IFYGL SHIPBOARD VISUAL WAVE OBSERVATIONS VS. WAVE MEASUREMENTS[1]

P.C. Liu and T.A. Kessenich
Great Lakes Environmental Research Laboratory, National Oceanic and
Atmospheric Administration, Ann Arbor, Michigan

Abstract. Data used for this study were collected in Lake Ontario during 1972, the International Field Year for the Great Lakes (IFYGL). Shipboard meteorological observations, which include visual estimates of wave height and wave period, are made in the Great Lakes by over 100 ships from the United States and Canada. Data collected from these ship reports cover a wide range of lake conditions and hence provide a useful basis for climatological studies of surface waves in the Great Lakes. The objective of this paper is to present an assessment of the reliability of these ship reports. Records from deep water wave gauges were compared with shipboard observations made within 50 km of the gauges. The results show that visually estimated wave heights, H_{vo}, and wave periods T_{vo}, are correlated with the recorded significant wave heights, H_S, and average zero-crossing wave periods, T_z, respectively by $H_S = (0.25 + 0.6 H_{vo})$ meters and $T_z = (2.0 + 0.2 T_{vo})$ seconds. Visual observations appear to substantially underestimate the steepness of the waves. Long-term distributions for wave heights and wave periods follow the log-normal distribution quite closely. These results are generally similar to those of oceanic studies.

INTRODUCTION

This paper presents a study comparing wave data as visually observed by those on board ships and as measured and recorded by wave-rider buoys manufactured by Datawell, Holland. The visual observations are very subjective; two persons observing the same waves may record two different sets of data. Because the accuracy of the observations depends upon the ability, experience, and objectivity of each observer, the quality of the visually observed data has been generally considered dubious. However, there are over 100 ships from the United States and Canada currently participating in a program of voluntary shipboard meteorological observations in the Great Lakes. In spite of the crude nature of the visual observations, the data observed and reported from these ships are valuable for climatological studies because they cover a large extent of lake area under a wide range of lake conditions and because in some cases the visual

---

[1] IFYGL (International Field Year for the Great Lakes).

observations represent the only information available. Recently the NOAA National Climatic Center at Asheville, N.C., has published a four volume "Summary of Synoptic Meteorological Observations for Great Lakes Areas" based on reported shipboard observations. In order to properly utilize and interpret these data, it is essential to determine their accuracy and reliability. During 1972, the International Field Year for the Great Lakes (IFYGL), both deep-water wave measurements and shipboard visual wave observations were made in Lake Ontario. The availability of these two sources of data has facilitated the present study. The results presented here can be used as a reference in evaluating shipboard visual observations, especially when they are compiled as a basis for climatological studies of surface waves in the Great Lakes.

DATA

Shipboard Wave Observations

The visually observed wave data used in this study were collected by both commercial and scientific vessels in Lake Ontario during 1972. These data are available on cards at the National Climatic Center in Asheville, N.C. Each card bears the ship's position and a complete set of observations of weather conditions. Many of these include visual estimates of wave height and period at the time of observation. Observations were made regularly at 3-hour intervals, starting with 0000 Greenwich Mean Time, but additional observations were made at other times if warranted by meteorological conditions.

The World Meteorological Organization (WMO) has provided coding instructions to the ship observers for making the visual estimates. The WMO code defines wave period, coded in seconds, as the time between the passage of two successive wave crests over a fixed point. Wave height, coded in half-meters, is defined as the vertical distance between trough and crest. Both are obtained from the "larger well-formed waves of the wave system being observed."

Deep-water Wave Measurements

As part of the IFYGL wave studies project, deep-water waves were measured by four waverider buoys deployed in the proximity of the U.S. Physical Data Collection System Buoy Stations 14, 17, 19, and 20 with recording stations located at Brockport, Pultneyville, Oswego-II, and Oswego-I, respectively. Buoy positions are shown in Fig. 1. The waverider buoys were located in approximately 150m of water. Analog wave data were recorded continuously on magnetic tape and subsequently digitized at a nominal rate of three samples per second. Each wave data point was computed from 10 minutes of digitized data during each hour. Wave parameters were determined by the zero-upcrossing method. The significant wave height, that is, the average of the highest one-third of the wave, and the average wave period, that is, the average of all zero-upcrossing periods, were used to correlate with the corresponding wave height and wave period visually observed from the ships.

