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On the growth of ocean waves

Paul C. Liu[a,*], Chen-Han Tsai[b], Hsuan S. Chen[c]

[a]*Great Lakes Environmental Research Laboratory, NOAA, Ann Arbor, MI, USA*
[b]*Department of Marine Environmental Informatics, National Taiwan Ocean University, Keelung, Taiwan*
[c]*National Center for Environmental Prediction, NOAA, Camp Spring, MD, USA*

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Abstract

The availability of 10 h of continuous, uninterrupted field measurements of wind waves recorded in the western Pacific and containing a complete wave growth episode, has provided a distinct opportunity for us to make a novel, unprecedented examination of detailed wave growth processes. We found that the significance of the size of data used in the measurement, which can only be addressed with continuous and uninterrupted measurements, reflected the ineptness of the conventional approach toward further detailed understanding of realistic wave growth processes, as the conventional 20 min data size essentially stamped out any dynamics with time scale below 20 min. While our conventional understanding and modeling were generally operative and useful, they left no real vestige on time localized mechanisms such as wave grouping or wave breaking processes all with time scales much less than 20 min.

Keywords: Ocean waves; Ocean wave growth processes; Time-frequency analysis

1. Introduction

The question "how do ocean wind waves grow" may strike someone as rather superfluous since twice in the last century, the problem of wave generation and growth was considered as theoretically solved. The first was in the mid-1920s after the publications of Jeffreys (1925) which advanced the concept of sheltering mechanism between wind pressure and the ambient atmosphere over waves. Then just over three decades later in 1957, the virtually simultaneous publication of Phillips (1957) and Miles (1957) separately and jointly formed the basic components of modern wind wave modeling that is still being used today. While Jeffreys' theory suffered a lack of observational supports, the substantiation for Phillips and Miles conjectures from experiments and field measurements had been mostly circumstantial at best. In a recent historical review, Mitsuyasu (2002) rightfully surmised that "we are still not in a position to completely understand the mechanism". So it does not matter how one might comprehend the classical, theoretical aspects of wind generation and growth, it is unlikely that anyone can unreservedly answer the question of how do wind waves grow. It is not our intent in this paper to belabor the theoretical aspects of wind waves. Rather we wish to present some unconventional, empirical evidences of wave growth processes based on continuous wave measurements that may help stimulate and steer new insights toward future theoretical considerations, since results from actual field measurement are still relatively rare.

2. The data

The data used in this study were recorded in the western Pacific Ocean, northeast of Taiwan outside the Bisa fishing harbor to the east of the city of Keelung. Wave measurements were made with an ultrasonic wave gage (Tsai et al., 2004) equipped with a 200 kHz upward looking acoustic transducer mounted on a gimbal mechanism, along with a pressure transducer and an electromagnetic current meter. The wave gage was deployed at (121.783 °E, 25.150 °N) in 26 m water depth and set to record three 20 min segments of data hourly at 2 Hz resolution. The

*Corresponding author.
E-mail addresses: Paul.C.Liu@noaa.gov (P.C. Liu), chtsai@mail.ntou.edu.tw (C.-H. Tsai), Hsuan.Chen@noaa.gov (H.S. Chen).

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continuous measurements, stretched across various extended time periods from the autumn of 1999 through the summer of 2003, had covered numerous cases of complete episodes of wave evolution process from calm sea, through growth to decay. Fig. 1 presents an example of one of the unexplored wave growth cases that displayed continuous time-series data for a 10 h sweep that ran through the morning hours of October 3, 1999. This is the data set we use in this paper. As there was no directly measured wind data at the wave measurement site, a set of corresponding hourly averaged wind speed and wind direction, recorded from the nearby Keelung harbor is plotted in Fig. 2 with the time concurrent part shown in red. It appears that the wave growth correlates with the rising in wind speed consentaneously.

