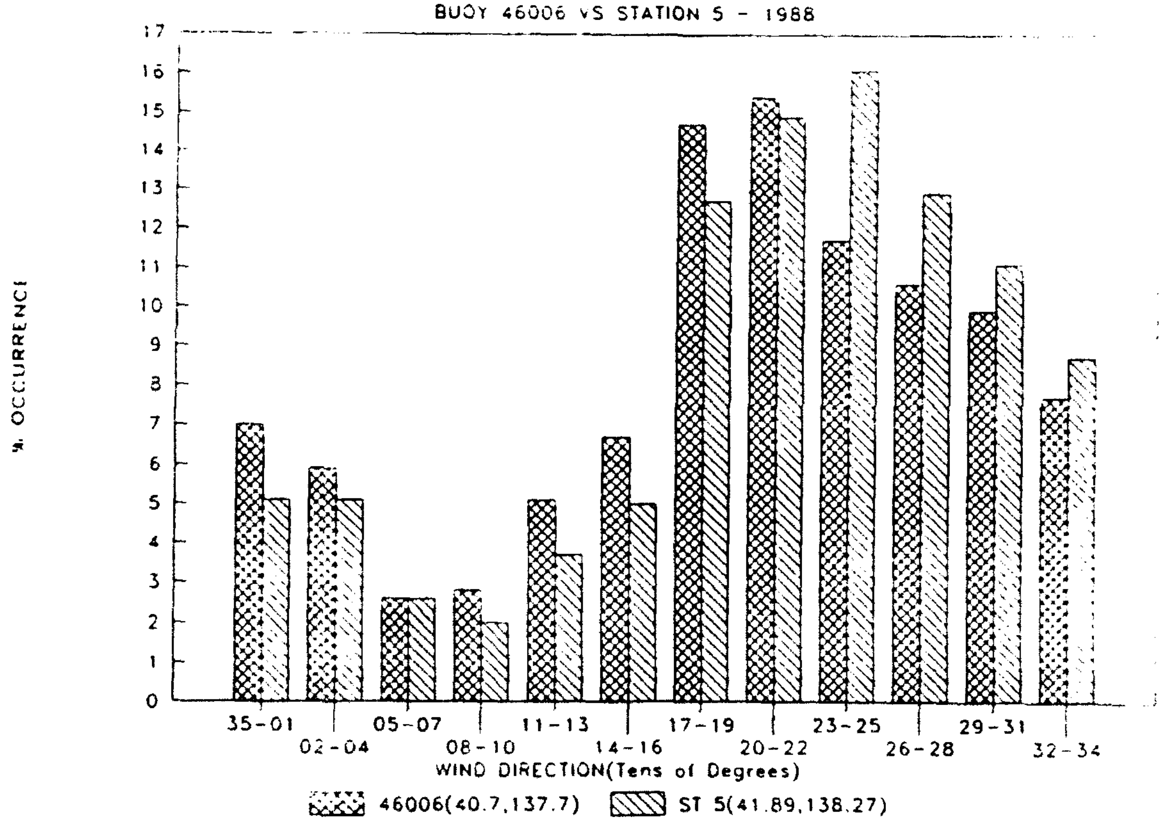
PERCENT OCCURRENCE WIND DIRECTIONS

BUOY 46003 VS STATION 2 - 1988



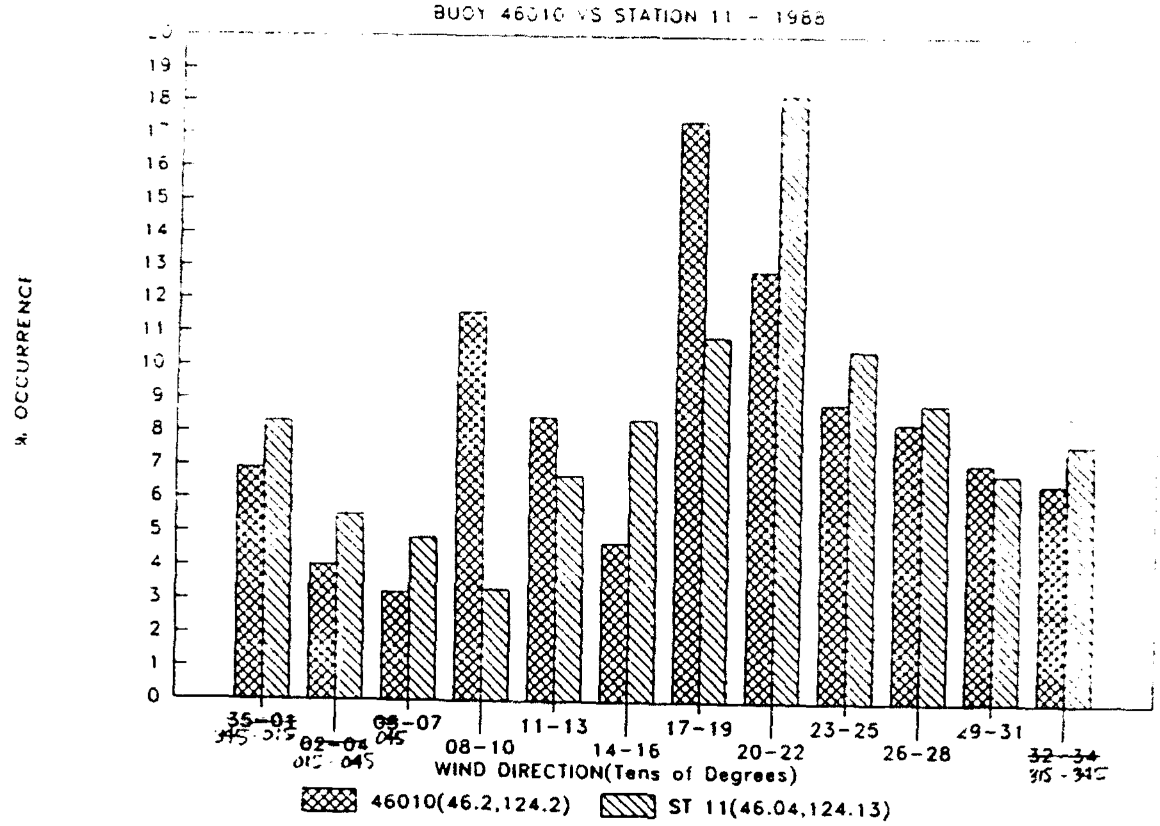
PERCENT OCCURRENCE WIND DIRECTIONS

BUOY 46006 VS STATION 5 - 1988



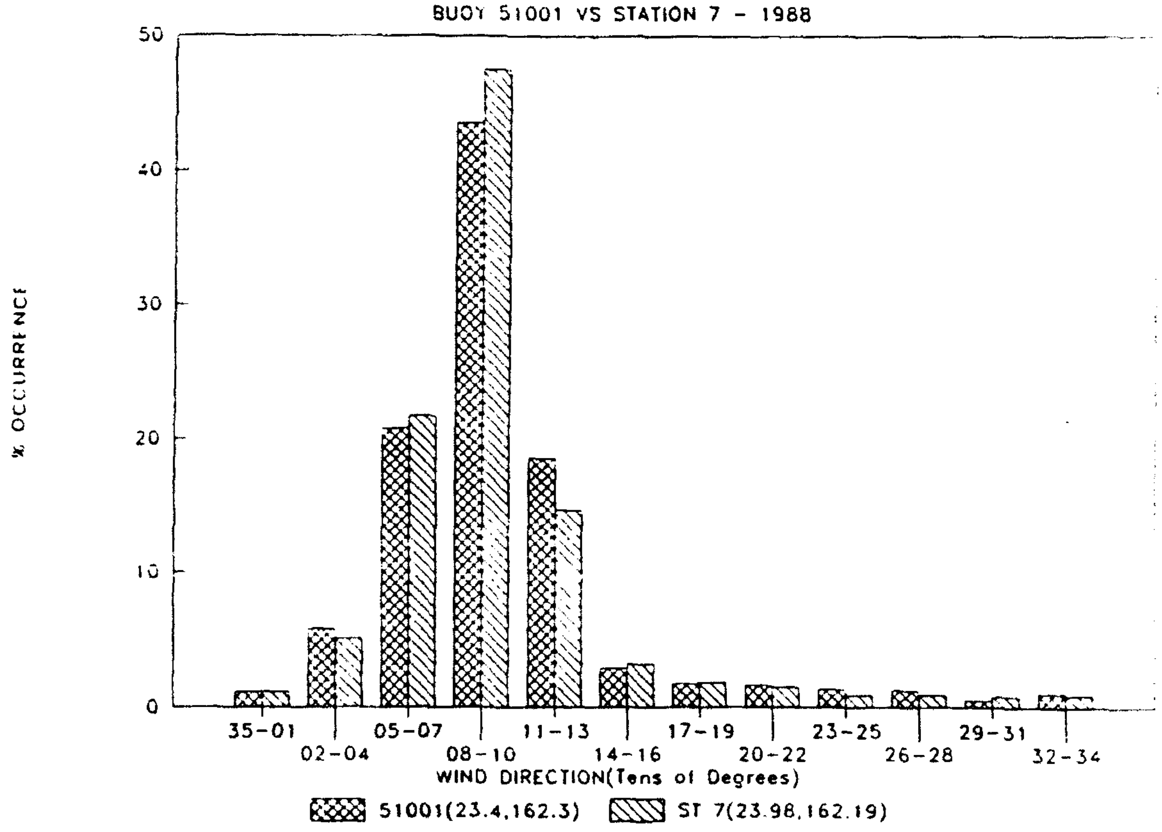
PERCENT OCCURRENCE WIND DIRECTIONS

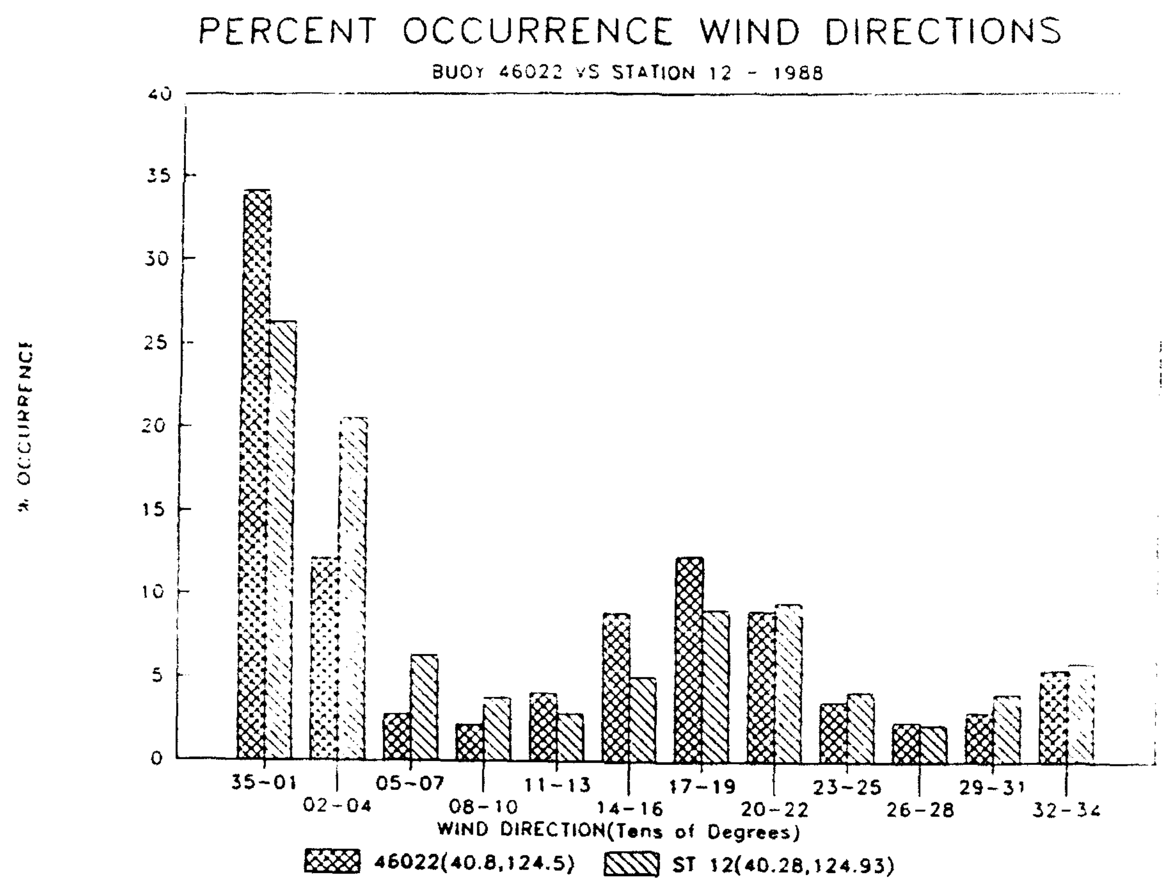
BUOY 46010 VS STATION 11 - 1988



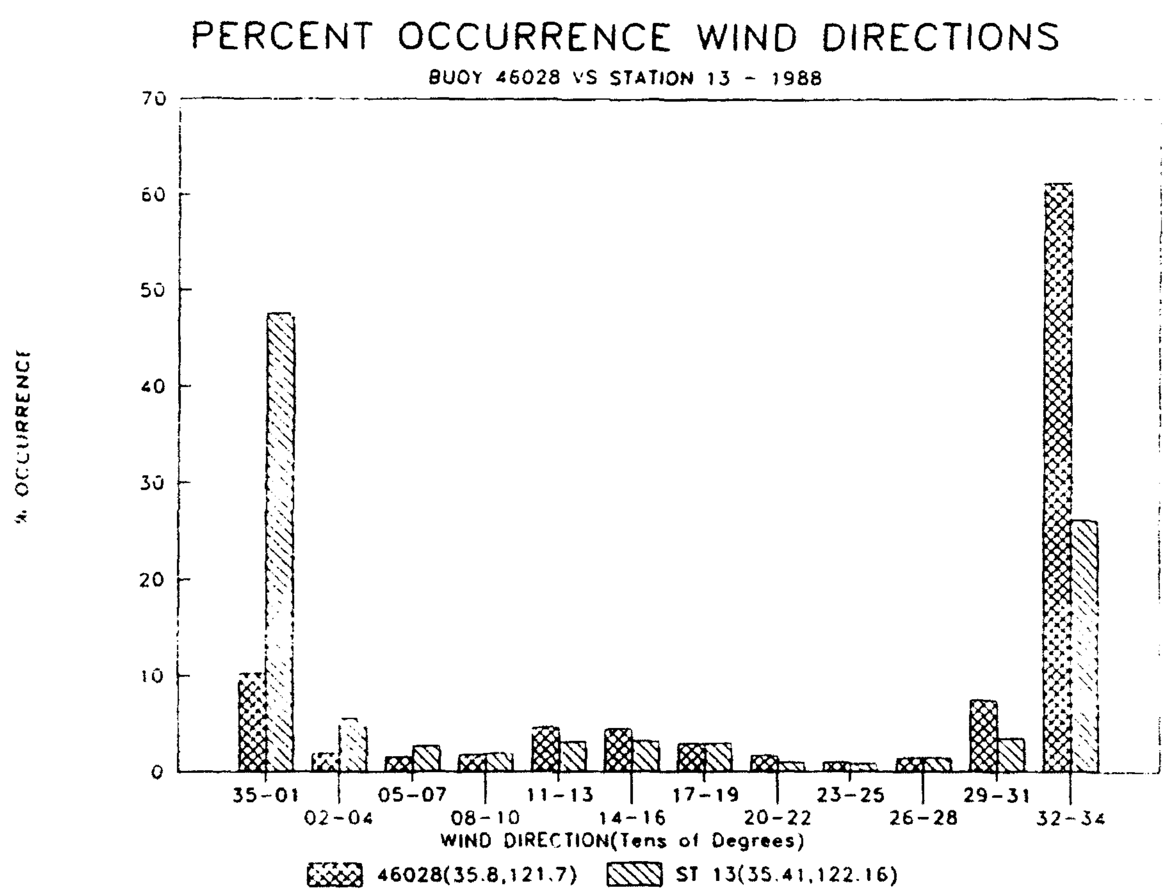
PERCENT OCCURRENCE WIND DIRECTIONS

BUOY 51001 VS STATION 7 - 1988

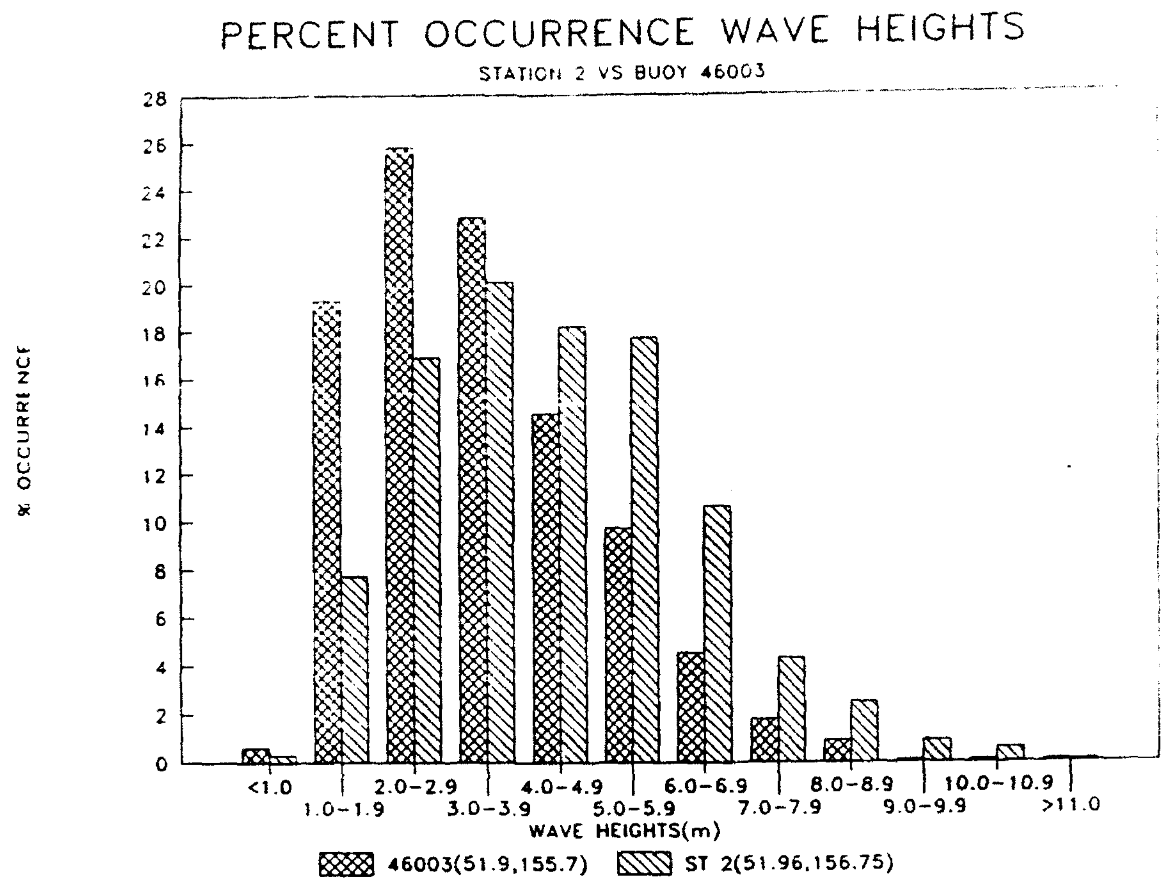


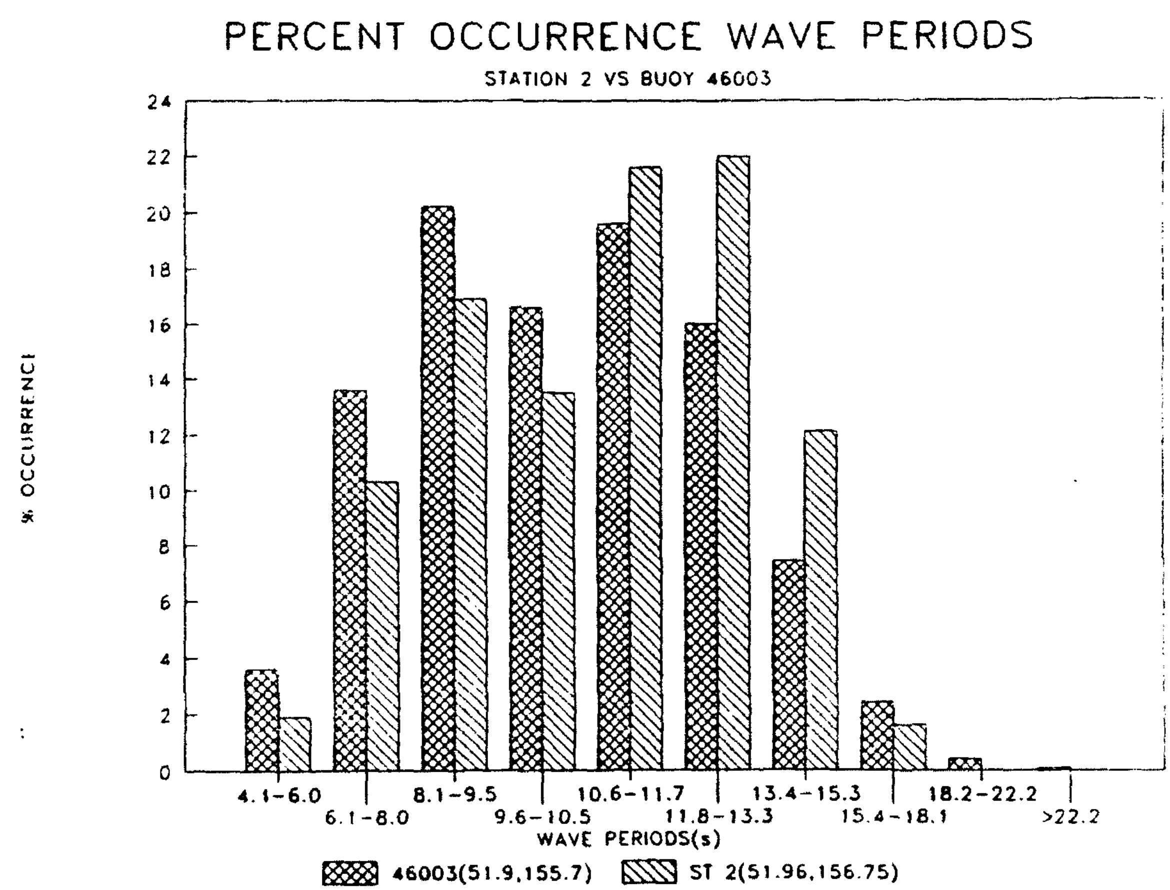


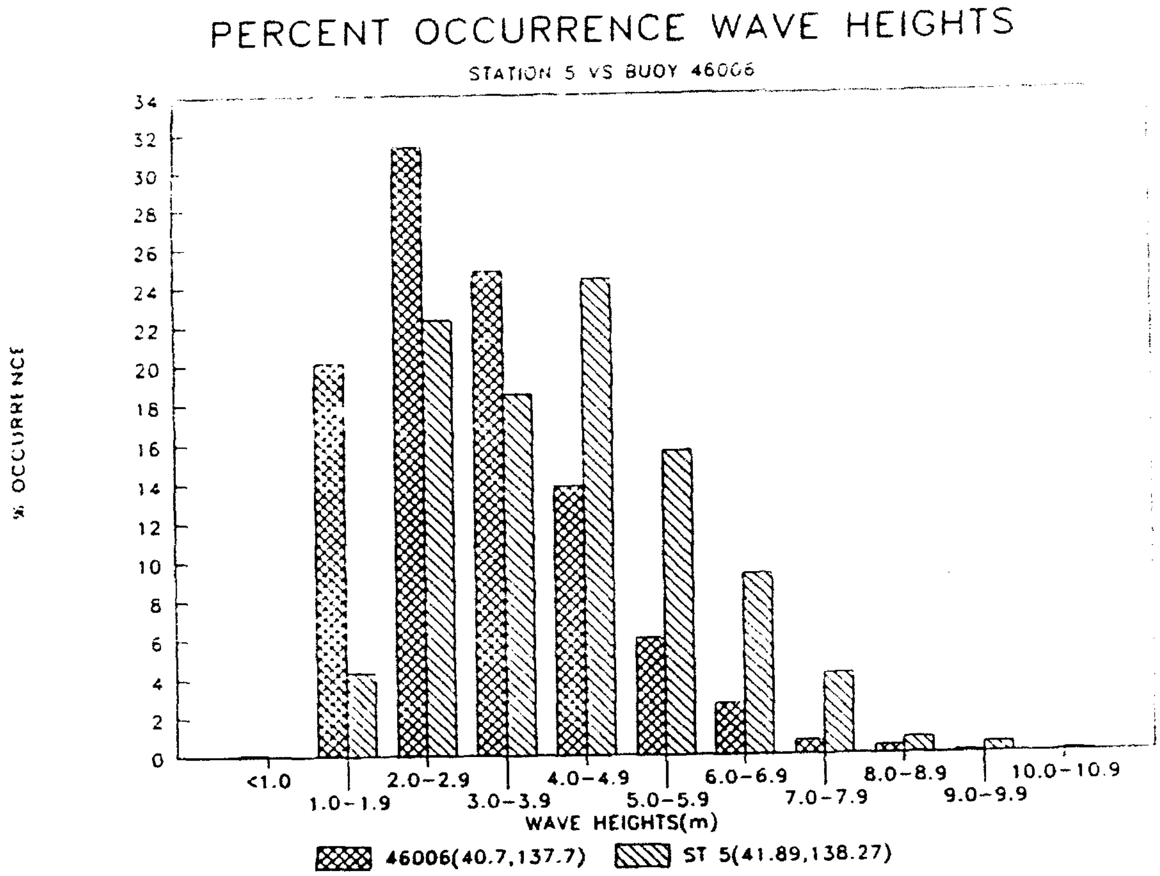
PERCENT OCCURRENCE WIND DIRECTIONS
BUOY 46022 VS STATION 12 - 1988
% OCCURRENCE
0
5
10
15
20
25
30
35
40
35-01
02-04
05-07
08-10
11-13
14-16
17-19
20-22
23-25
26-28
29-31
32-34
WIND DIRECTION(Tens of Degrees)
