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WAVE HEIGHTS IN A 4D OCEAN WAVE FIELD

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ABSTRACT

This paper presents a preliminary examination and analysis of a small suite of 4-D wave data to explore what new insight or inference we can garner -- particularly toward the realm where conventional approaches have not been traversed. While we caught a few glimpses that might indicate a need for new conceptualizations, it by no means to negates the vast positive contributions the conventional approaches have been made in the past century. We feel it is timely to encourage further 4-D ocean wave measurement and thereby facilitate fresh new states of study and understanding of ocean waves.

INTRODUCTION

The configuration of ocean waves, even to the most casual observers, should be an ostensibly four-dimensional phenomenon, (x, y, z, t). But for over six decades, to this day, the ocean waves research community has been content with a general perception of ocean waves that was predominantly based on single-point in-situ wave measurements, (x, t), either Eulerian from fixed probes or Lagrangian from floating buoys. As a result, the present day conventional conceptualization of ocean wave studies has been strictly (x, t) oriented, with seemingly three dimensional dynamics and models built around it. Thus developed a kind of subjective reality for which whole ocean wave processes are described through this one-dimensional, single-point wave measurement realization.

One of the main consequences of single-point measurement is clearly reflected by the difficulties that all the established ocean wave theories and conventional ocean wave models have been facing in trying to making further advances. The lament of Komen et al. (1994) that we are

> ". . . not able to make wave predictions that always fall within the error bands of the observations,"

made in the early 1990's remains true today, nearly two decades later.

In this paper we wish to present some preliminary results of 4-D wave data analysis on the available data obtained from the emerging ocean wave measurement system, the Automated Trinocular Stereo Imaging System (ATSIS) developed by Wanek and Wu (2006). The ATSIS is developed for non-intrusively measuring the temporal evolution of three-dimensional wave characteristics. This is unquestionably a new frontier of ocean wave measurement and analysis.

THE ATSIS MEASUREMENT

The ATSIS system basically consists of three digital cameras mounted and configured as manageably portable system that can be readily installed in the field as shown in Figure 1

While most of us are brought up knowing only single-point wave measurements, measuring ocean waves in 3D space rather than at a single point is certainly not new. Long before the all-embracing use of pressure cell, step-resistance staff, or buoy accelerometer measurements at a single location that started since the 1950's era, stereophotogrammetry had been used in the 1920's to derive the topography of the sea surface as shown in Figure 2 from the book of Sverdrup *et al*. (1942). It was certainly a remarkable accomplishment over 8 decades ago. But it's only one snap shot of the contours of ocean surface behind understandably extensive efforts. The ATSIS system of Wanek and Wu (2006), on the other hand, can provides a contour picture of the ocean surface every fraction of a second or more, depending on whatever resolution is required. So while the idea of stereo 3D imaging is not exactly new, the advancement in the technology in recent years, especially in the digital camera area, makes it possible for the ATSIS system to provide a 4D wave field (x, y, z, t), a new arena we are only starting to explore.

Figure 1. A set up of ATSIS system of 3 digital cameras.

Figure 2. From Sverdrup *et al.* (1942). Topography of the sea surface derived from stereophotogrammetric pictures of the sea surface taken onboard the Meteor on January 23, 1926.

DATA AND ANALYSIS

Widening from a single-point measurement to the measurement of a spatial area of the ocean surface is clearly a new venture. As much as the latter is making a giant step closer to the objective reality if not the true reality of ocean waves, we are really at a stage where we do not have a clear notion on how to proceed with the analysis of 4D data. Instead of the familiar approach for the usual single-point time series data that usually led to a single significant wave height through frequency spectrum analysis, now the ATSIS system instantly provides a field of data that is equivalent to tens of thousands of single-point time-series data and a wide distribution in sizes of significant wave heights and spectra. What then is the pertinent course to follow in order to analyze these new wealth of data?

Undoubtedly new approaches will continue to evolve as more and more data become available. In the mean time, we are confronted with the availability of 15 seconds of 4D (x, y, z, t) data, which was recorded in a small lake, specifically Lake Mendota near Madison, Wisconsin. The data was sampled at a frequency of 10 Hz. To proceed, we shall start with an exploratory approach by performing conventional analysis for each individual single point data. For a pixel grid of (441x 251), there are 110,691 single points with each point providing time series data 15 seconds with 10 Hz resolution. To effectively visualize all these volumetric data, we simply calculate the total energy represented by each individual standard deviation wave height, i.e., 4*standard deviation, to demonstrate their essential character and then plot them in 3D space as shown in Figure 3. It is rather surprising and even pleasant to see this well formed result from basically a statistical estimate for each pixel point. Furthermore the distribution of the standard deviation of the wave heights is shown by the histogram in Figure 4. One might be tempted to try fitting a distribution function to this clearly skewed case. We do not feel that really serve much meaningful purpose. Suffice it to say that in the 3D frame work, we can readily obtain useful information of the wave field even from merely 15 seconds data. This is something rather inconceivable in the conventional approach.