A detailed description of the wave measurements, data processing, digitization, and the analysis system is given by Liu and Robbins (1974). The recorded data used in this study, analyzed and compiled daily as summaries of
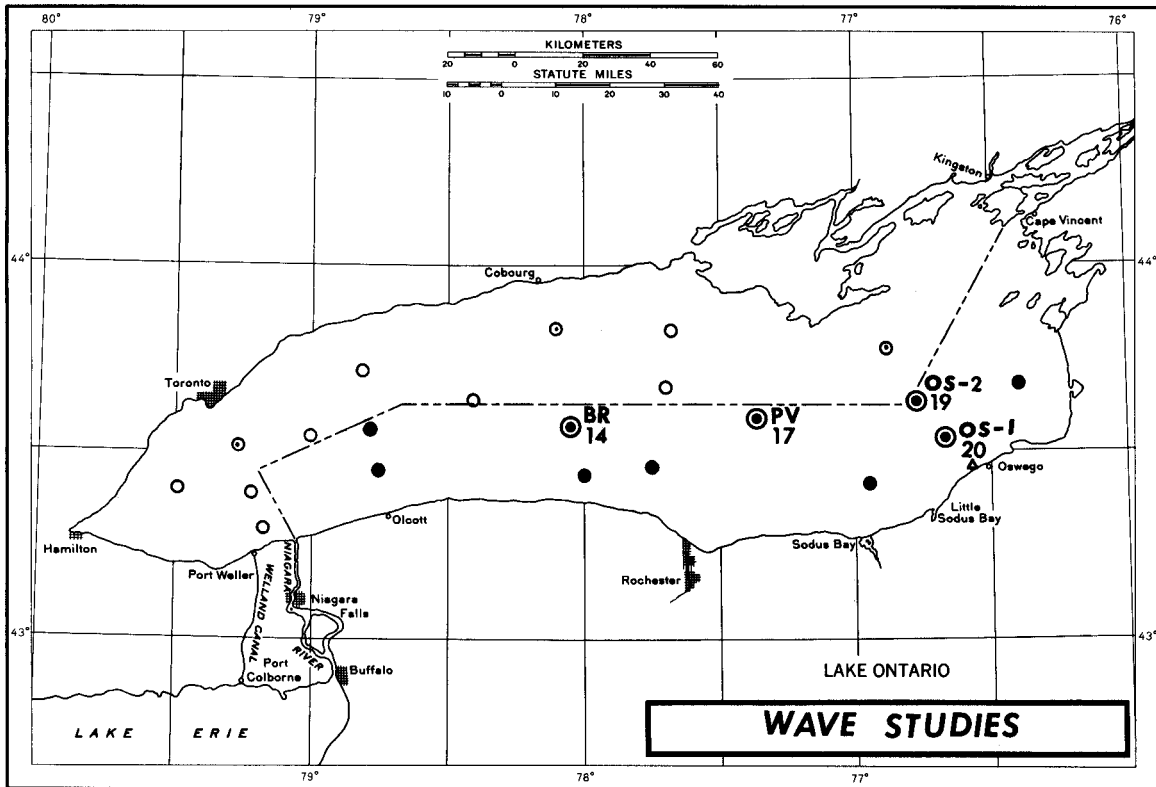
FIG. 1. Locations of wave recording stations in Lake Ontario.

hourly wave statistics from each waverider, are reported by Liu and Kessenich (1975).

RESULTS AND DISCUSSION

Scheme Used for Data Comparison

Because the shipboard observations were made at varied locations during passage, whereas the waverider recordings were made at a fixed station, direct comparison between observed and recorded waves is certainly not possible. However, in the mesoscaled Great Lakes it is not uncommon to consider a whole lake as a generating area for wind waves; therefore an assumption of homogeneity in wave parameters within the generating area was made and waves observed