46022(40.8,124.5)
ST 12(40.28,124.93)

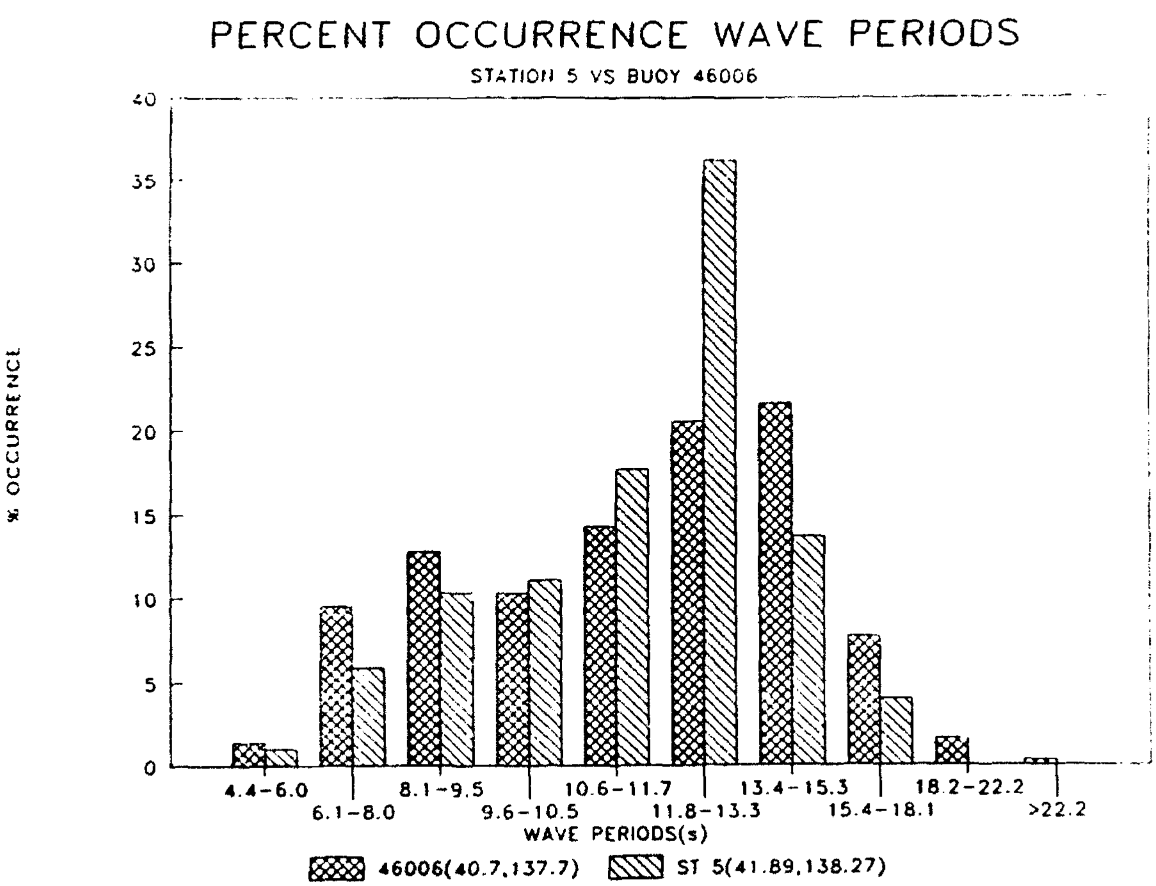


PERCENT OCCURRENCE WIND DIRECTIONS
BUOY 46028 VS STATION 13 - 1988
% OCCURRENCE
0
10
20
30
40
50
60
70
35-01
02-04
05-07
08-10
11-13
14-16
17-19
20-22
23-25
26-28
29-31
32-34
WIND DIRECTION(Tens of Degrees)
46028(35.8,121.7)
ST 13(35.41,122.16)


PERCENT OCCURRENCE WAVE HEIGHTS
STATION 2 VS BUOY 46003
% OCCURRENCE
WAVE HEIGHTS(m)
<1.0
1.0-1.9
2.0-2.9
3.0-3.9
4.0-4.9
5.0-5.9
6.0-6.9
7.0-7.9
8.0-8.9
9.0-9.9
10.0-10.9
>11.0
46003(51.9,155.7)
ST 2(51.96,156.75)

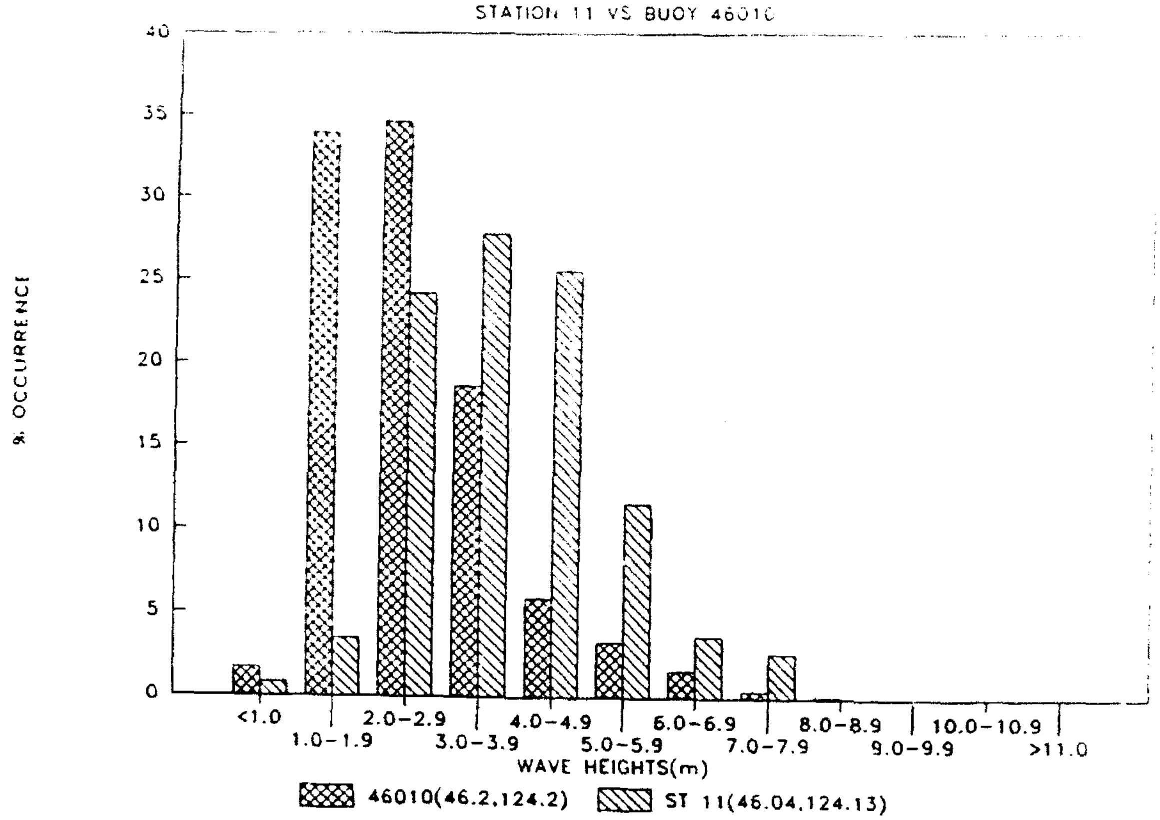

PERCENT OCCURRENCE WAVE PERIODS
STATION 2 VS BUOY 46003
% OCCURRENCE
WAVE PERIODS(s)
4.1-6.0
6.1-8.0
8.1-9.5
9.6-10.5
10.6-11.7
11.8-13.3
13.4-15.3
15.4-18.1
18.2-22.2
>22.2
46003(51.9,155.7)
ST 2(51.96,156.75)


