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Technical Note

Wave grouping characteristics in nearshore Great Lakes II

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Abstract

This is a sequel with extensive new data to Liu's (Liu, 2000a. Wave grouping characteristics in nearshore Great Lakes. Ocean Engineering 27, 1221–1230) exploratory study on wave grouping characteristics in the nearshore Great Lakes. We analyze recent GLERL time-series measurements recorded by pressure sensors deployed at four nearshore stations in southern Lake Michigan during 1998–1999. With the advantage of continued application of time-frequency wavelet spectrum analysis, the extensive new measurements substantially confirmed the effectiveness of the empirical characterization of wave grouping parameters defined in Liu. We show that a wave group is really the basic element for a detailed understanding of wave processes, in contrast to the conventional approach of using a frequency spectrum as the basic element, which depends on the recording length and requires the data to be stationary. While studying wave time-series alone does not really alleviate the vast intricacies of the wind wave processes, the embodiment of wave grouping as the predominant feature in the wind wave processes clearly represents a significant step forward toward sound conceptual advancement.

Keywords: Wave groupings; Great lakes; Near shore waves

1. Introduction

The fact that waves in the oceans and lakes always come in intermittent groups of successive higher wave heights remains a well-known, readily-observed, but poorly

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Fig. 1. A Lake Michigan map showing the general locations of GLERL pressure sensors deployed in the southern basin during 1998–1999.

Table 1
Details of gage moorings

Station	Muskegon	Benton Harbor	Michigan City	Milwaukee
Latitude	43° 12′ 19.2″ N	42° 8′ 5.4″ N	41° 44′ 6.6″ N	42° 57′ 30″ N
Longitude	86° 20′ 26.4″ W	86° 29′ 30″ W	86° 54′ 26.4″ W	87° 48′ 47.4″ W
Water depth	12.8 m	10.0 m	9.5 m	16.1 m
Date deployed	7/24/98	10/15/98	10/15/98	10/27/98
Date retrieved	8/13/98	4/19/99	4/20/99	5/10/99

understood phenomenon. Numerous conventional efforts to contend with this problem have failed to establish any substantive advances. The conventional approach to the study of wave groupings is circuitously tied to the notion of a wave spectrum. In his recent book, Ochi (1998) summarized the conventional studies of statistical properties of wave grouping as using either the envelop process approach or the Markov chain approach. Both approaches basically derive statistical parameters related to the properties of the frequency spectrum. While the frequency spectrum concept has remained as a pivotal part of ocean and coastal engineering research and development over the last five decades, it requires a stationary time series. Although wave measurements in nature are seldom stationary, this requirement is usually either taken for granted or ignored.