and recorded simultaneously at nearby locations were compared. Under this presumption the following simple comparison scheme was adopted in this paper: shipboard observations made in the middle part of Lake Ontario were compared with waverider data at the Brockport station and observations made in the eastern end of the lake were compared with the Oswego-II data. Figures 2a and 2b illustrate these two groups and indicate the frequency of observations made at each ship location. A few longer distance comparisons of up to 70 km were also made. Some observed data along the boundary area that separates the two groups were compared with both waverider recordings. There is no distinguishable difference in the results from these two groups. The subsequent
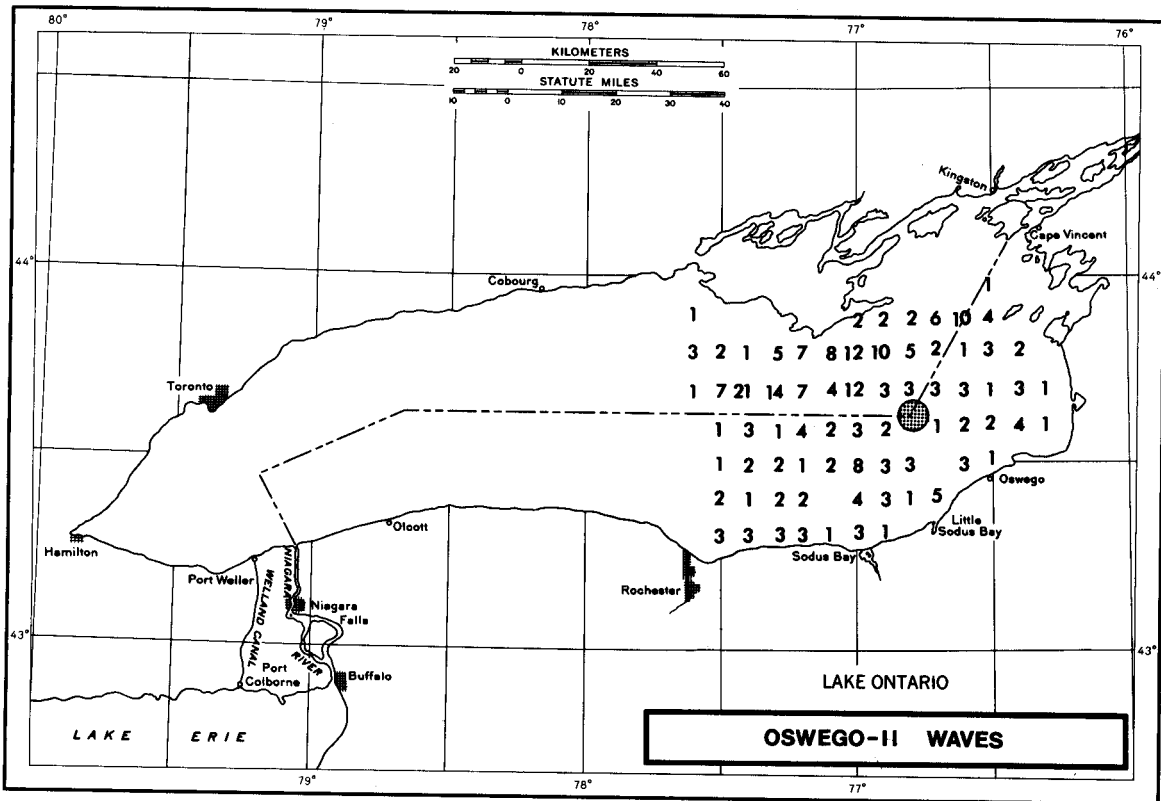
FIG. 2a. Locations of Brockport waverider and shipboard observations.
The numbers refer to frequency of occurrence.

discussions presented in this paper are therefore based on combined data from both groups.

Simultaneous recordings between neighboring waveriders were compared to verify the comparison scheme used in this study. The comparisons of average wave period, T_z, and significant wave height, H_s, between Brockport and Pultneyville, Pultneyville and Oswego-II, and Oswego-II and Oswego-I are shown in Fig. 3. The points plotted in these Figures are scattered around the one-to-one correlation line in a fairly even distribution. Most of the scatter is explainable by the effect of fetches and durations of the wind field. These results indicate that the inference of wave-parameter homogeneity within the lake area can be considered as valid in a broad sense and the comparison scheme is generally acceptable within a limited scope.