PERCENT OCCURRENCE WAVE HEIGHTS
STATION 5 VS BUOY 46006
% OCCURRENCE
<1.0
1.0-1.9
2.0-2.9
3.0-3.9
4.0-4.9
5.0-5.9
6.0-6.9
7.0-7.9
8.0-8.9
9.0-9.9
10.0-10.9
WAVE HEIGHTS(m)
46006(40.7,137.7)
ST 5(41.89,138.27)


PERCENT OCCURRENCE WAVE PERIODS
STATION 5 VS BUOY 46006
% OCCURRENCE
4.4-6.0
6.1-8.0
8.1-9.5
9.6-10.5
10.6-11.7
11.8-13.3
13.4-15.3
15.4-18.1
18.2-22.2
>22.2
WAVE PERIODS(s)
46006(40.7,137.7)
ST 5(41.89,138.27)

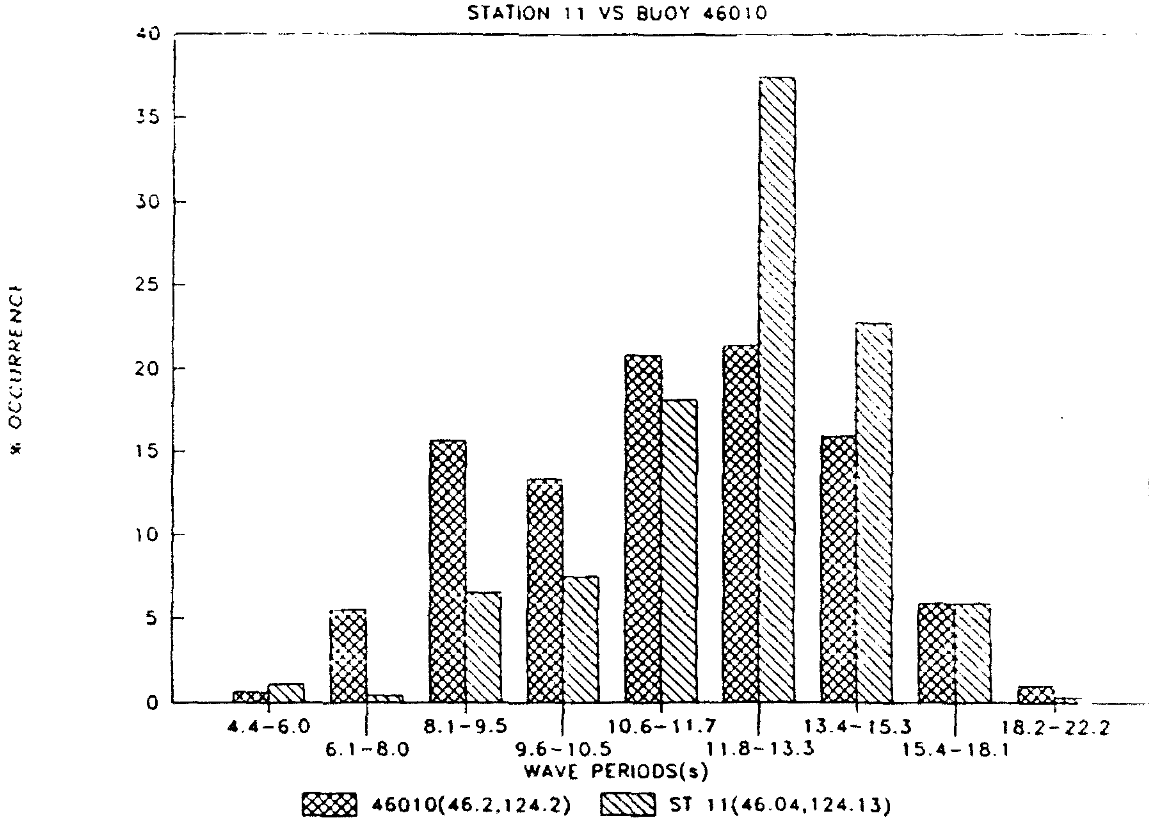
PERCENT OCCURRENCE WAVE HEIGHTS

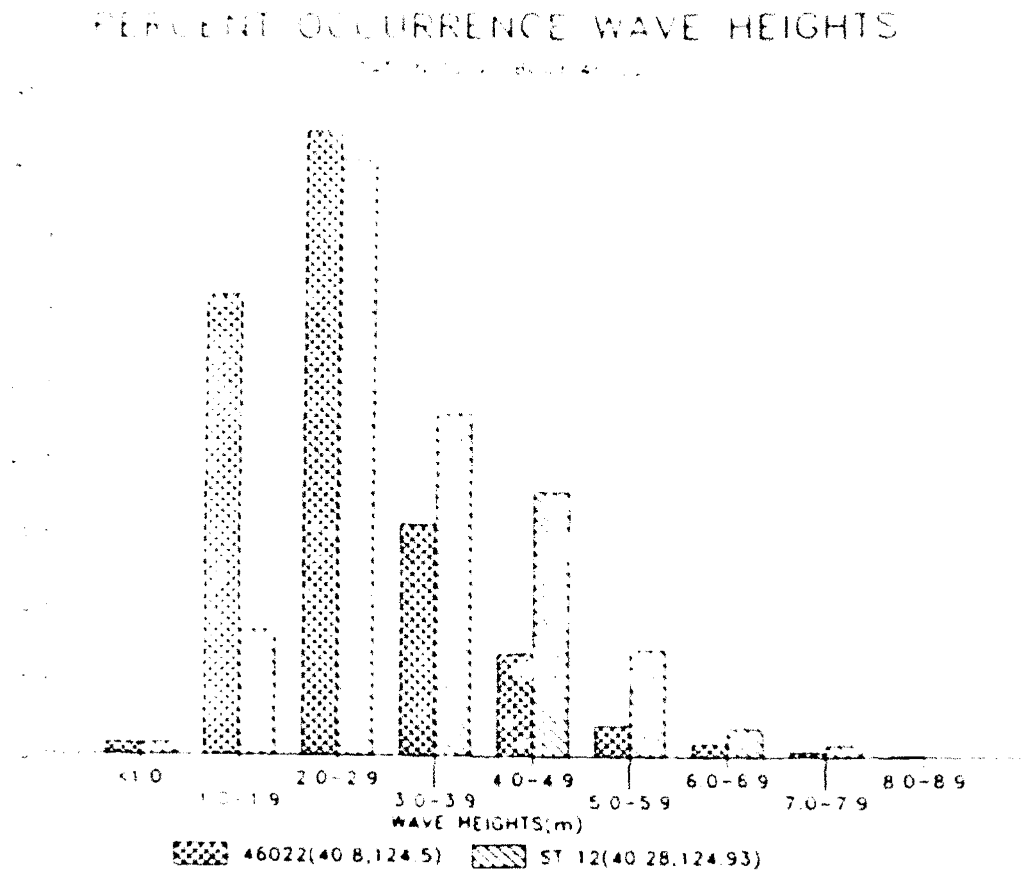
STATION 11 VS BUOY 46010

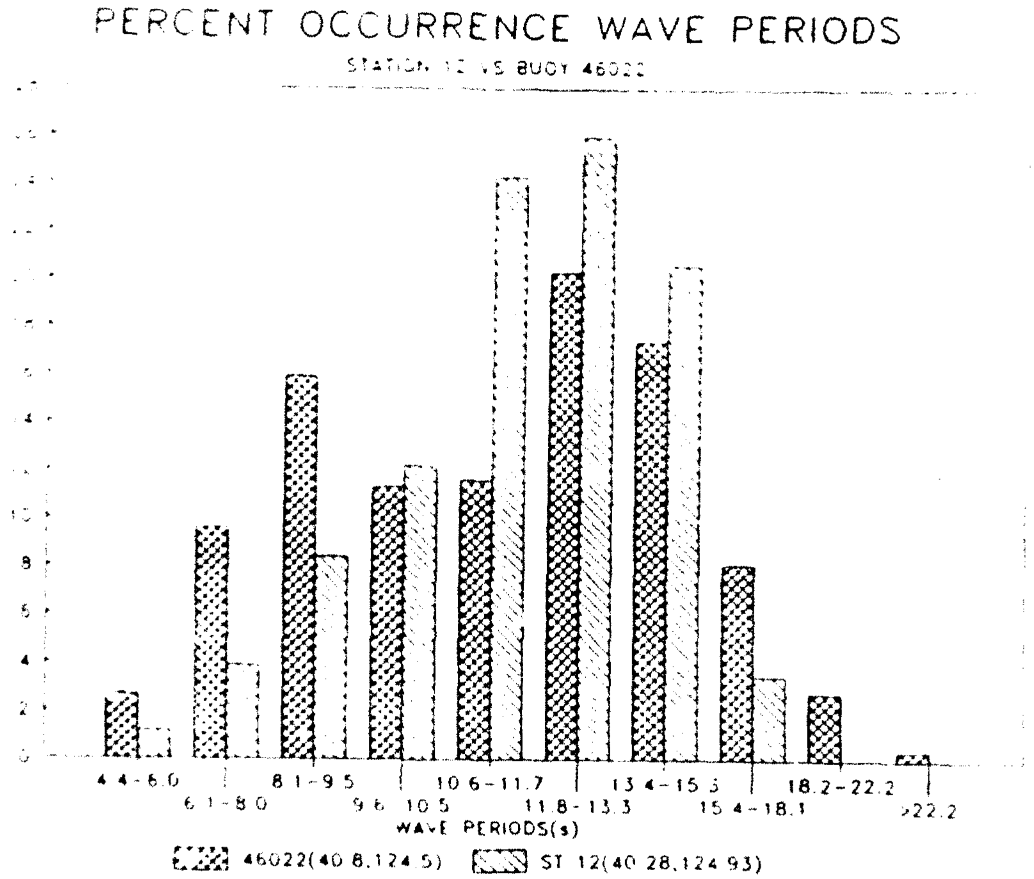


PERCENT OCCURRENCE WAVE PERIODS

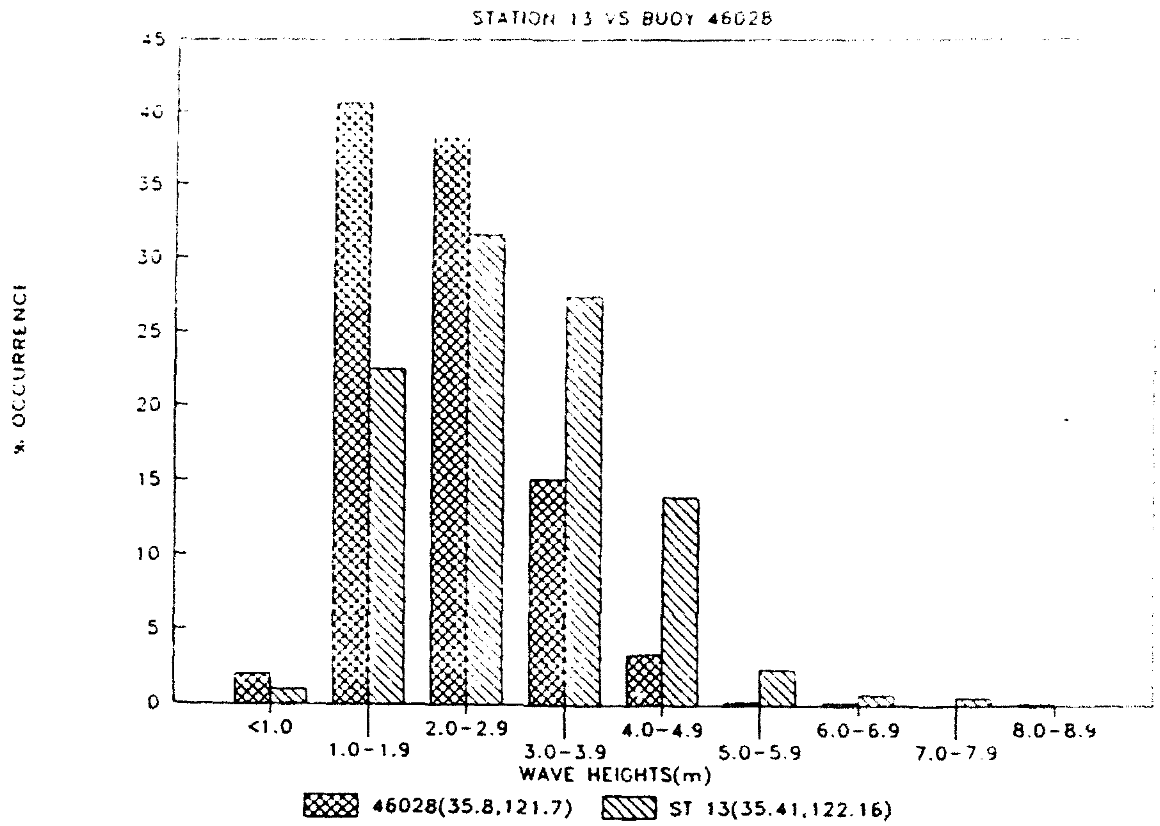
STATION 11 VS BUOY 46010



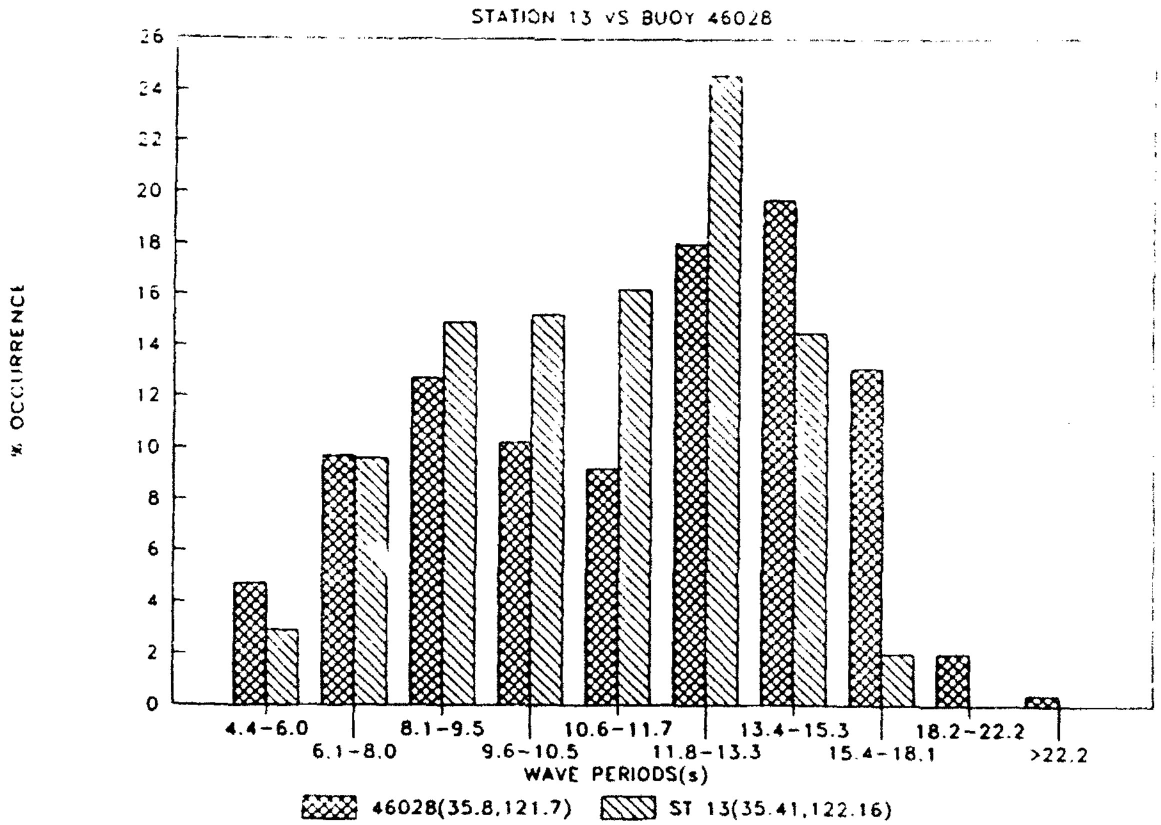

PERCENT OCCURRENCE WAVE HEIGHTS
<1.0
2.0-2.9
3.0-3.9
4.0-4.9
5.0-5.9
6.0-6.9
7.0-7.9
8.0-8.9
WAVE HEIGHTS(m)
46022(40.8,124.5)
ST 12(40.28,124.93)


PERCENT OCCURRENCE WAVE PERIODS
10
8
6
4
2
0
4.4-6.0
6.1-8.0
8.1-9.5
9.6-10.5
10.6-11.7
11.8-13.3
13.4-15.3
15.4-18.1
18.2-22.2
>22.2
WAVE PERIODS(s)
46022(40.8,124.5)
ST 12(40.28,124.93)