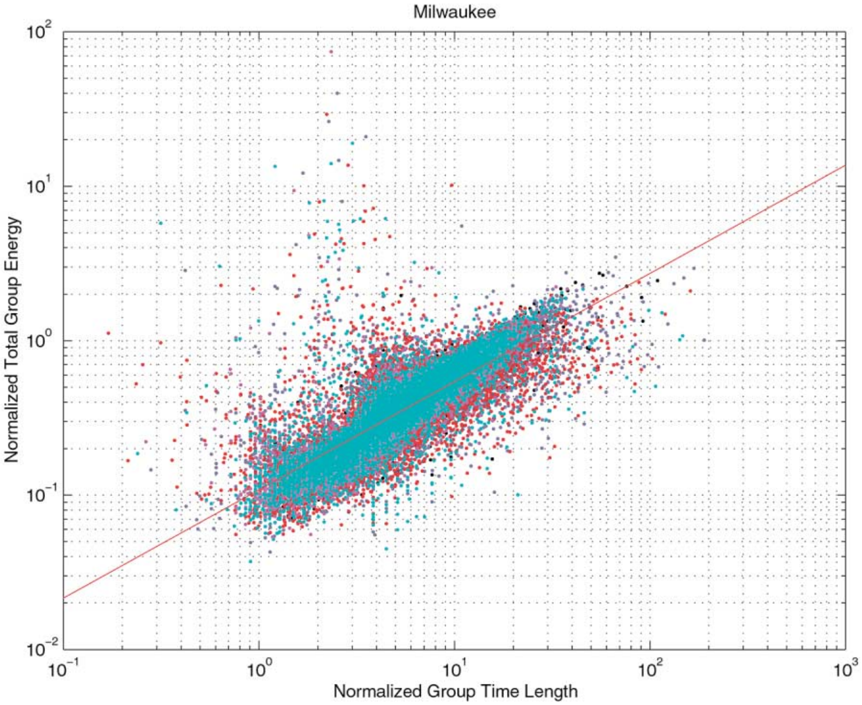

Fig. 2. A scatter plot of normalized total group energy versus normalized group time length for the pressure sensor at Milwaukee, the solid line is a linear regression best fit for the data. (The regression constant α=0.1081 and the exponent b=0.7008.) The different colors of the dots represent measurements from different months.

In an earlier exploratory work, Liu (2000a) put forward an alternative view in which the wave group rather than the wave spectrum is the fundamental parameter for describing wind waves. Liu conducted a time-frequency wavelet spectrum analysis of time-series measurements made in the Great Lakes from 1986 to 1989 and developed several new parameters to characterize an individual wave group. As a sequel to that study, this paper applies these parameters to more recently collected time-series measurements from pressure sensors deployed at four nearshore stations in southern Lake Michigan: one during the summer of 1998 and three during the winter of 1998–1999. The results from these extensive new measurements further substantiate the effective characterization of wave groups presented previously. Thus it seems reasonable to assume that wave groups are really the best basic descriptor of wind waves, in contrast to the conventional approach of using a frequency spectrum as the basic descriptor. While the use of wave groups does not completely alleviate the complexities of wind wave generation, their use is a significant step forward.

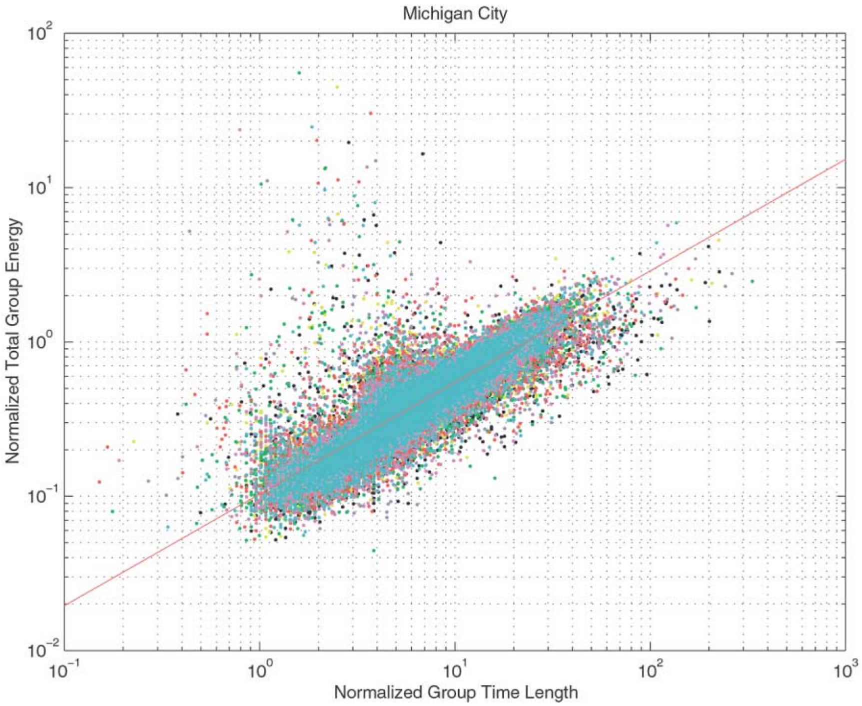

Fig. 3. Same as Fig. 2 for the pressure sensor at Michigan City. (The regression constant α=0.1033 and the exponent b=0.7231.)