Direct Comparison of Wave Parameters

Between May and November of 1972, there were 678 pairs of simultaneously observed and recorded wave heights and 340 pairs of simultaneously observed and recorded wave periods available for comparison. Figures 4 and 5 present the correlations based on these data. In these Figures the observed wave heights, coded in half-meters, and wave periods, in seconds, are respectively correlated with recorded significant wave heights and average wave periods, computed in fractions of meters and seconds.

FIG. 2b.   Locations of Oswego 11 waverider and shipboard observations.
The numbers refer to frequency of occurrence.

The gray dots represent correlated data points. Averages and standard deviations of recorded data corresponding to the observed data are calculated and plotted in the Figures as open circles and ticked marks, respectively. A one-to-one correlation line is plotted through the origins. A best-fit line through the average points is also plotted to show that linear relationships can be obtained for both wave height and wave period correlations. The correlation coefficients for the wave height data in Fig. 4 and wave period data in Fig. 5 are, respectively, 0.79 and 0.40. The low correlation for wave periods indicates that visual observations of wave period is of dubious value. In addition, the linear relationships can be represented by the following regression equations:

$$H_s = (0.25 + 0.6 H_{vo}) \text{ meters}$$
and
$$T_z = (2.0 + 0.2 T_{vo}) \text{ seconds}$$

where H_s is the recorded significant wave height, T_z is the recorded average wave period, and H_{vo} and T_{vo} are the visually observed wave height and period, respectively.