PERCENT OCCURRENCE WAVE HEIGHTS

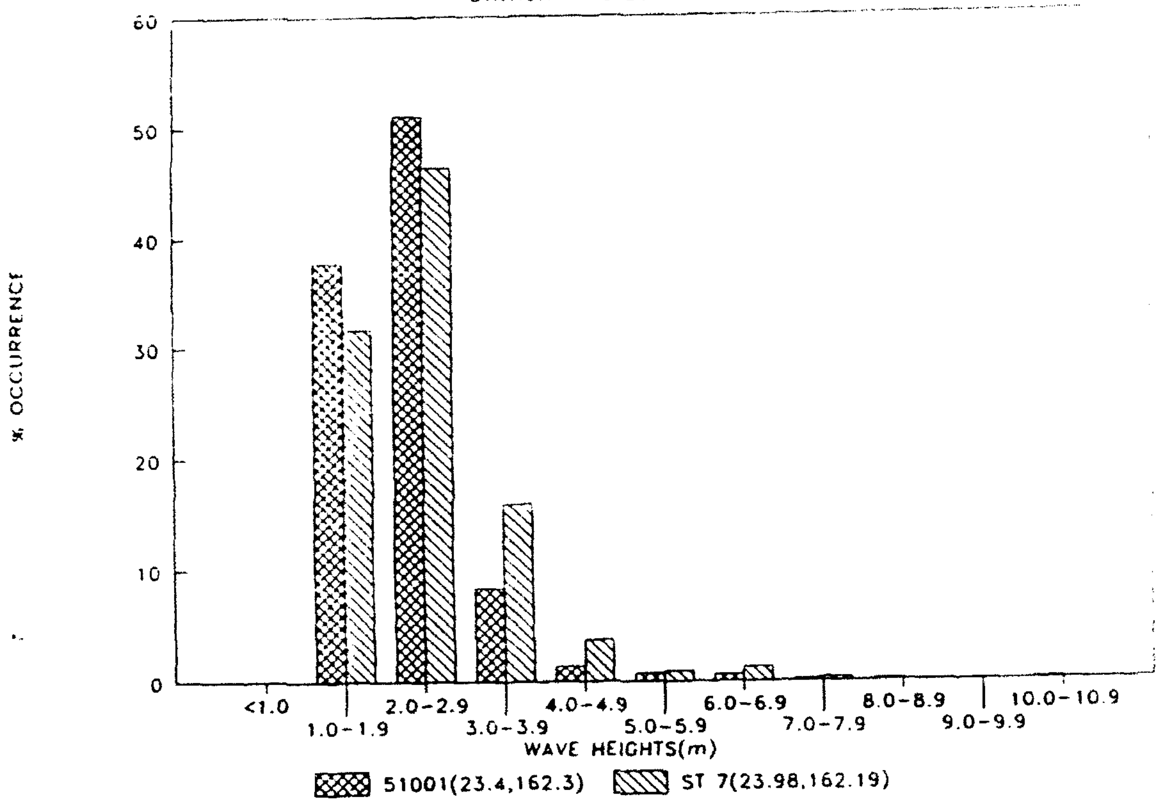


PERCENT OCCURRENCE WAVE PERIODS



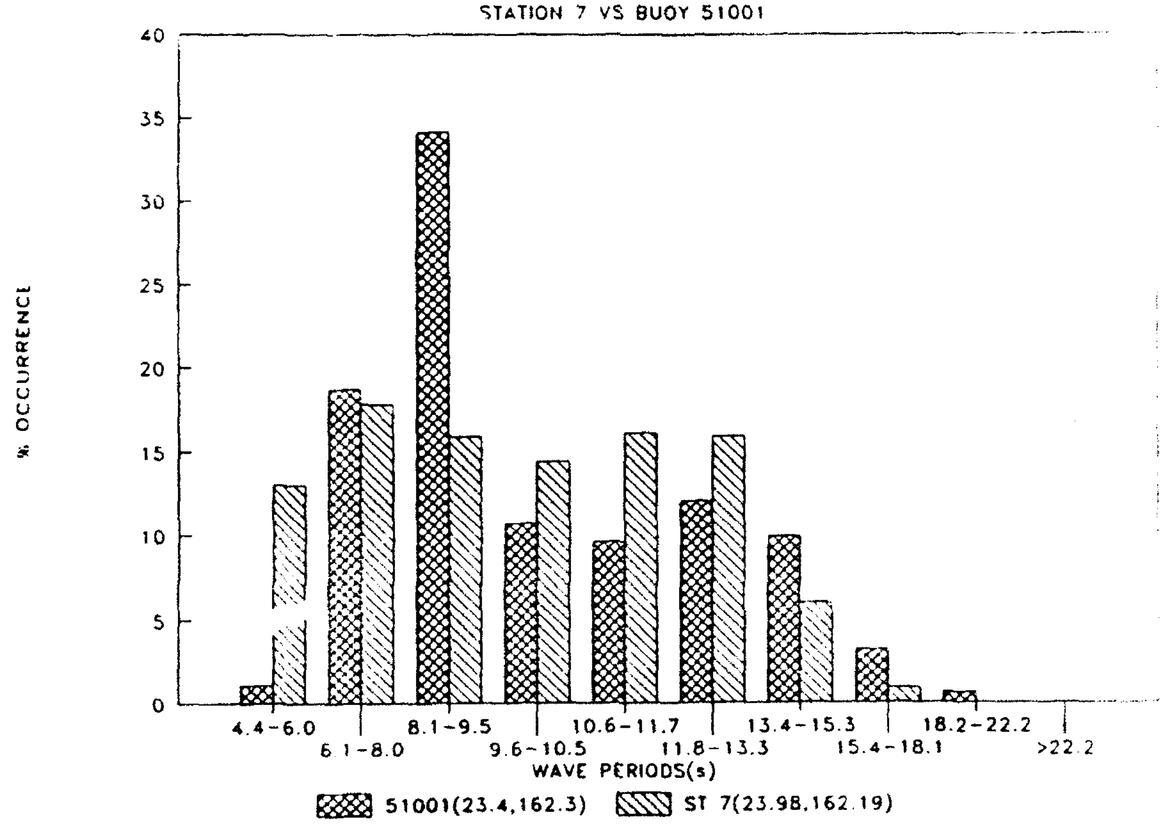
PERCENT OCCURRENCE WAVE HEIGHTS

STATION 7 VS BUOY 51001

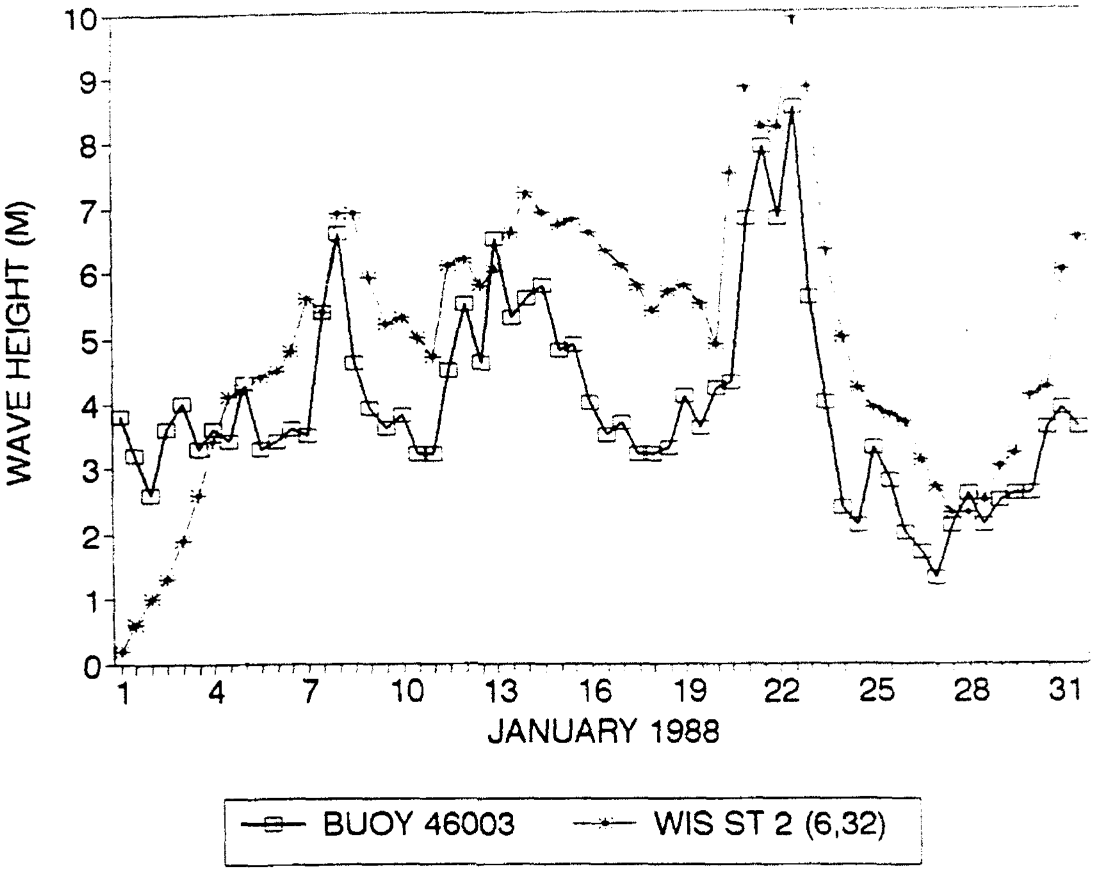


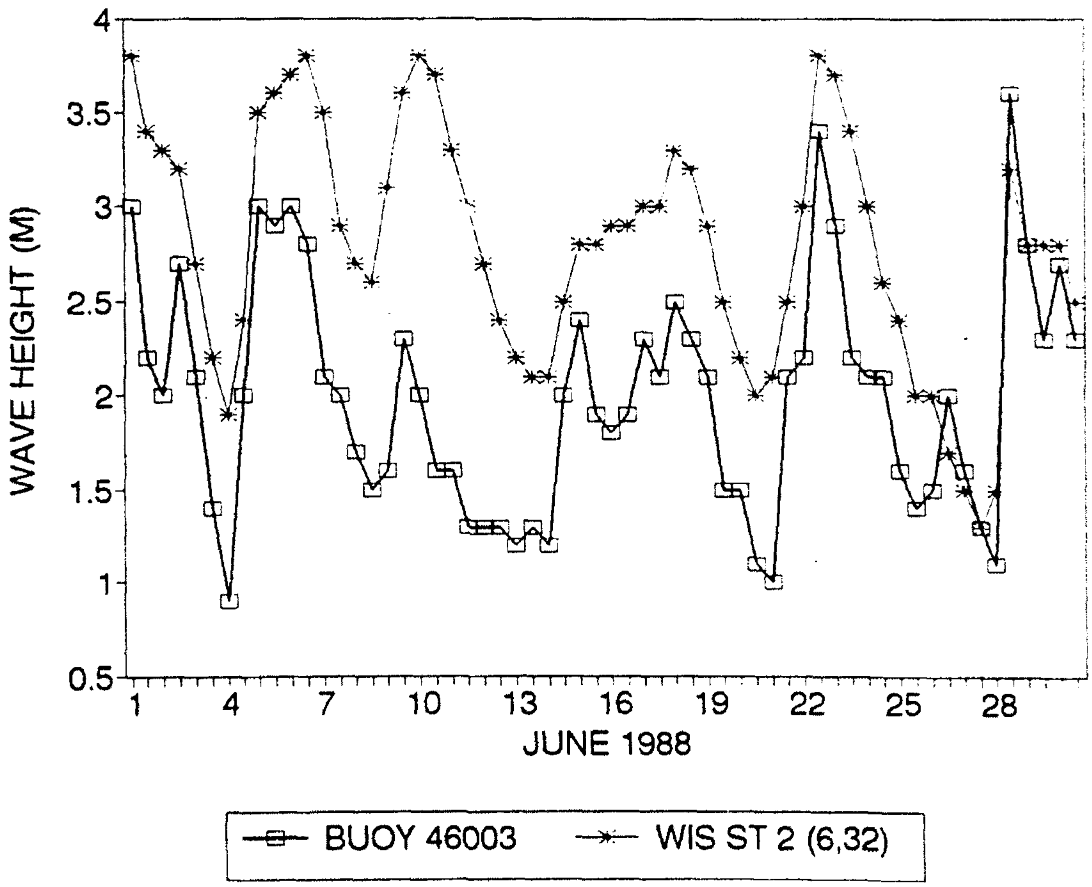
PERCENT OCCURRENCE WAVE PERIODS

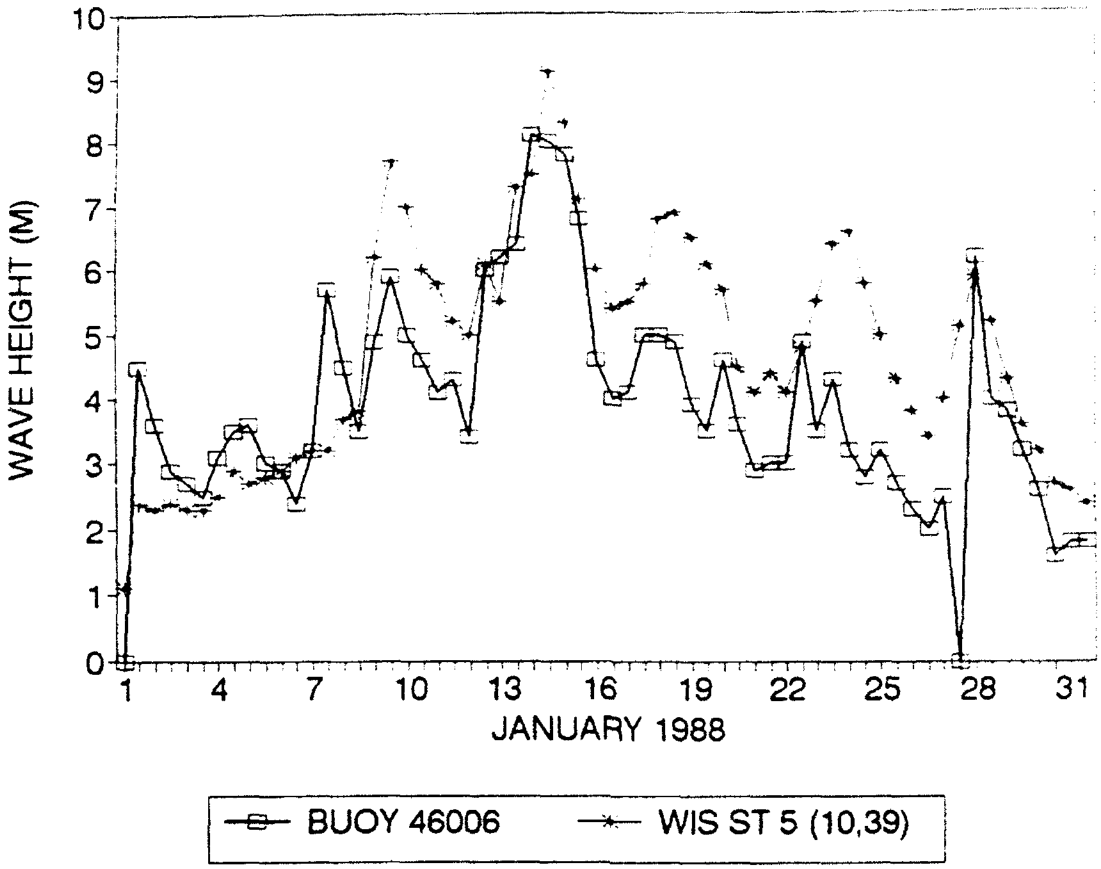
STATION 7 VS BUOY 51001

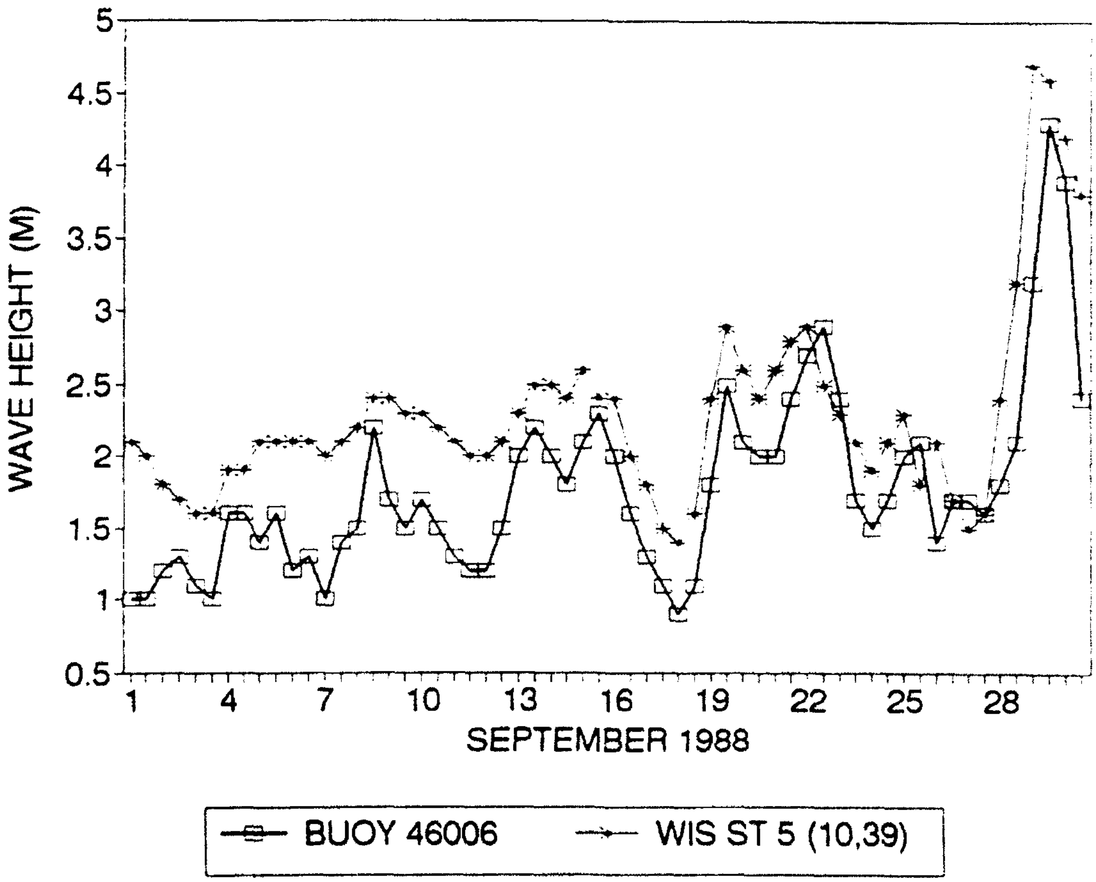


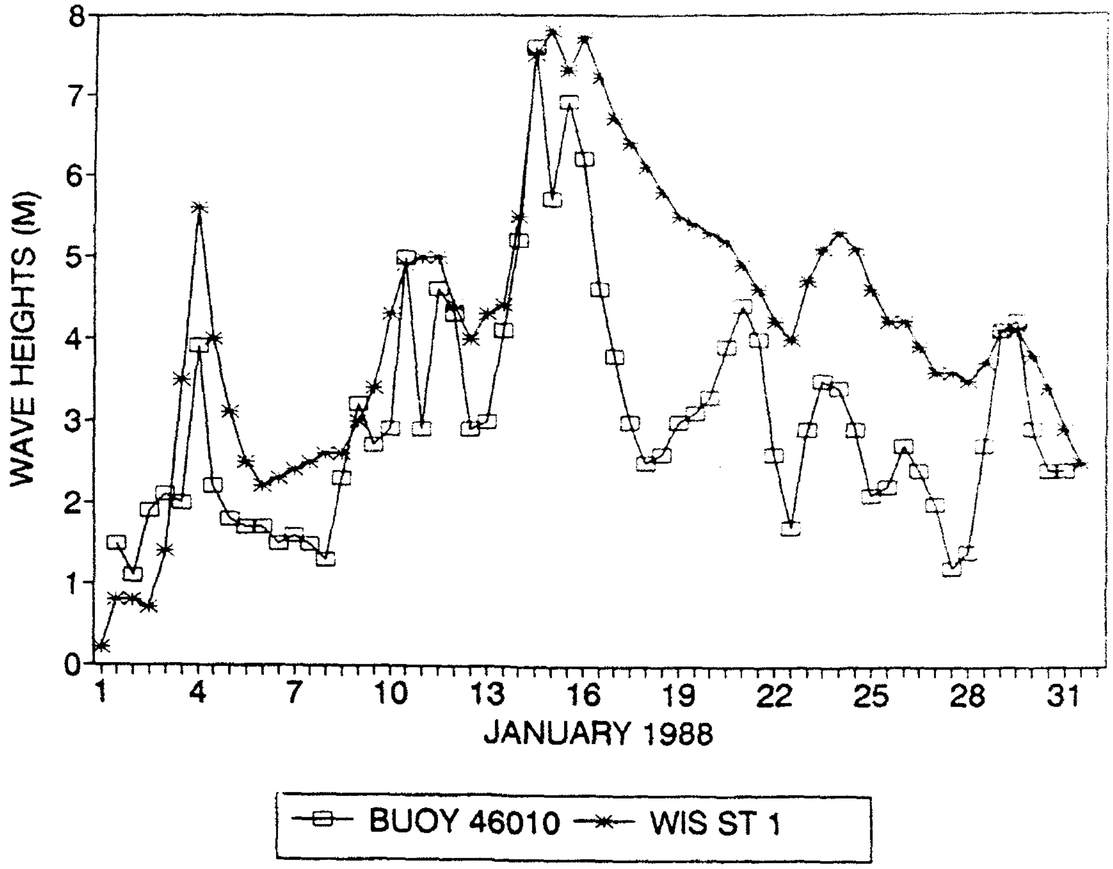
APPENDIX D: SELECTED MONTHLY TIME HISTORIES OF WIS AND MEASURED WAVE HEIGHT AND PEAK PERIOD

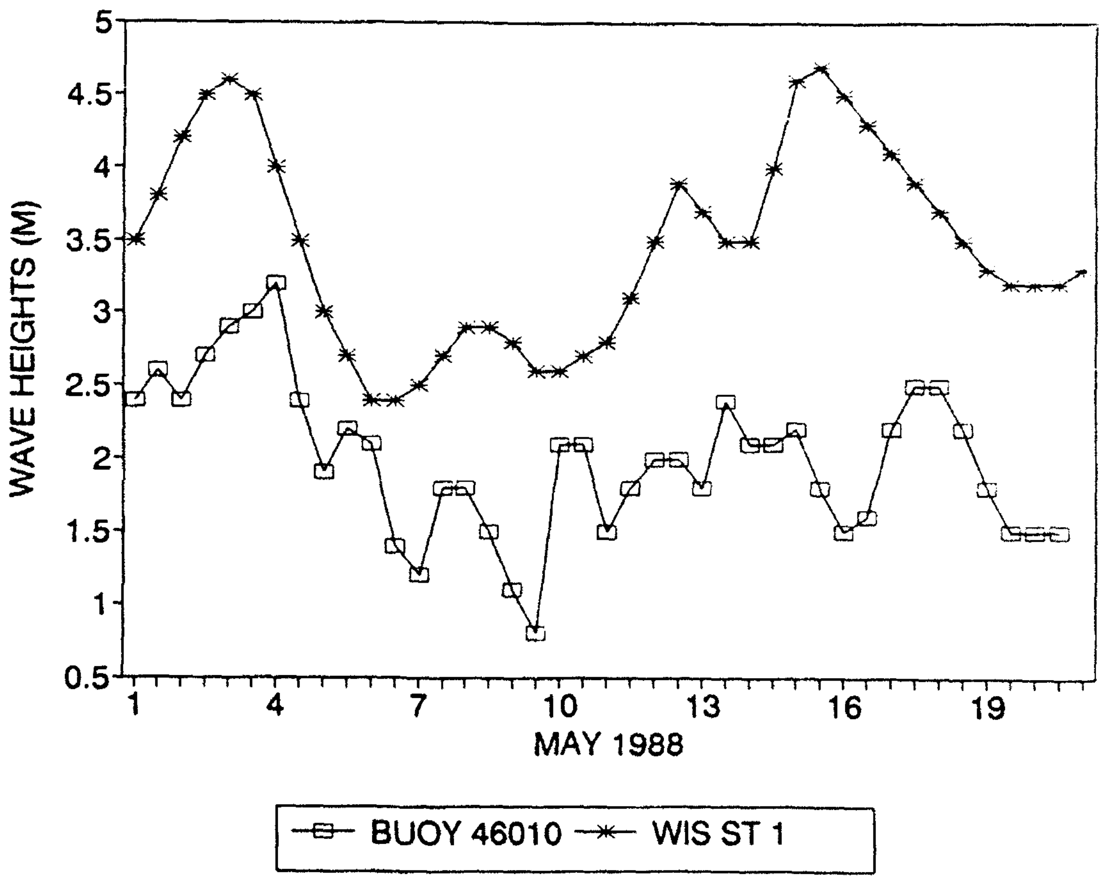

WAVE HEIGHT (M)
JANUARY 1988
BUOY 46003
WIS ST 2 (6,32)