2. The measurements

The practice of measuring waves with subsurface pressure sensors to deduce surface wave conditions at a nearshore location has been used widely by coastal and oceanic engineers and scientists since the 1940's. Pressure sensors are convenient to install, and the installations are generally robust and non-intrusive. The underwater measurements provide only an attenuated record of the fluctuations at the surface since the high frequency fluctuations are filtered out. It is still unclear how to best calculate surface wave characteristics from pressure measurements if the frequency spectrum is used to describe the data, but since the properties of wave groups are not affected by the high frequency signals, the measured pressure data can be used directly without converting them to surface measures.

As part of a GLERL study of nearshore wind and wave processes, four moorings of underwater pressure transducers were deployed on tripods in southern Lake Michigan during 1998 and 1999. The tripods were located near Milwaukee, Wisconsin, Michigan City, Indiana, and Benton Harbor and Muskegon, Michigan (Fig. 1); details of the moorings are given in Table 1. Paroscientific pressure sensors (Model 8DP060-1) were mounted 1.4 m above the bottom on each mooring. The sensors were calibrated before the deployments; each has an accuracy of 3.5 mm of water. Sensors

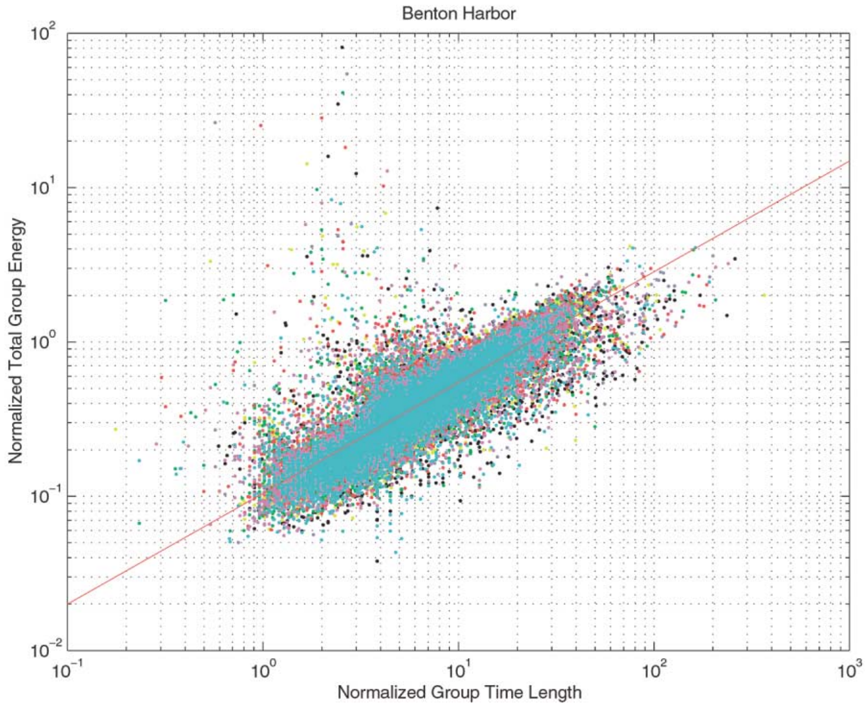

Fig. 4. Same as Fig. 2 for the pressure sensor at Benton Harbor. (The regression constant α=0.1044 and the exponent b=0.7178.)

were sampled at 2 Hz for 2048 samples each hour. All observations were recorded on a data acquisition system mounted on the tripod. After the moorings were retrieved, each time series of water depth was analyzed using the wavelet analysis described by Liu (2000a). In each time series, a value equal to 20 percent of the peak energy density in the wavelet spectrum was used to determine the bounds of the wave groups.

3. Dimensional analysis of wave grouping

Here we follow the exploratory steps first introduced in Liu (1994, 2000a) and define a few basic parameters for a wave group from the time-series data and its corresponding local wavelet spectrum contours:

- The group time length, t_g, with dimension T, which is the difference between the relative maximum and minimum time marks in the time series which the group boundary spanned.
- The total group energy, E_g, with dimension L^2, which is an integration of the local wavelet spectrum over the time length t_g.