These results indicate that for wave heights over 1/2 m and wave periods over 3 seconds the visually observed data tend to overestimate, at a gradually increasing rate, the data as measured. The rate of overestimation for observed wave periods is consistently higher than that for observed wave heights. While these results, based on 6-month data in Lake Ontario, are unique for Great Lakes studies, they are generally
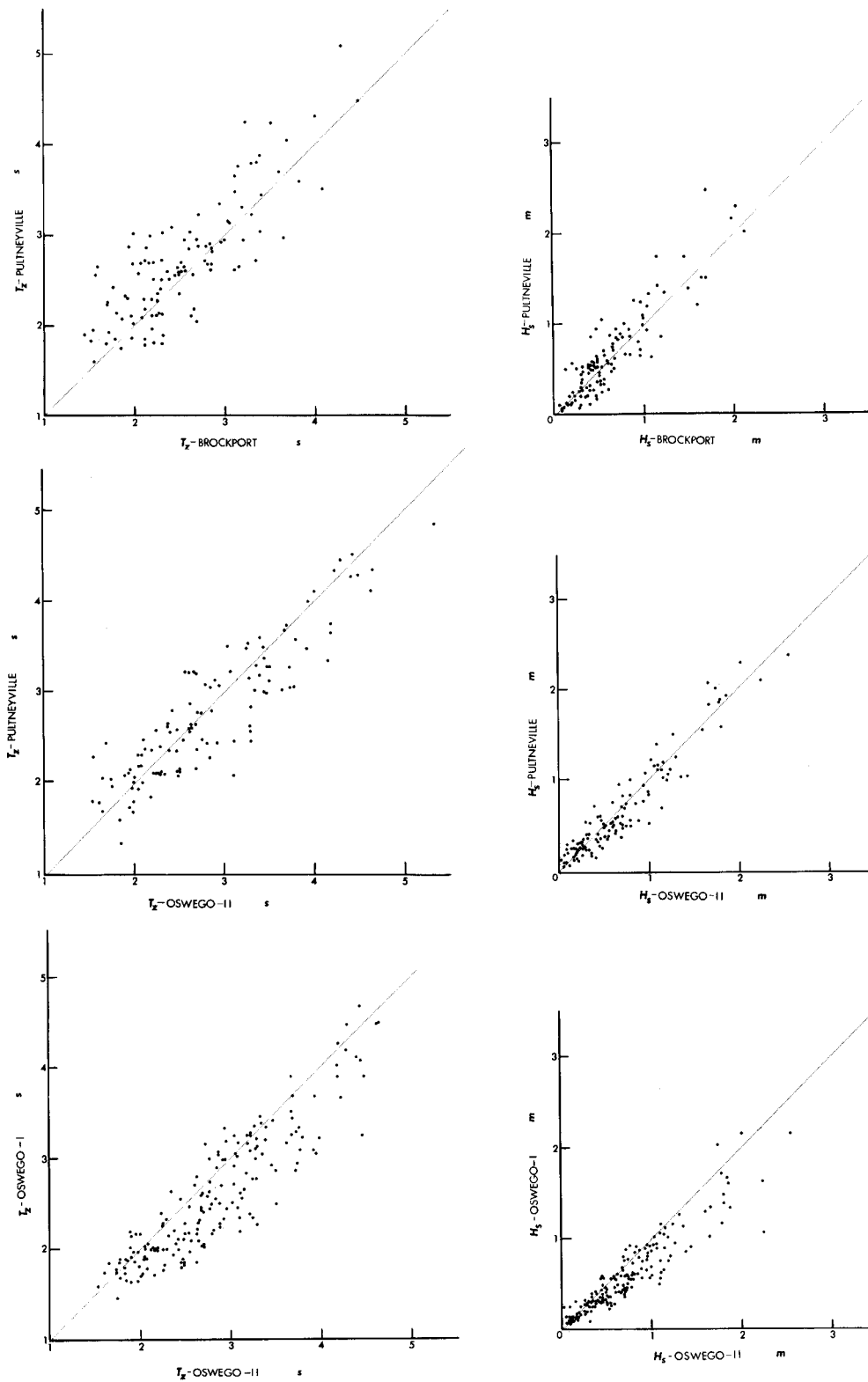
FIG. 3.   Intercomparisons of significant wave heights, H_S, and average wave period, T_Z, between waveriders.
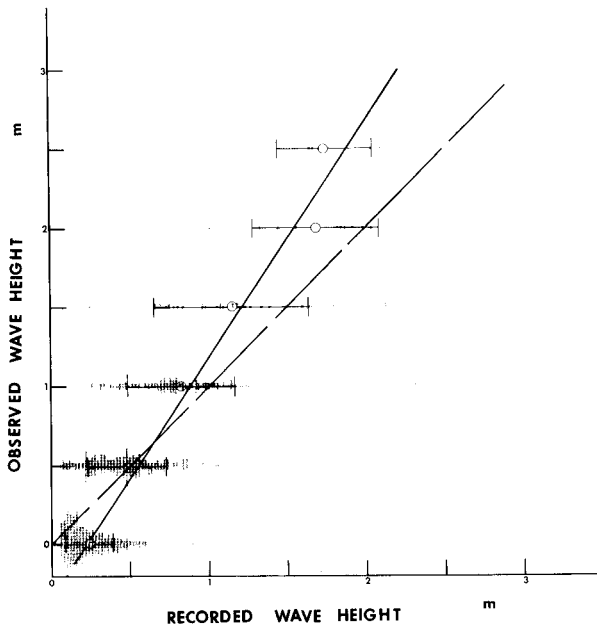
FIG. 4. Correlation of recorded with observed wave height. Dashed line represents one-to-one correlation.

FIG. 5. Correlation of recorded with observed wave period. Dashed line represents one-to-one correlation.

similar to those of more extensive oceanic studies. Hogben and Lumb (1967) compared visual observations with recordings made from North Atlantic ocean weather ships that were equipped with shipborne wave recorders. Their results, derived from several years of data, show trends similar to those depicted in Figs. 4 and 5. Their correlation coefficients for wave height and wave period data are 0.86 and 0.50 respectively.

Comparison of Distribution of Wave Parameters

One of the frequently used analyses in characterizing a large amount of data is to evaluate the probability distributions of the data. Previous oceanic studies (e.g., Jasper 1955; Darbyshire 1956) have found that long-term distribution of significant wave heights and wave periods can be represented by the log-normal distribution. This is evidenced by the linear relationship resulting from plotting on probability paper the percentage of time a given wave height or wave period is exceeded versus the logarithm of wave height or wave period respectively. The results of this study are presented in Figs. 6 and 7.