3. The conventional approach

The first step of the conventional approach in basic analysis of recorded wind wave data is customarily the calculation of a frequency spectrum for a 20 min segment of the time-series data. From the calculated spectrum, usual wave characteristics, such as significant wave height and various wave periods can be readily extracted. These extracted wave parameters are generally used to test and calibrate wave models. One of the most important and widely used parameter is the significant wave height. There are, however, two approaches in extracting this basic parameter that were taken for granted and used interchangeably. One approach is based on the original use of significant wave height, $h_{1/3}$, defined as the average of the highest one-third of the crest to trough waves in that segment of time series by sifting through each individual trough to crest waves in the data. The other, perhaps more prevalently used, approach of getting the significant wave height, h_s is simply obtained by four times the standard deviation, as it is also the square root of the variance of the data segment, corresponding to the integration of the calculated wave frequency spectrum. While for an assumption of Rayleigh distribution for the wave heights, the two approaches, h_s and $h_{1/3}$, are, theoretically, expected to yield the same outcome. In actuality, however, they can vary by as much as 5–10 percent. In this paper, we choose to make a pertinent distinction. We feel it is timely and apropos to clarify the indistinct practice by literally calling the height obtained from variance, h_s, the *standard deviation wave height*, which is more factual than the commonly mixed labeling of significant wave height.

In analyzing the episode shown in Fig. 1, we focused our interest on two parameters in particular: the standard deviation wave height and the maximum zero-upcrossing wave height. The results based on consecutive 20 min segments of time-series data recorded in the morning of October 3, 1999 illustrated a reasonably smooth, composed display of conventionally accustomed wave height growth picture as shown in Fig. 3. Perhaps the only difference

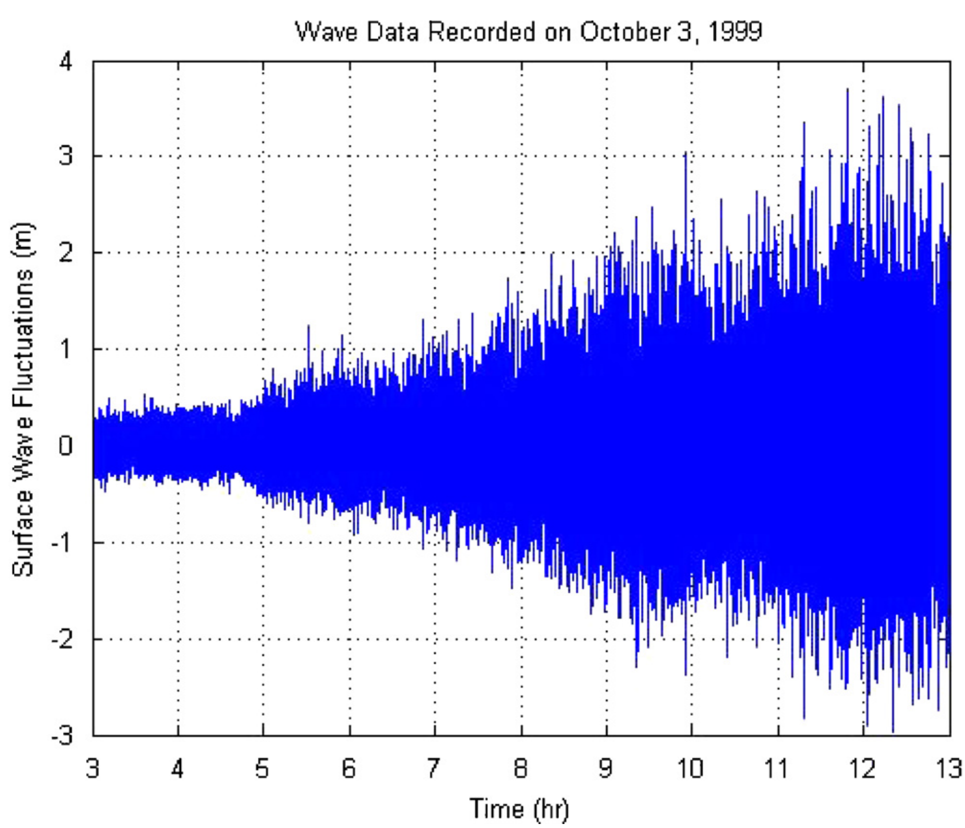

Fig. 1. An episode of continuous wave growth time-series data on October 3, 1999.