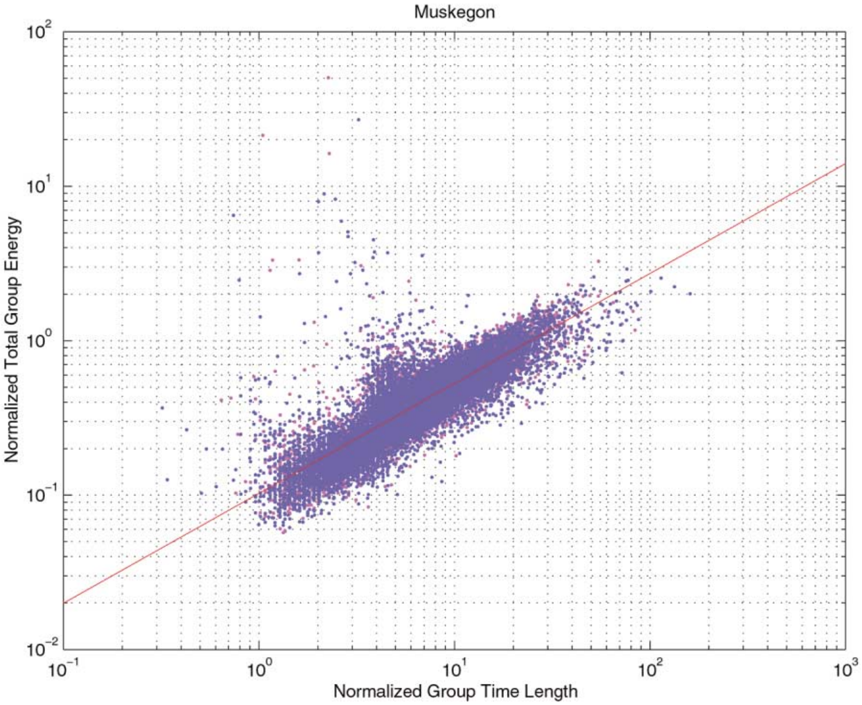

Fig. 5. Same as Fig. 2 for the pressure sensor at Muskegon. (This gage had less data than the other gages. The regression constant α=0.1028 and the exponent b=0.7116.)

- The dominant group frequency, f_p, with dimension T^{-1}, which is the frequency of the peak energy over the time length t_g.
- The dominant group wave height, h_p, with dimension L, which can be obtained from the time series as the maximum trough-to-crest wave height over the time length t_g.

so that we have:

$$f(E_g, h_p, t_g, f_p) = 0 \tag{1}$$

With these four wave group related parameters and two basic dimensions, T and L, classical dimensional analysis leads to the two parameters $t_g{*}f_p$ and E_g/h_p^2 representing measures of normalized group time length and normalized total group energy respectively. Thus we can expect the following empirical relation to prevail:

$$E_g/h_p^2 = f(t_g{*}f_p) = \alpha(t_g{*}f_p)^b, \tag{2}$$

where the coefficient α and exponent b can be determined empirically from data analysis.

4. Results and discussion

Plots of the two normalized group parameters are presented in Figs. 2–5 for the four recording stations in southern Lake Michigan, counterclockwise from west shore: Milwaukee, Michigan City, Benton Harbor, and Muskegon respectively. The different colors in the dots signify the data recorded in different months. With the exception of Muskegon (where data was only recorded for 3 weeks), data was recorded for at least 6 months at each station. The logarithmic plots show a reasonably well-defined linear relationship between the normalized group energy and normalized time length at each station. This means that the more waves present in a given wave group, the higher the normalized energy of that group, and vice versa. The solid lines shown in the figures are the linear regression best fit lines. While the regression constant and exponent are slightly different for the different stations, the lines can all be represented by the averaged values as

$$E_g/h_p^2 = 0.1046*(t_g*f_p)^{0.7133}, \tag{3}$$

which, as the formulated form of Eq. (2), is virtually indistinguishable from the actual regression lines shown in the figures.