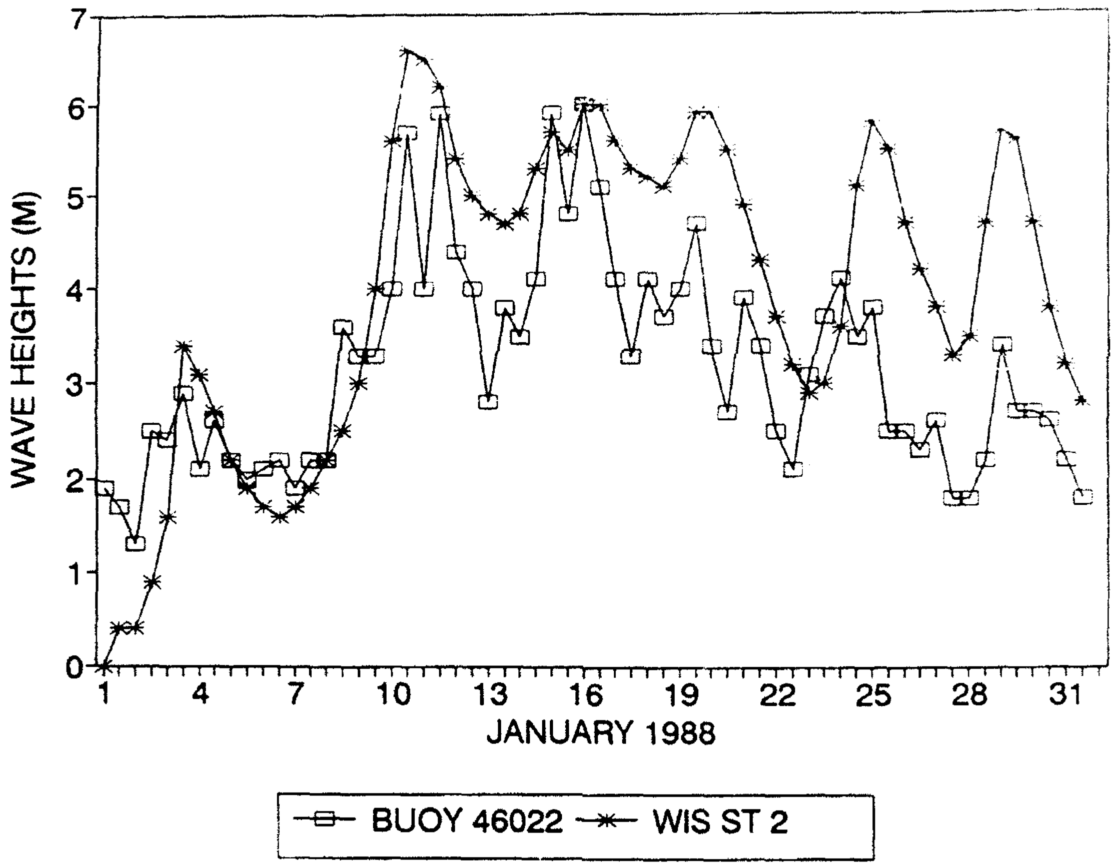

WAVE HEIGHT (M)
JUNE 1988
BUOY 46003
WIS ST 2 (6,32)


WAVE HEIGHT (M)
0
1
2
3
4
5
6
7
8
9
10
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46006
WIS ST 5 (10,39)

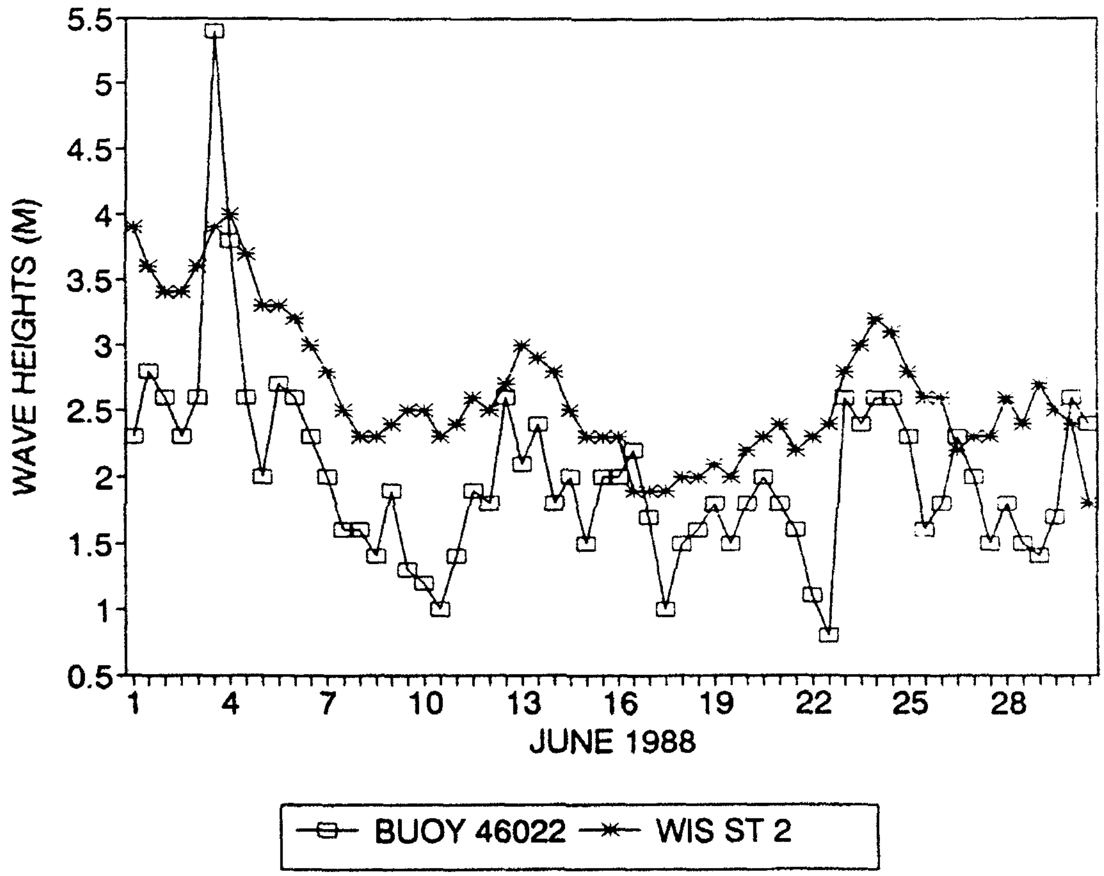

WAVE HEIGHT (M)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
1
4
7
10
13
16
19
22
25
28
SEPTEMBER 1988
BUOY 46006
WIS ST 5 (10,39)


WAVE HEIGHTS (M)
8
7
6
5
4
3
2
1
0
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46010
WIS ST 1

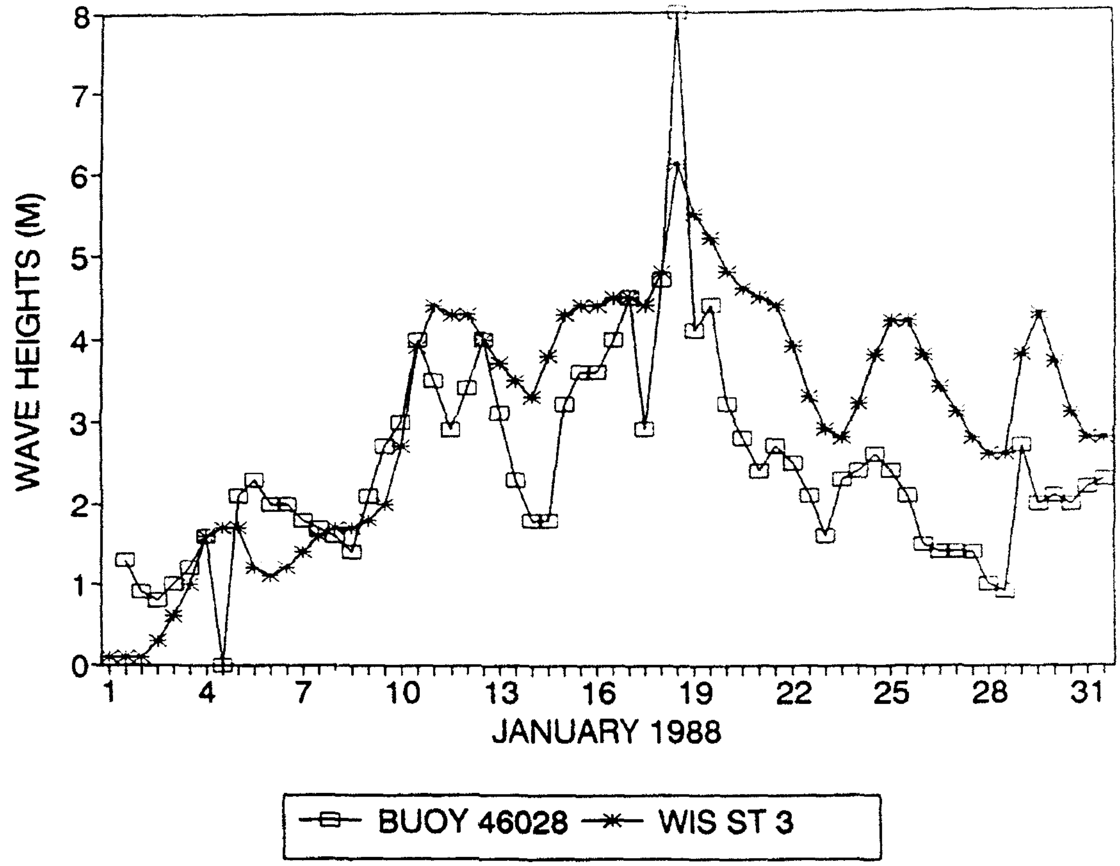

WAVE HEIGHTS (M)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
1
4
7
10
13
16
19
MAY 1988
BUOY 46010
WIS ST 1