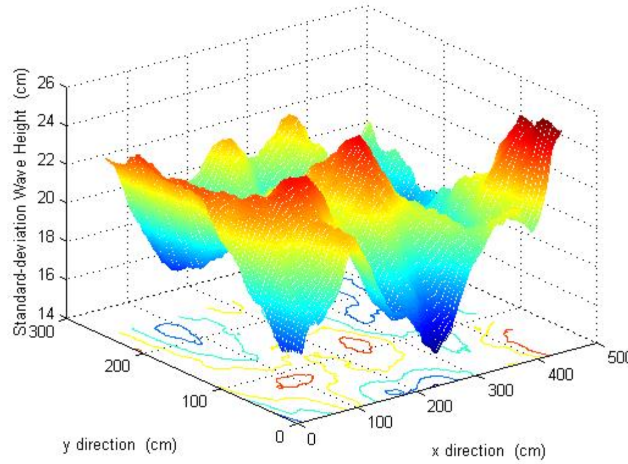

Figure 3. A 3D plot of the standard deviation wave heights for the pixels, each represents a single point data set.

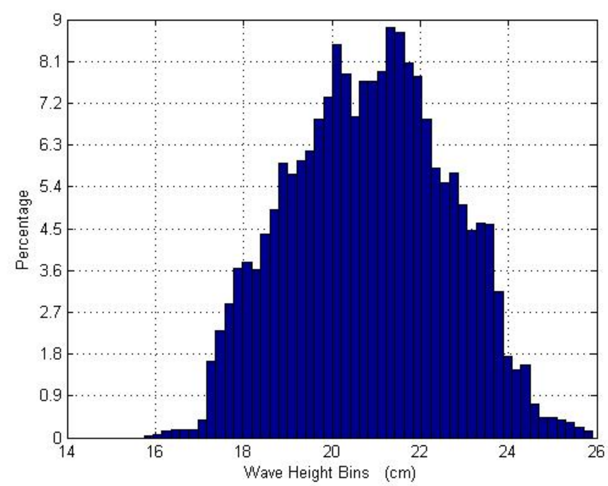

Figure 4. Histogram of the standard deviation wave height given in Figure 3.

To advance with the 4D data, we are immediately faced a very basic question: what is the wave height in a 3D wave field?

Being completely nurtured in the conventional conceptualization, we are conditioned to regard a wave height as the distance between the trough and crest in a single location. This is very perceptive and straightforward when we look at a customary plot of time series data at a single location. But in the open ocean, how do we sift through a distance between a crest and a trough? So what is the wave height for a given region of the ocean?

The conventional practice of using one single-point significant wave height to represent the wave height of a region of the ocean surface is clearly no longer valid in a 3D wave field. Conceivably when a seafarer in the open ocean talks about a wave height, it is most likely the height of a visible crest rather than something between trough and crest. So we choose to first examine the highest crest at each instance of the data.

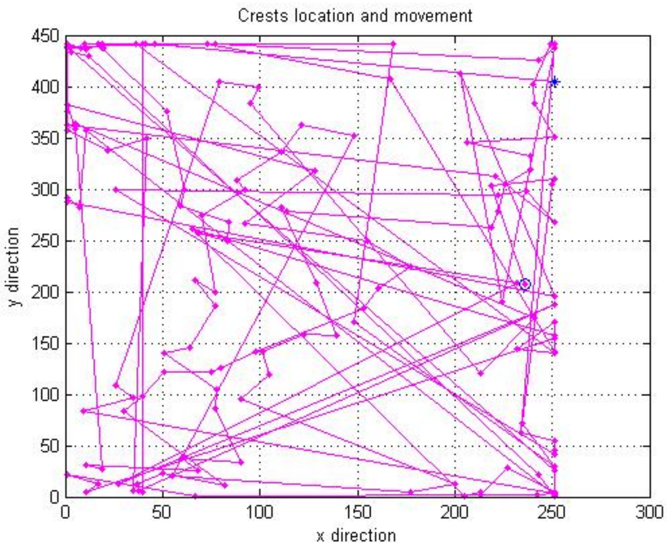

Figure 5. The crest locations of the data set. The starting and ending locations are marked by an * and a circle respectively.