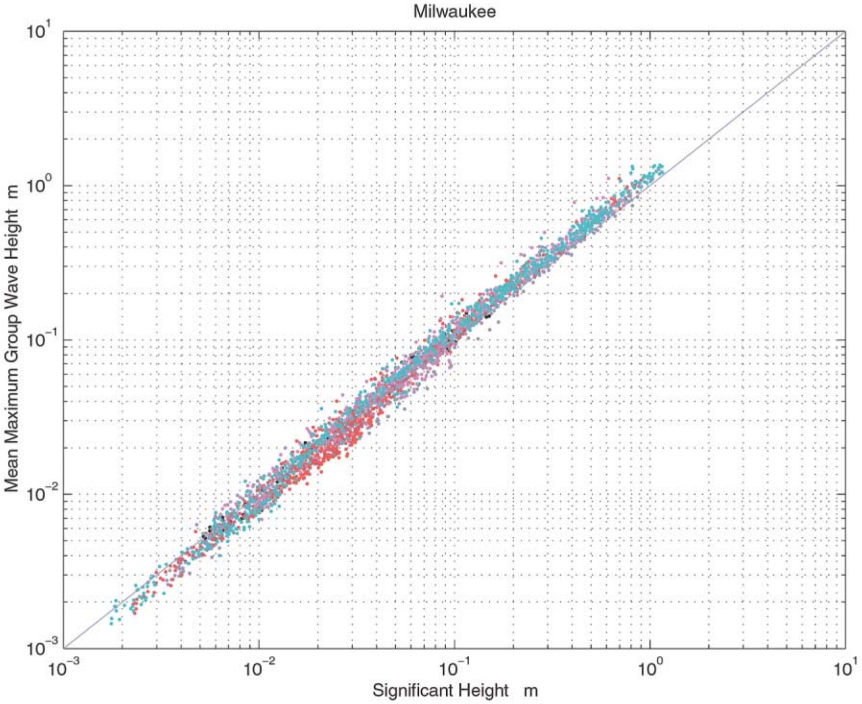

Fig. 6. A scatter plot of mean dominant group wave height versus significant height at Milwaukee, the solid line is the perfect fit line. The different colors of the dots are again representing measurements from different months.

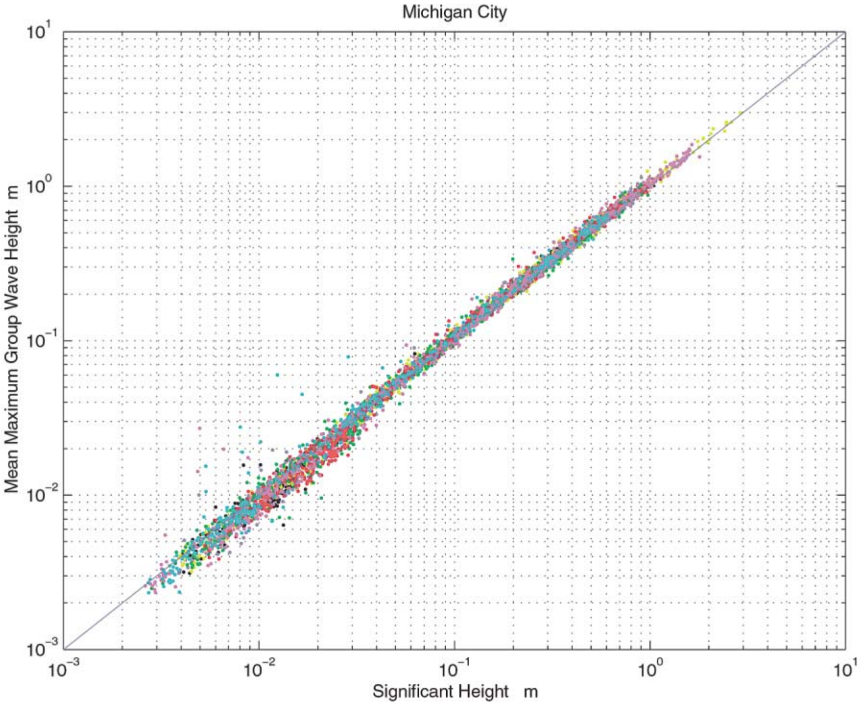

Fig. 7. Same as Fig. 6 for the pressure sensor at Michigan City.