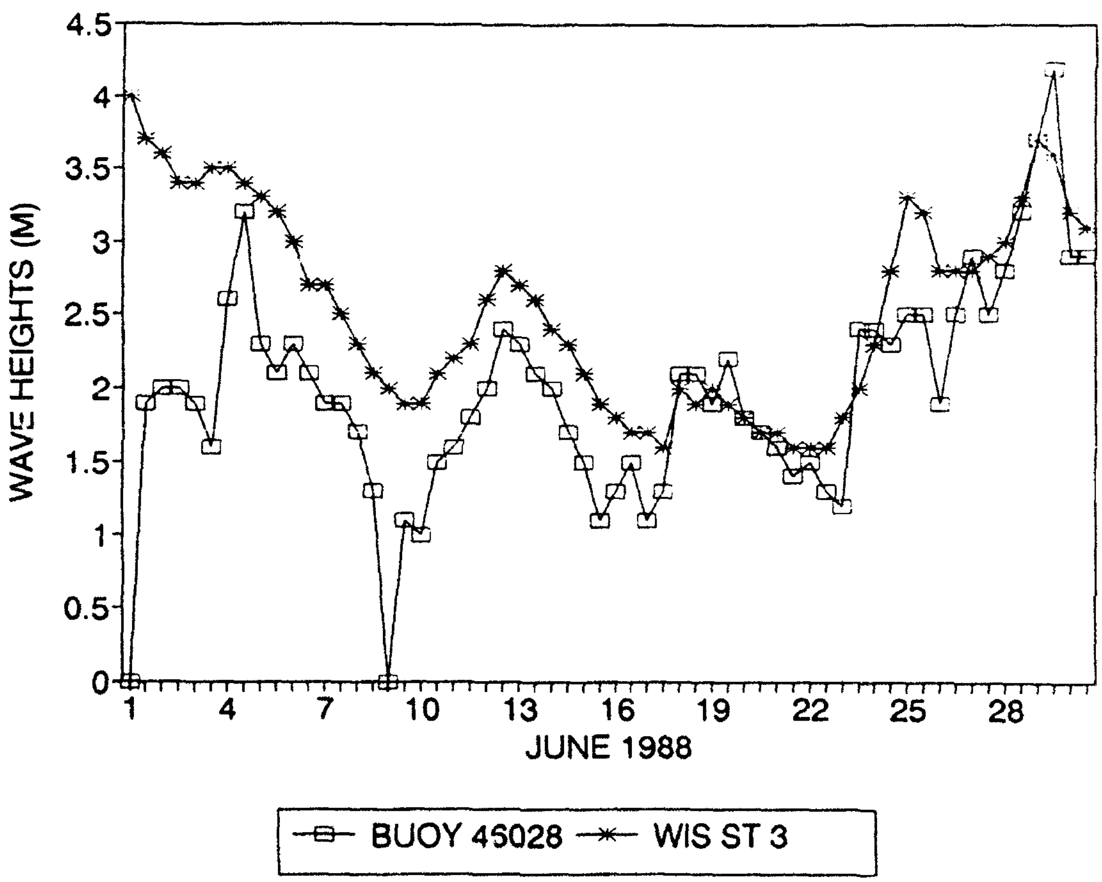


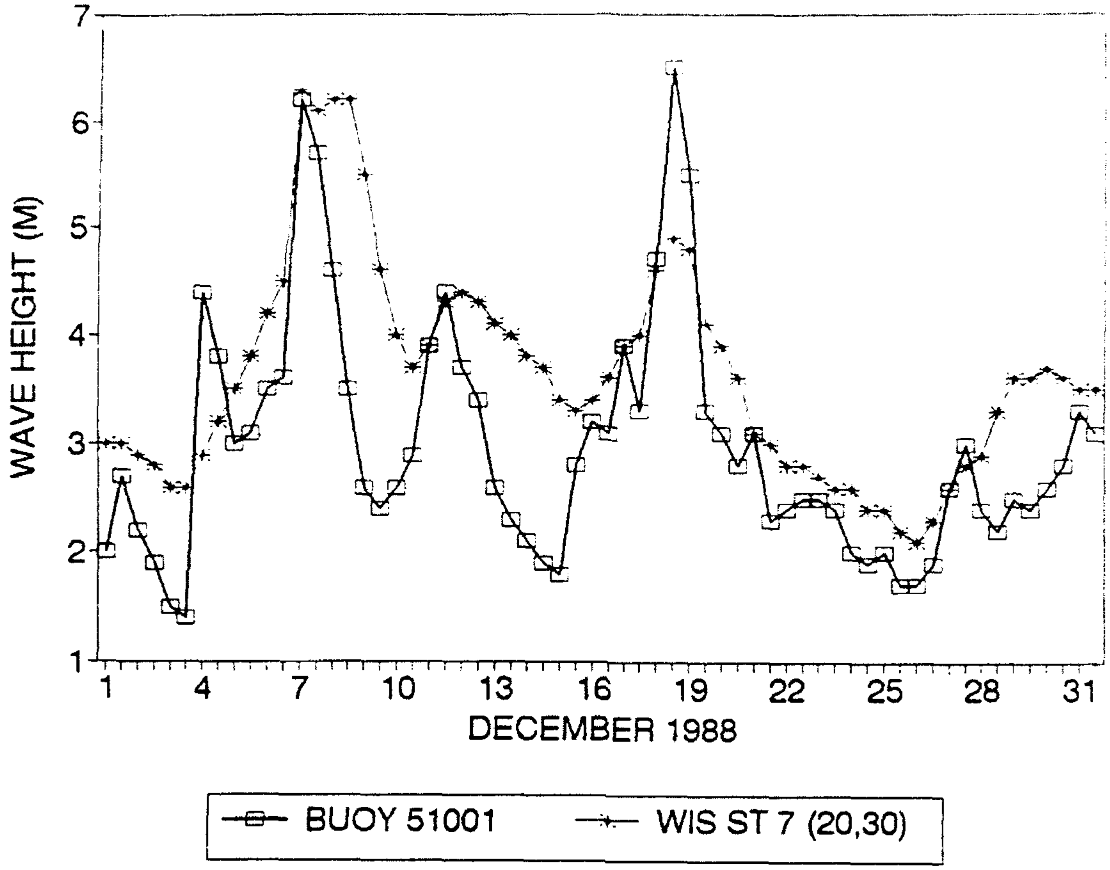
WAVE HEIGHTS (M)
0
1
2
3
4
5
6
7
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46022
WIS ST 2

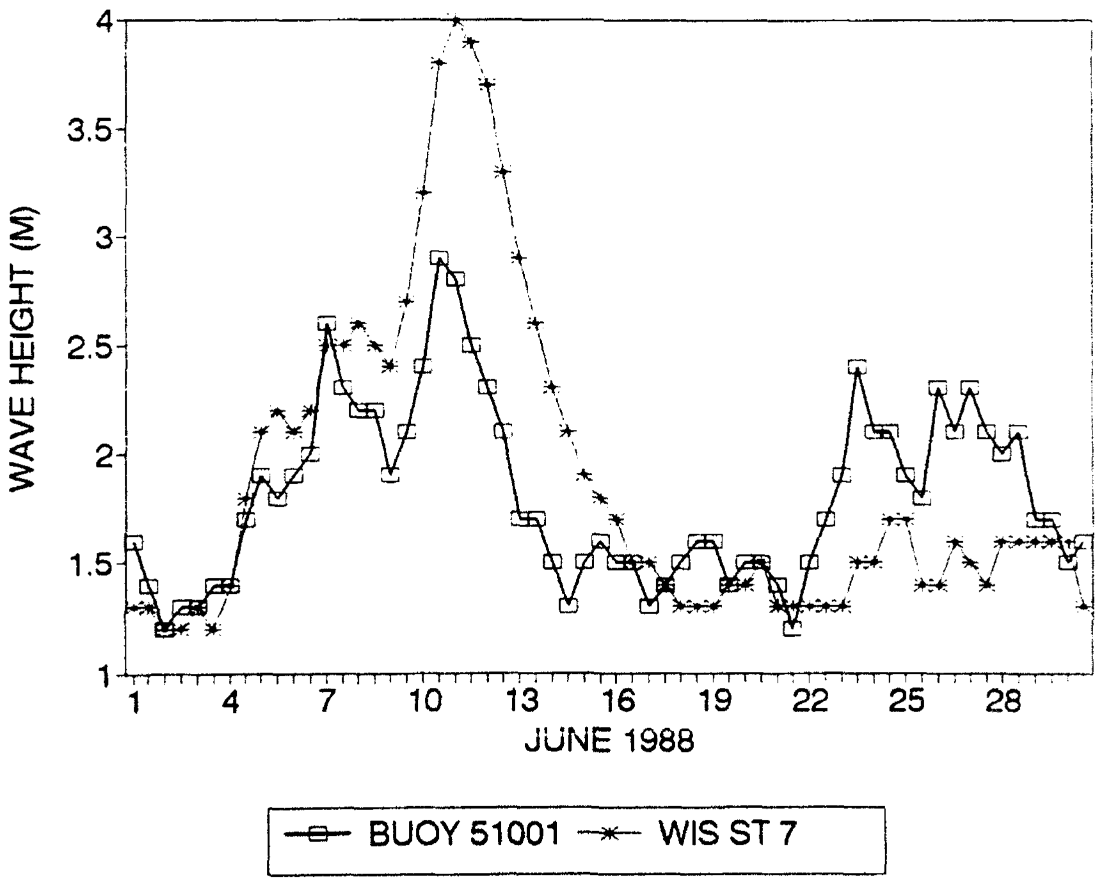


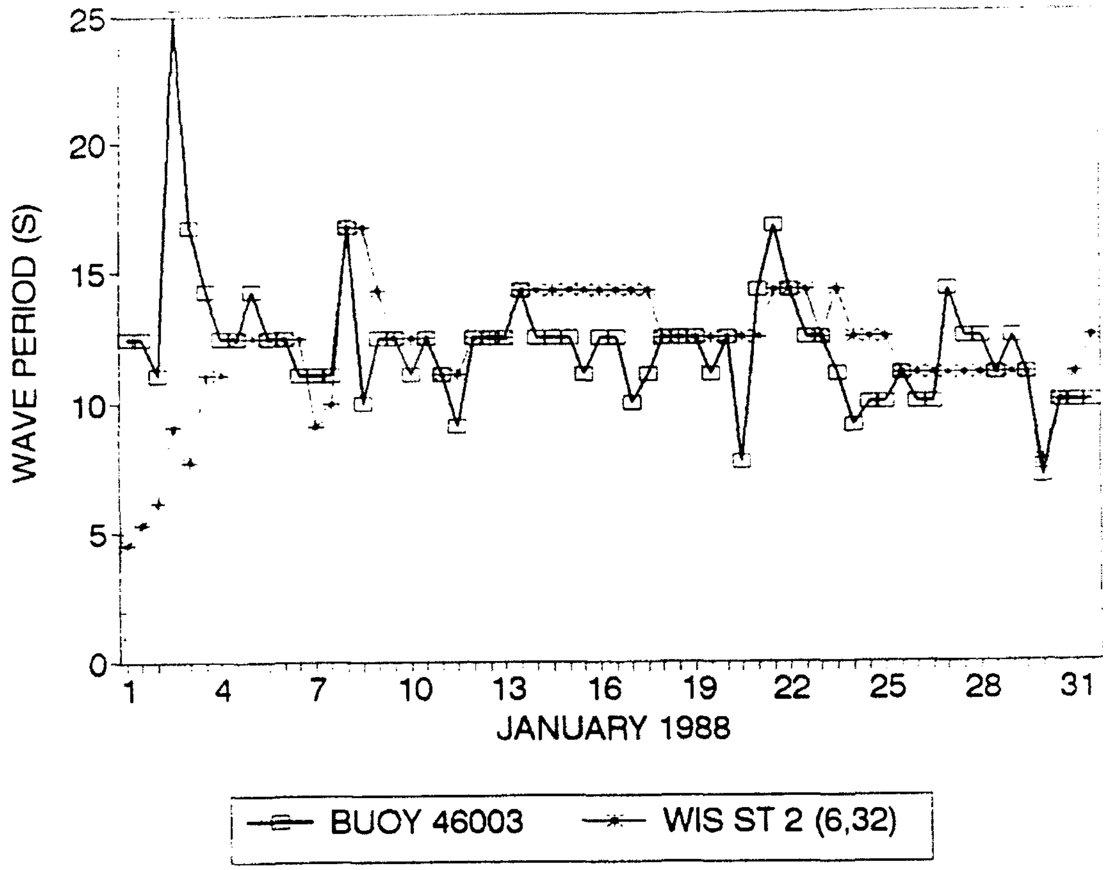
WAVE HEIGHTS (M)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
1
4
7
10
13
16
19
22
25
28
JUNE 1988
BUOY 46022
WIS ST 2