In these Figures the open circles represent waverider data collected from all four stations. With some departures at the highest and lowest ends of the data, the fairly well defined linear relationships indicate that the log-normal distribution is indeed applicable to the data presented. As these results are formed from the recorded and observed data separately, the linearity implies that these data are consistent within themselves. These results also indicate that visually observed data are overestimated. For instance, 50% of the time when recorded and significant wave
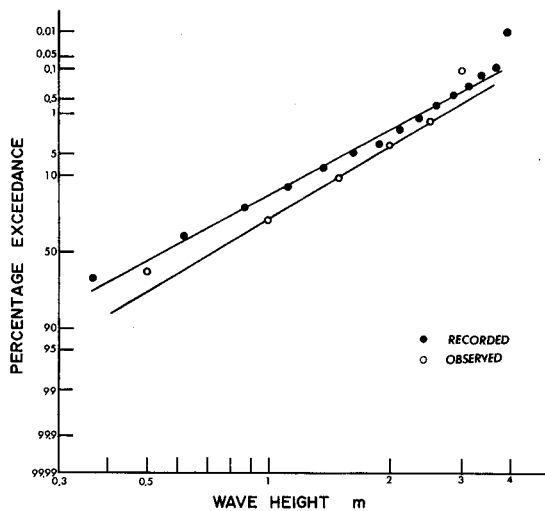
FIG. 6. Cumulative distribution of wave heights.

FIG. 7. Cumulative distribution of wave periods.

heights and average wave periods are 0.5 m and 2.5 sec, respectively, observed wave heights and wave periods are 0.75 m and 4 sec, respectively. Another advantage of the linear relationship is the possible extrapolation to determine lifetime waves. However, because six months of data are not adequate to present any statistically meaningful extrapolations, no such effort is attempted in this study.

Comparison of Joint Distributions of Wave Height and Wave Period

Following the presentation suggested by Draper (1966), scatter diagrams that correlate wave height with the corresponding wave period for recorded and observed data are shown in Figs. 8 and 9 respectively. The numbers of occurrences are expressed in tenths of one percent. Contours of equal frequency of occurrence were drawn in each Figure to bring out the distributions more clearly. Using the relationship derived from linear wave
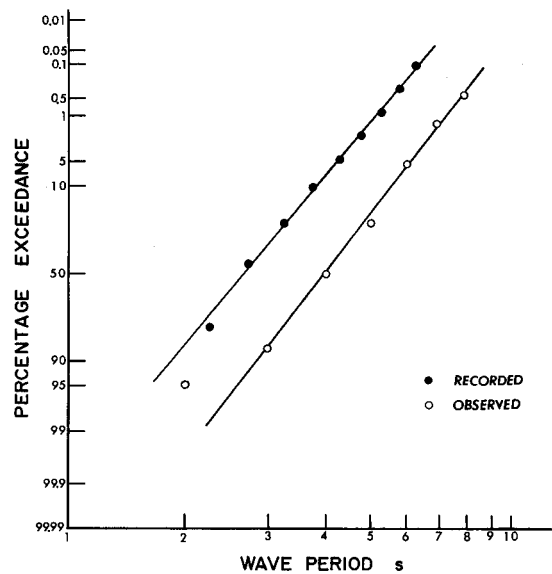
theory between wave period, T, and wave length, L, $L = gT^2/2\pi$, the wave steepness, defined as the ratio of wave height/wave length, can be obtained. Lines of constant wave steepness are also drawn on the Figures. Based on combined data recorded from all four waveriders, Fig. 8 shows that the majority of recorded waves cluster around steepness lines of 1:10 and 1:20. The most frequent conditions are those with a significant height of 0.5 m and an average wave period of 2.5 sec. On the other hand, Fig. 9, based on the shipboard observed data used in the previous comparisons, shows a broader scatter of data distributed around the steepness lines of 1:20 and 1:30. Several data points even exceed the maximum theoretical steepness of 1:7. The most frequently observed wave has a wave height of 0.5 m and a wave period of 3.5 sec. The characteristics depicted by these two joint distributions are dissimilar with the recorded waves
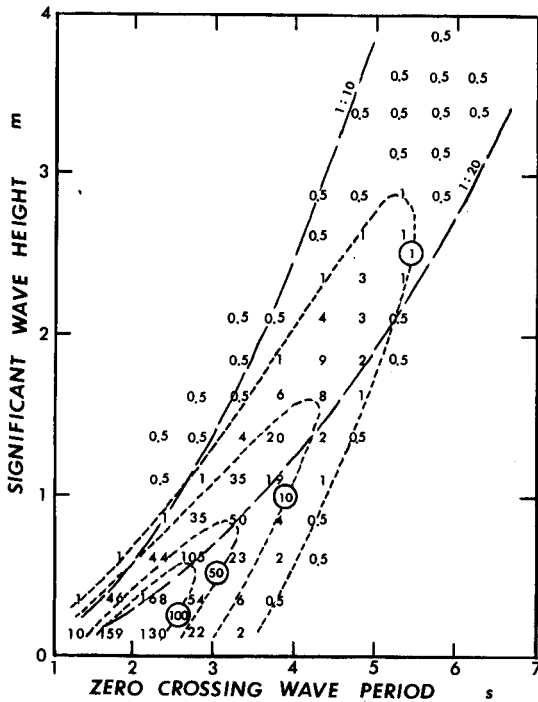
FIG. 8. Joint distribution of significant wave height and average zero-crossing wave period.