Figs. 2–5 are practically identical. In fact it would be impossible to distinguish them without the captions. When these results are compared to the previous results given in Liu (2000a) for data from northern Lake Michigan and other Great Lakes and in Liu (1994) for data from the continental shelf of mid-Atlantic Ocean, the same relationship exists. So a rational inference would be that the empirical relation in Eq. (3) can be considered to be a universal relation, unaffected by either seasonal or geographical differences. Using Eq. (3) one can easily estimate an approximate energy level from a knowledge of how many waves are in a group. Conversely for a specified energy content, one can determine the number of waves in an individual wave group.

Of course, in spite of the encouraging linear trend shown, the scatter in the figures is really quite extensive, and is similar to the sort of scatter seen in conventional wave-spectrum analysis. In this regard it is difficult to say that this new approach is an improvement. However we wish to emphasize the conceptual difference here. Our results come from an analysis of the individual wave groups, which are more realistic physically than the rather out-dated, intangible wave spectrum (Liu, 2000b). Although using wave groups does not completely alleviate the intricacies of wind wave processes, the results are no worse than those using spectral analysis. By basing the analysis on a more physically realistic description of the observations, the use

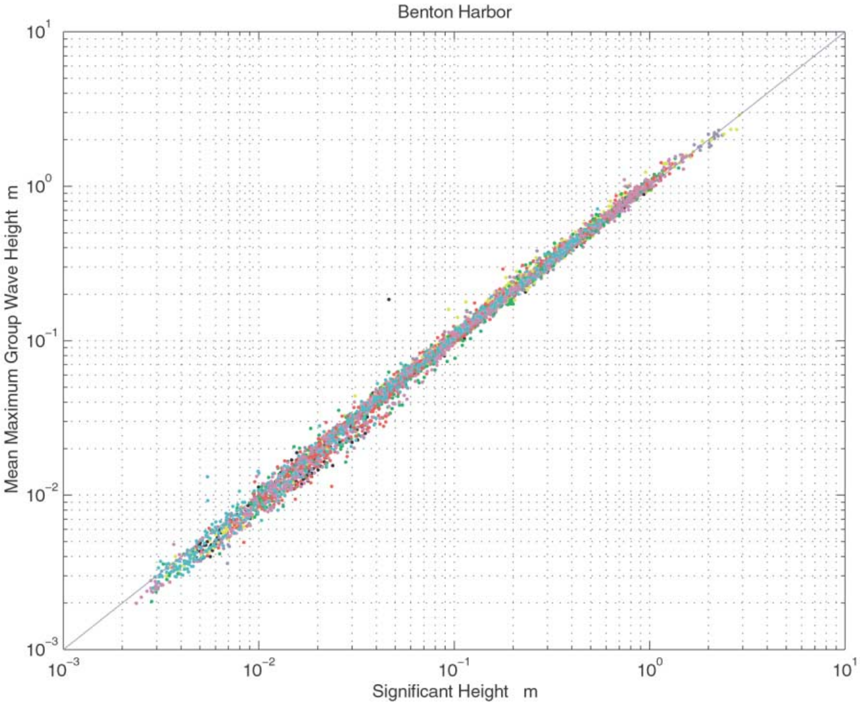

Fig. 8. Same as Fig. 6 for the pressure sensor at Benton Harbor.

of wave groups represents a significant step forward (hopefully) toward a sounder conceptual model.

The parameters developed from the individual wave groups are basically unprecedented and unconventional, so it would be nice to link them with some familiar parameters if possible. Here we again followed the approach given in Liu (2000a), and average the dominant group wave heights, h_p, in each data set and plot them against the corresponding conventional significant wave heights. Note that this is not the height at the surface, but is the significant height (as determined from conventional spectral analysis) of the elevation differences measured by the pressure sensors. The results are shown in Figs. 6–9, for the four stations Milwaukee, Michigan City, Benton Harbor, and Muskegon respectively. Note that in these figures the data are no longer normalized, so in fact they are dimensional data of wave heights in meters.