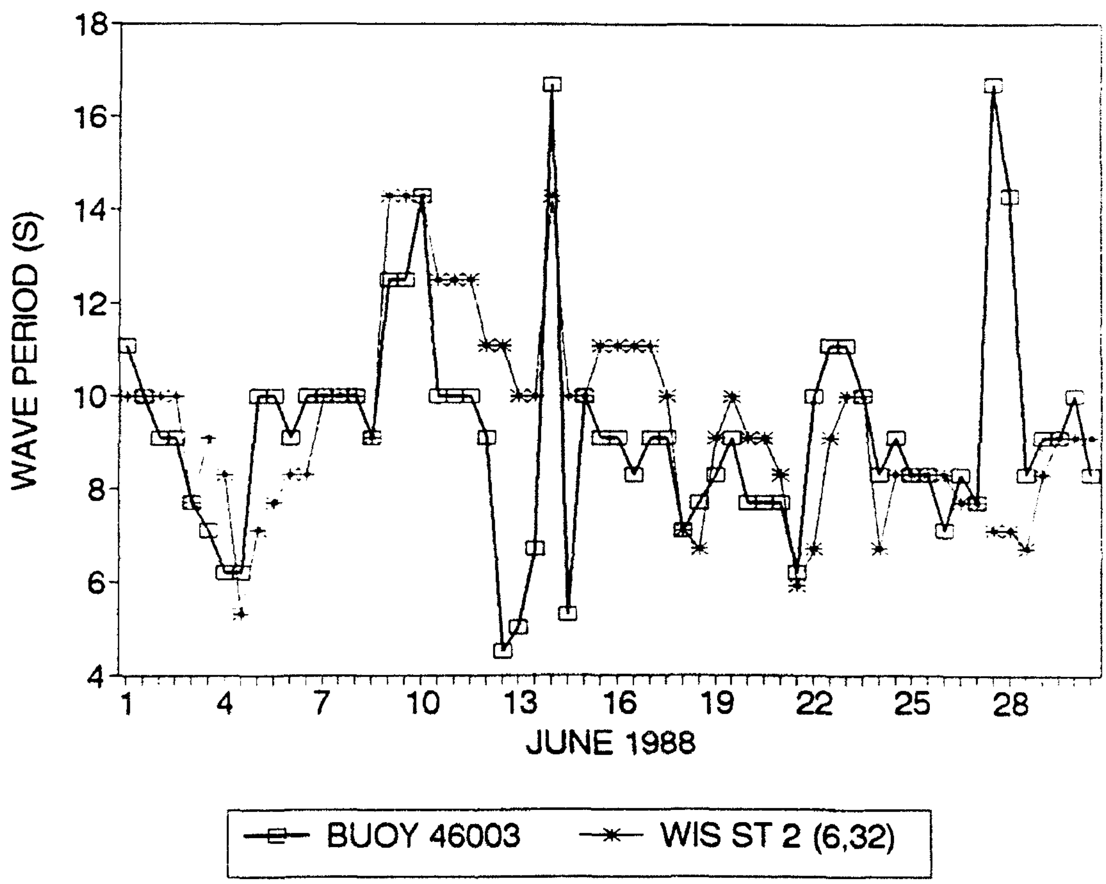

WAVE HEIGHTS (M)
JANUARY 1988
BUOY 46028
WIS ST 3

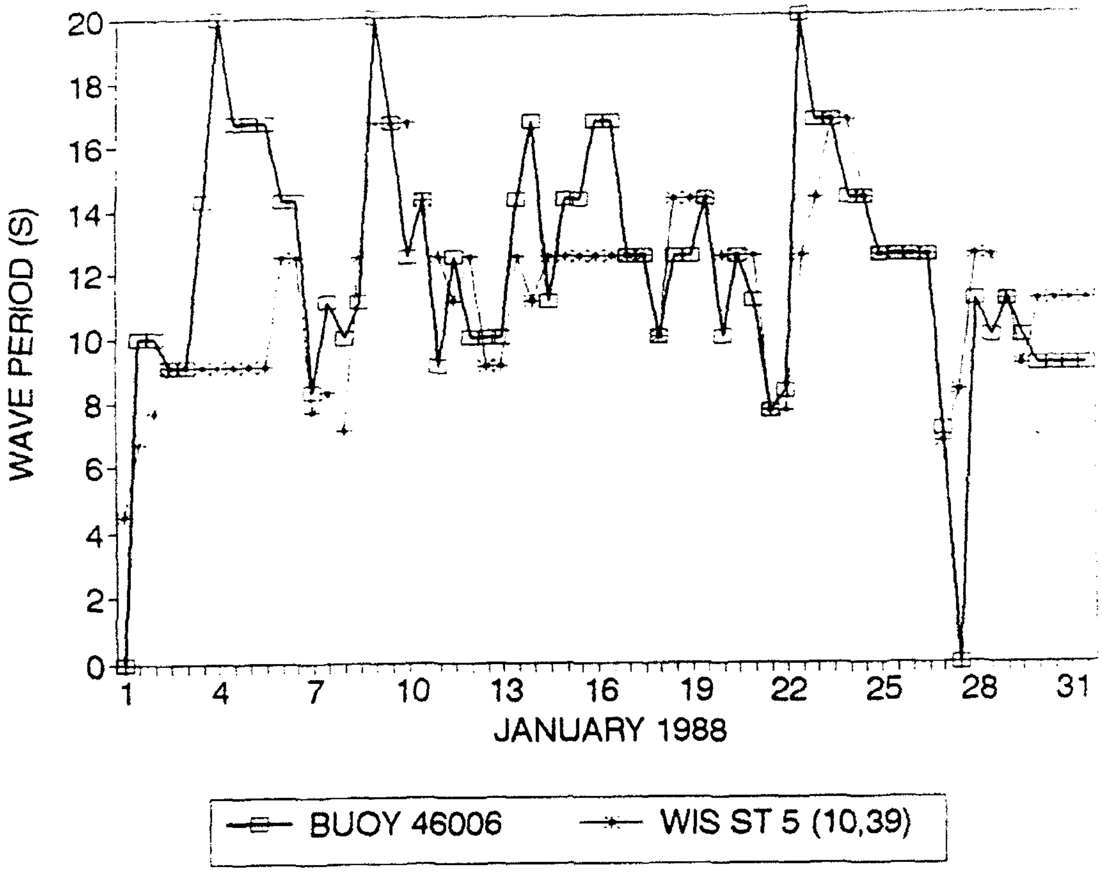

WAVE HEIGHTS (M)
JUNE 1988
BUOY 46028
WIS ST 3


7
6
5
4
3
2
1
WAVE HEIGHT (M)
1
4
7
10
13
16
19
22
25
28
31
DECEMBER 1988
BUOY 51001
WIS ST 7 (20,30)

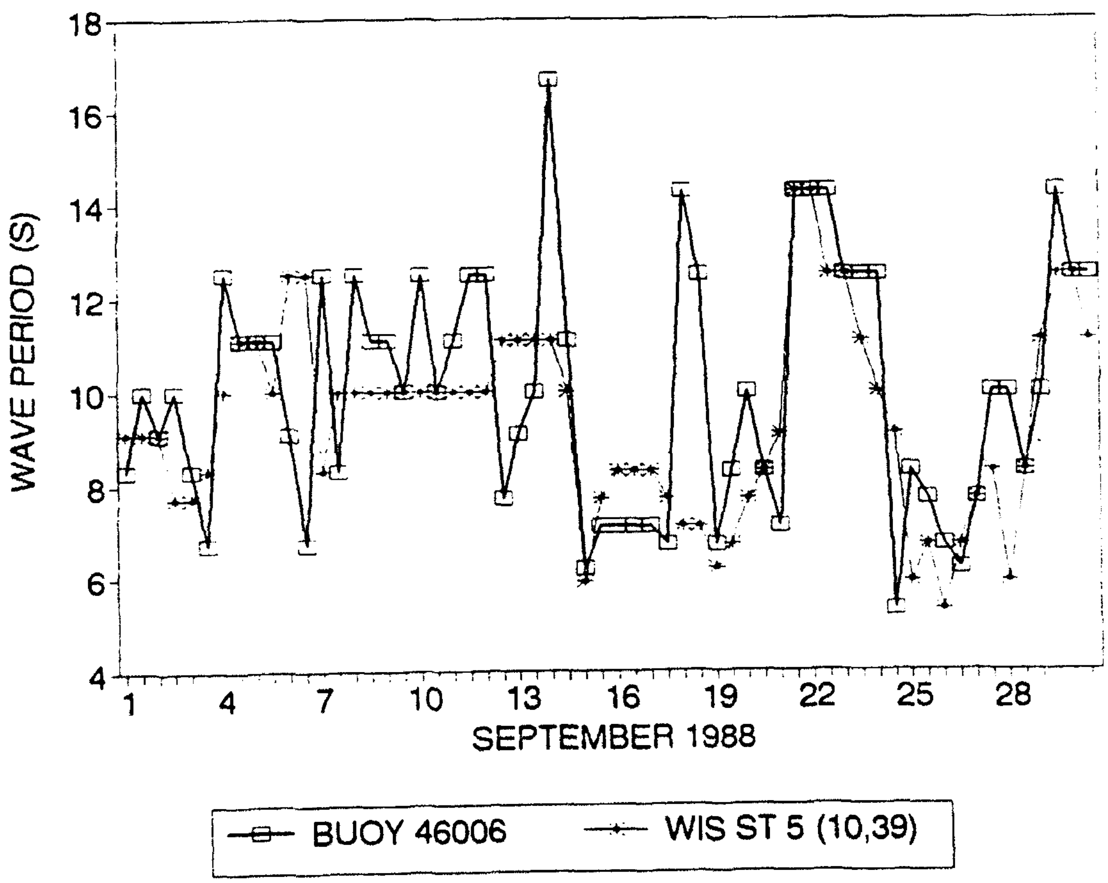

4
3.5
3
2.5
2
1.5
1
WAVE HEIGHT (M)
1
4
7
10
13
16
19
22
25
28
JUNE 1988
BUOY 51001
WIS ST 7


WAVE PERIOD (S)
25
20
15
10
5
0
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46003
WIS ST 2 (6,32)

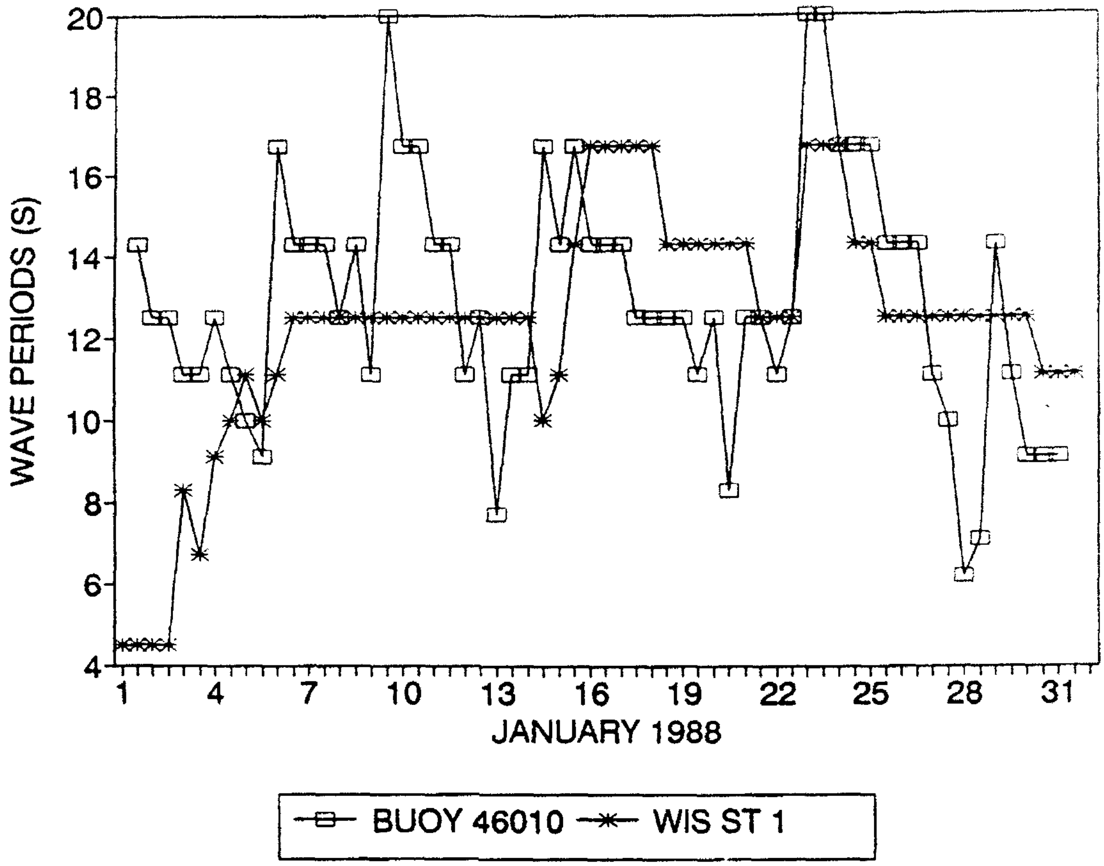

WAVE PERIOD (S)
18
16
14
12
10
8
6
4
1
4
7
10
13
16
19
22
25
28
JUNE 1988
BUOY 46003
WIS ST 2 (6,32)

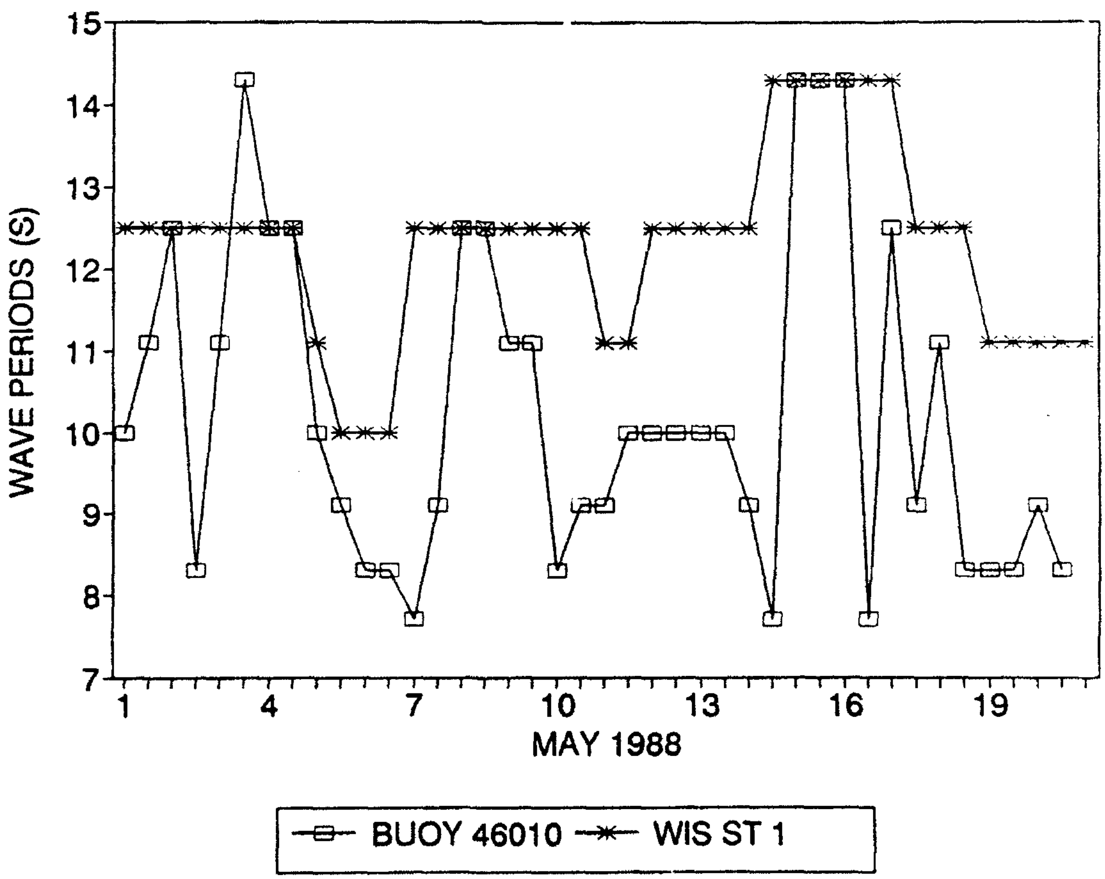


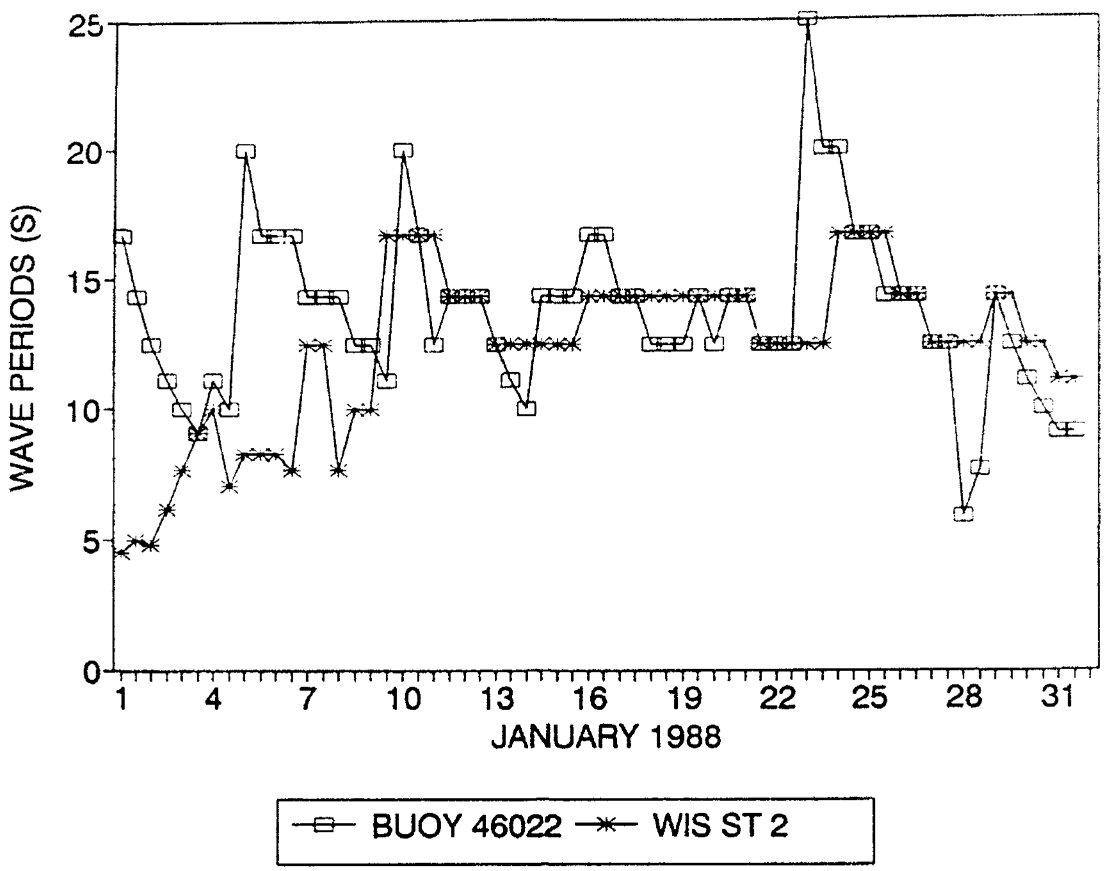
WAVE PERIOD (S)
20
18
16
14
12
10
8
6
4
2
0
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46006
WIS ST 5 (10,39)