FIG. 9. Joint distribution of visually observed wave height and wave period.

generally steeper than the observed waves. This seeming flattening of observed waves is undoubtedly due to visual overestimation of the wave periods, relative to the wave heights.

CONCLUSION

This paper has presented a set of simple analyses to compare the shipboard visually observed waves during IFYGL with the corresponding recorded wave data. The results provide useful refe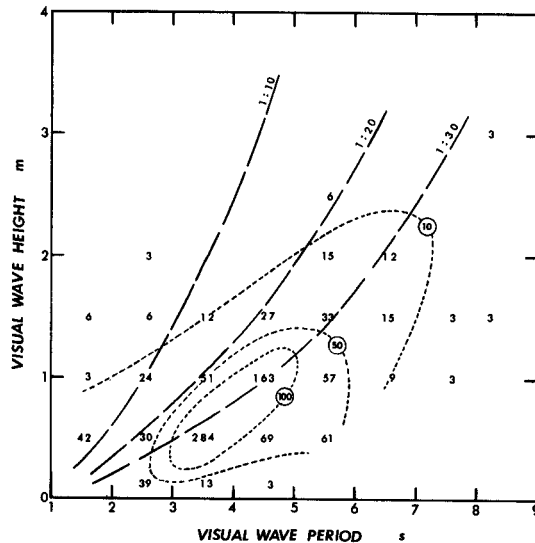rences for applying available wave climatology, mostly derived from shipboard observations to design problems. As a 6-month data set is quite limited, additional comparison studies usina a longer data base are certainly desirable. Perhaps in the future many ships could be equipped with shipborne wave recorders to provide accurate wave climatoloqy data. However, as such implementation is neither economical nor practical, a set of more detailed instructions on visual wave observations, such as those given in Pierson et al. (1960), should be furnished to shipboard observers to improve the quality of the observations. Until further improvments are made, comparison studies like this one will continue to be useful endeavors.

REFERENCES

Darbyshire, J. 1956. The distribution of wave heights. *The dock and Harbor Authority*, pp. 31-32.
Draper, L. 1966. The analysis and presentation of wave data - a plea

for uniformity. *Proc. 10th Conf. Coastal Engineering,* 1:1-17.

Hogben, N. and Lumb, F.E. 1967. *Ocean wave statistics.* Natl. Physics Lab., H.M. Stationary Off., London, 263 p.

Jasper, N.H. 1955. Statistical distribution patterns of ocean waves and of wave-induced ship stresses and motions, with engineering applications. *Trans: Soc. Naval Arch. and Marine Eng.,* 64:375-432.

Liu, P.C. and Robbins, R.J. 1974. Wave data analysis at GLERL. *Proc. Internat. Symp. on Ocean Wave Measurement and Analysis,* 1:64-73.

————. and Kessenich, T.A. 1975. Surface wave data recorded in Lake Ontario during IFYGL. NOAA Tech. Memorandum ERL GLERL-2, 197 p.

Pierson, W.J., Neumann, G. and James, R.W. 1960. Practical methods for observing and forecasting ocean waves. H.O. Publ. No. 603, U.S. Navy Hydrog. Off., 284 p.