The solid line in Figs. 6–9 represents the perfect fit one–one correlation, so the figures show that averages of dominant group wave heights measured at depth correlate extremely well with the corresponding significant heights (also measured at depth). These results appear to be different from the cases presented in Liu (2000a, 1994) where the surface mean dominant group wave heights are shown to be approximately 17 percent higher than the corresponding surface significant wave heights. But these results are quite certainly not inconsistent with the earlier results. The contention that in practical applications, such as in engineering design, the mean

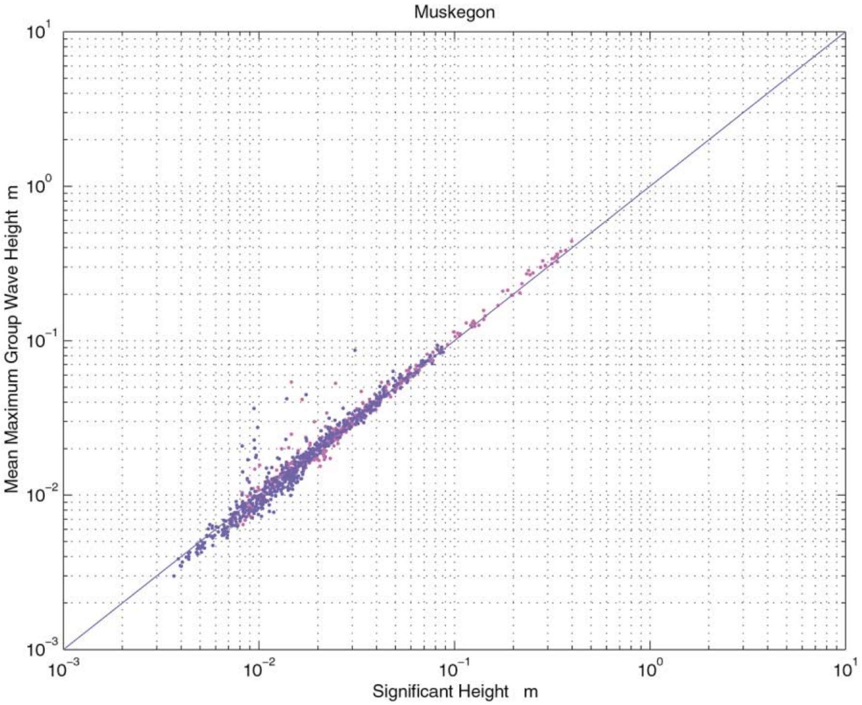

Fig. 9. Same as Fig. 6 for the pressure sensor at Muskegon. (This gage had less data than the others).

dominant group wave height would be more pertinent than the significant wave height continues to be warranted. The effect of filtering in the pressure data for both mean dominant group wave heights and significant wave heights may account for the 17 percent discrepancy. It is very much within the uncertainty range of 6 to 37 percent for conversion factors in conventional studies based on the approach of small amplitude wave theory (Horikawa, 1988). Transformation of pressure measurements to surface waves is still an unsolved matter, but it is much more complicated than the linear or spectral conversions used in conventional analyses.

5. Concluding remarks

We present here a further study using an extensive new data set to supplement the earlier exploratory attempt of Liu (2000a) in applying wavelet spectrum to the analysis of wind wave grouping characteristics. While the results substantially confirmed the earlier findings that an individual wave group can be used as the basic element for wind wave processes, they do not provide an easy paradigm for further research. An individual wave group, while conceptually sound, is by no means easily measured. One important defect is that there is absolutely no indication of how one individual wave group is correlated to the next one in the time domain. Our simplistic approach of examining these group parameters collectively is of practical expediency, but not totally satisfactory. We may expect that the key to the comprehension of dynamics of wind waves would be to grasp and discern the dynamics of wind wave groupings. While the study of wave time series alone does not really solve the vast intricacies of the wind wave processes, the embodiment of wave grouping as the predominant feature in the wind wave processes clearly represents a significant step forward toward sound conceptual advancement.

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