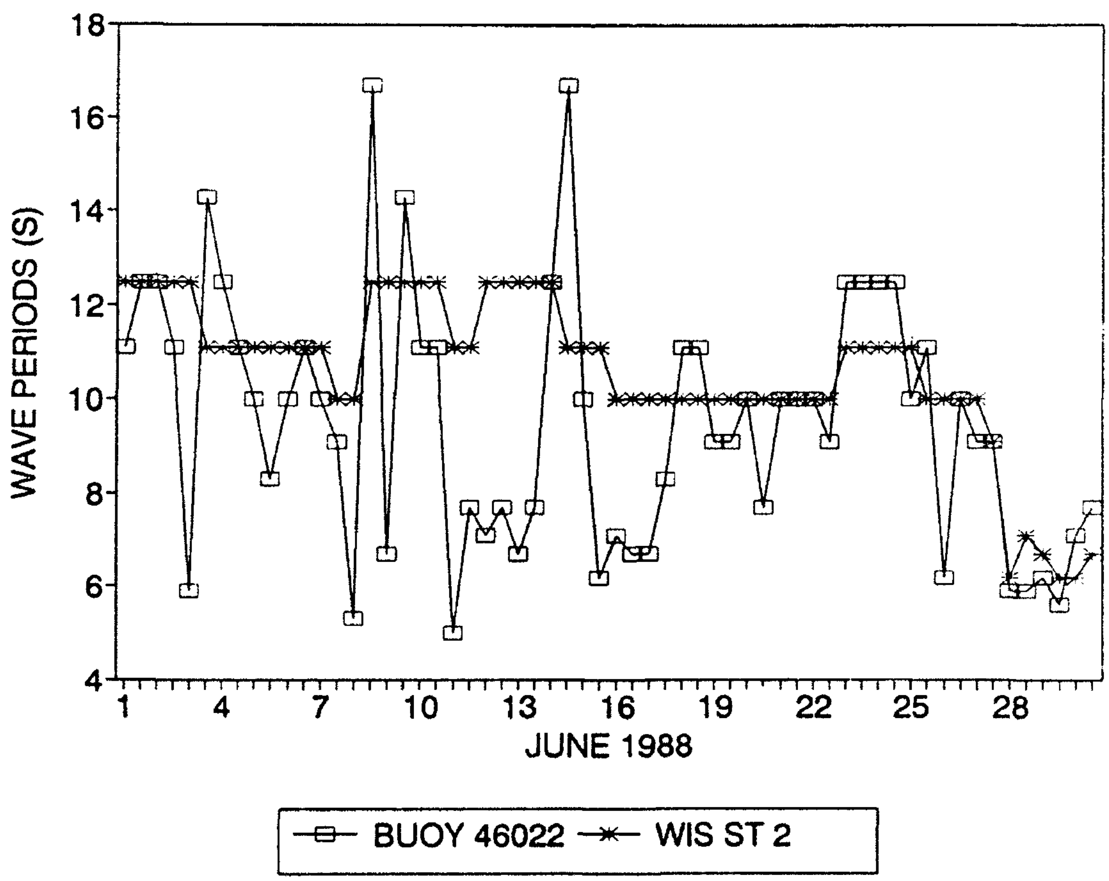
WAVE PERIOD (S)
18
16
14
12
10
8
6
4
1
4
7
10
13
16
19
22
25
28
SEPTEMBER 1988
BUOY 46006
WIS ST 5 (10,39)


WAVE PERIODS (S)
20
18
16
14
12
10
8
6
4
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46010
WIS ST 1

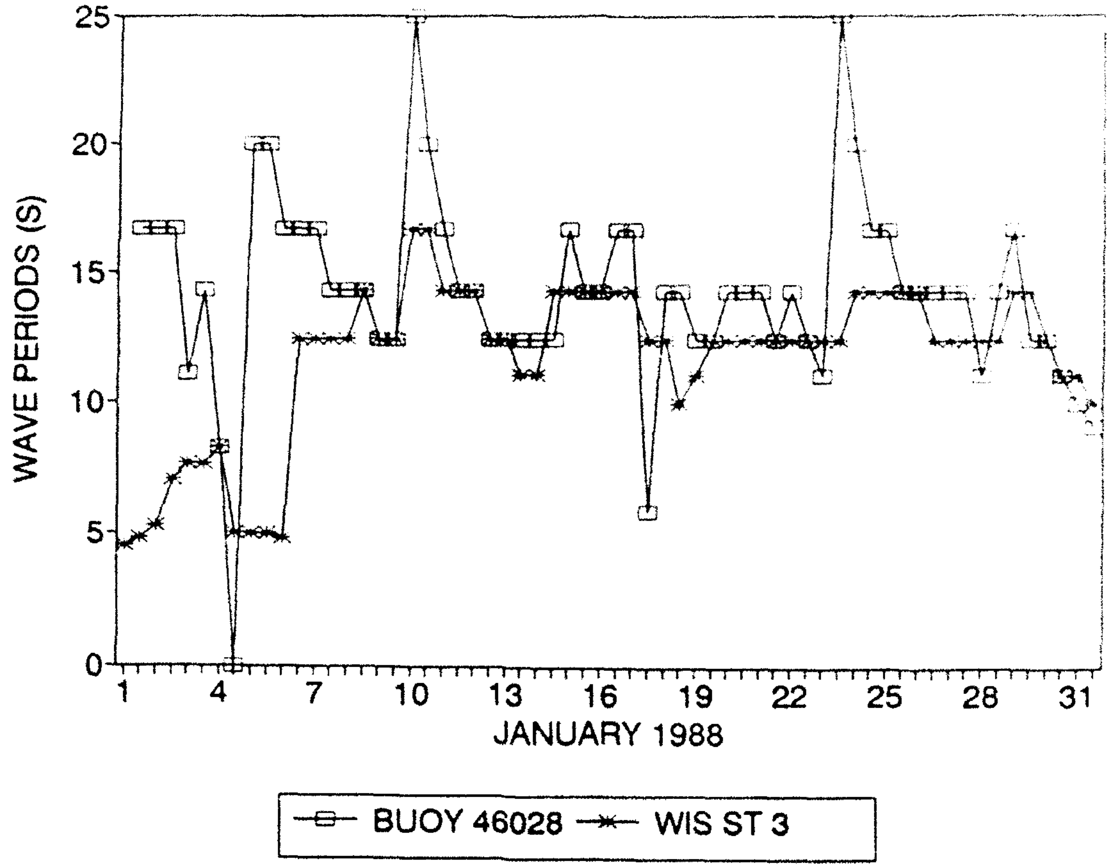

WAVE PERIODS (S)
15
14
13
12
11
10
9
8
7
1
4
7
10
13
16
19
MAY 1988
BUOY 46010
WIS ST 1

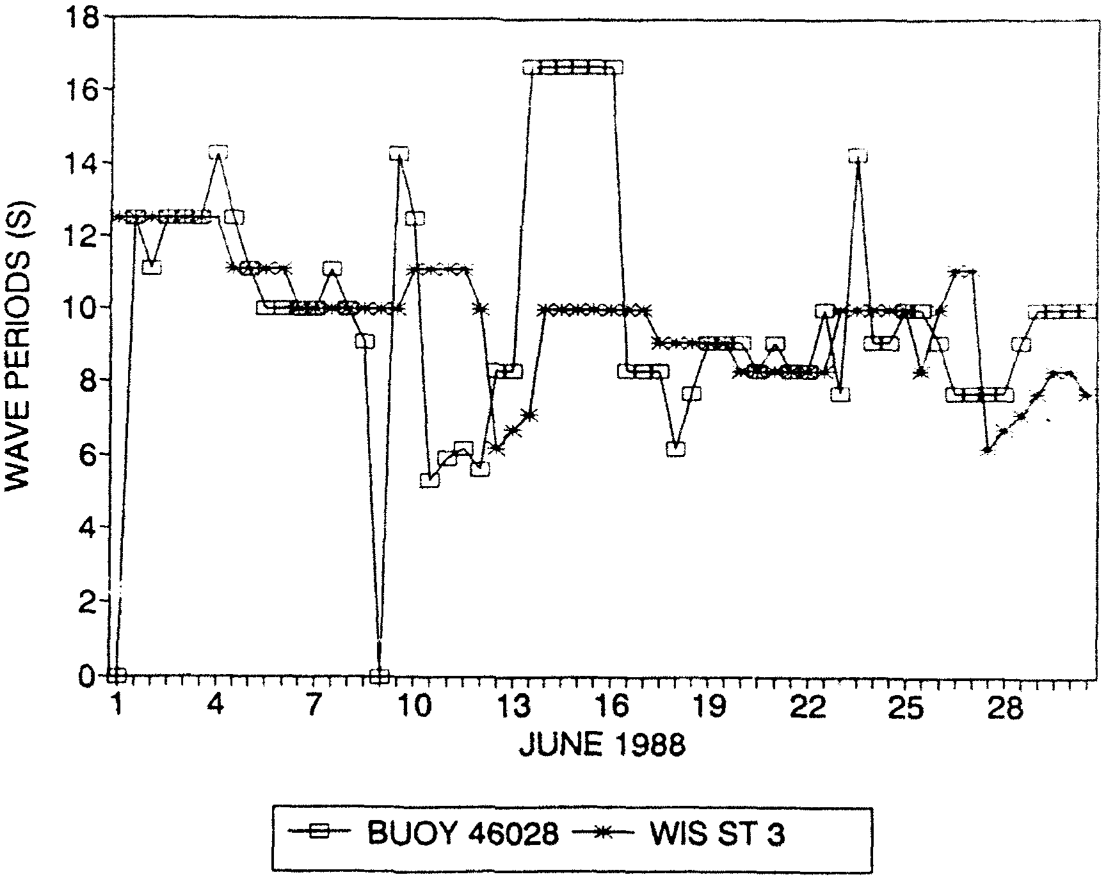


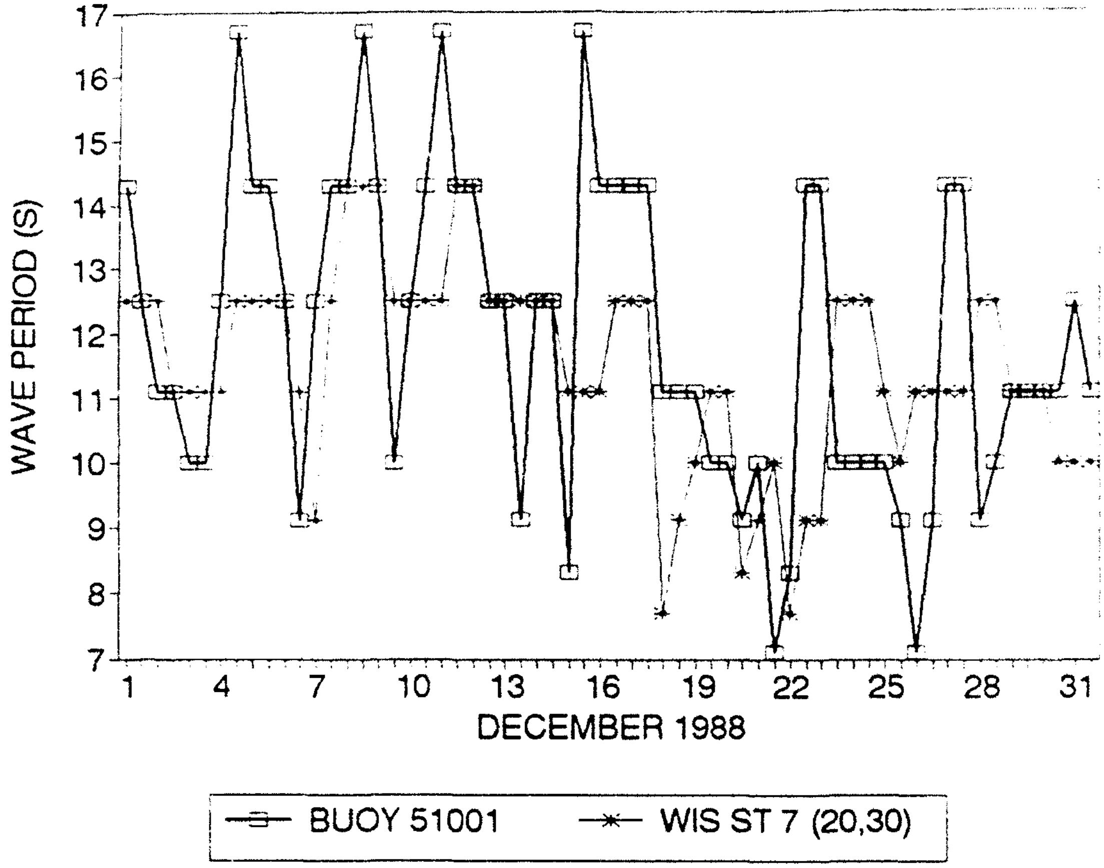
25
20
15
10
5
0
WAVE PERIODS (S)
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46022
WIS ST 2



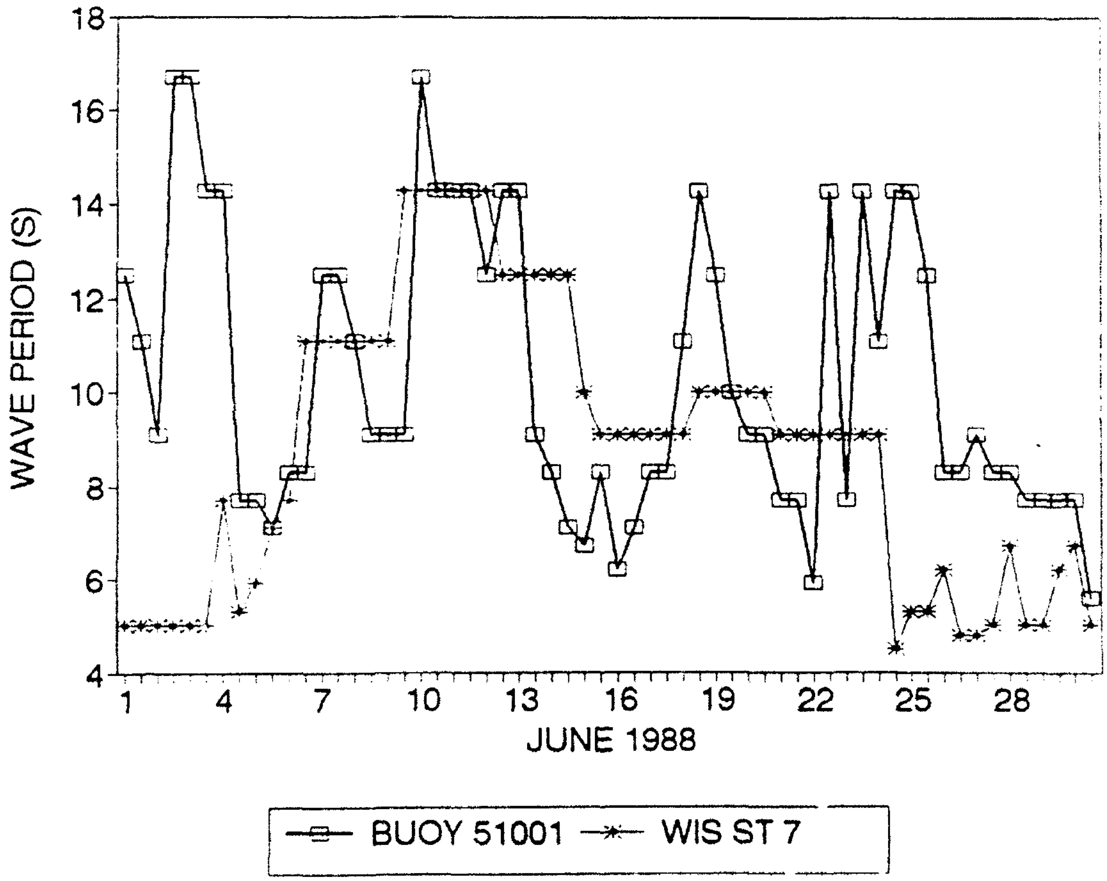
18
16
14
12
10
8
6
4
WAVE PERIODS (S)
1
4
7
10
13
16
19
22
25
28
JUNE 1988
BUOY 46022
WIS ST 2


25
20
15
10
5
0
WAVE PERIODS (S)
1
4
7
10
13
16
19
22
25
28
31
JANUARY 1988
BUOY 46028
WIS ST 3


18
16
14
12
10
8
6
4
2
0
WAVE PERIODS (S)
1
4
7
10
13
16
19
22
25
28
JUNE 1988
BUOY 46028
WIS ST 3



WAVE PERIOD (S)
DECEMBER 1988
BUOY 51001
WIS ST 7 (20,30)



WAVE PERIOD (S)
JUNE 1988
BUOY 51001
WIS ST 7

Waterways Experiment Station Cataloging-in-Publication Data

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1. Ocean waves — Pacific Ocean —Statistics. 2. Wind waves — North Pacific Ocean — Statistics. 3. Oceanography — Pacific Ocean. 4. Water waves — North Pacific Ocean — Statistics. I. Hubertz, Jon M. II. United States. Army. Corps of Engineers. III. Coastal Engineering Research Center (U.S.) IV. U.S. Army Engineer Waterways Experiment Station. V. Wave Information Studies of US Coastlines.
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