While the height of the crest varies from one instance to the next, the location of the crest also varies constantly. Figure 5 plots the crest locations of the data set. Clearly from one instance to the next, the location of the crest moves all over the region. Similarly for the locations of the troughs, they too are moved all over the region as shown in Figure 6. In each figure the starting and ending locations of the troughs and crests are marked with an * and a circle respectively. Evidently the crest and trough of the same instance are never occurring in the same location. Thus it is understandable that the familiar notion of wave height evolved from trigonometry and time series analysis can not be generalized to the 3D wave field as one might wish to bring it into play. For practical reference, which may or may not be meaningful, we plotted the crests, troughs, and corresponding sum of crest and trough, with respect to time as shown in Figure 7.

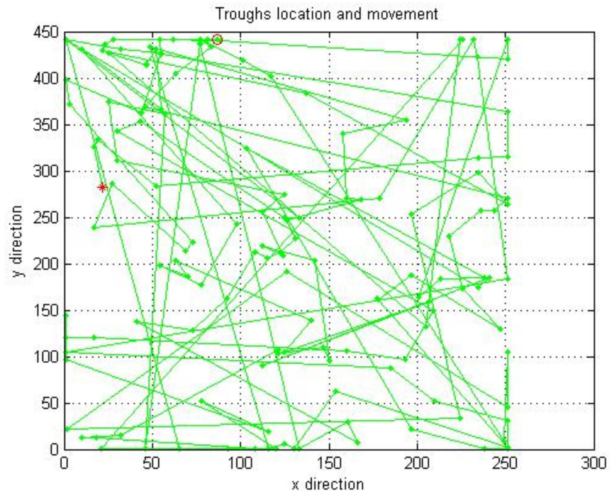

Figure 6. The trough locations of the data set. Again the starting and ending locations are marked by an * and a circle respectively.

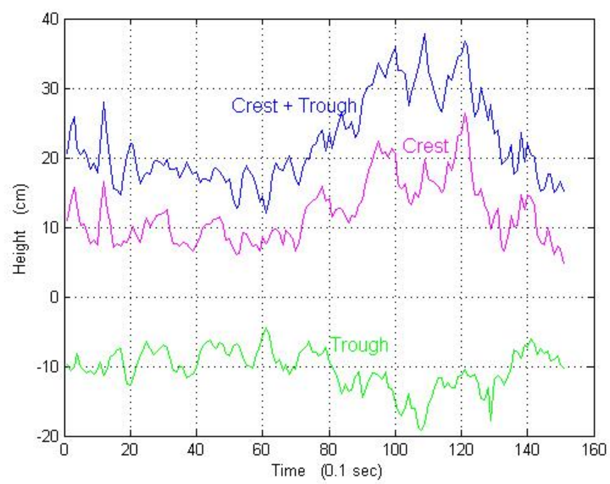

Figure 7. Plottings of the height of crest, trough, and crest+trough with respect to time.

It gives us some indication of the surface fluctuations of the ocean surface in that region. But the question regarding what is the wave height in a 3D wave field remains unanswered.

FURTHER DISCUSSIONS

The title for this paper is "Wave height in a 4D wave field." May be it is more appropriate to turn it into a question as: "What is the wave height in a 4D wave field?" But either way we are not able to provide an expressively satisfactory answer to the question at the present. We are exploring the unexplored realm. May be our familiar basic notion of a wave height is no longer feasible in the 4D wave field. At any rate when a seafarer in the deep ocean encountering a very large wave, what really matters at that moment is really the height of the crest that will crushing down. So probably it's time for us to cast off the crest-to-trough notion of wave height in favor of a simple crest height in the 4D wave field. As we alluded to earlier that we are confronting a new frontier and new reality of ocean wave measurement and analysis, we need to be flexible not stuck on outmoded suppositions.

One of the basic premises of the conventional conviction on the long standing single location ocean wave measurement is that the data from this single location measurement represents the wave condition of a general region. So if waves are measured from another point of this region, it should be generally the same. We found that is not the case. Even for a small pixel region the data are in fact varying from one pixel to the next. Herein holds the answer of why Komen et al. were not able to make wave predictions that always fall within the error bands of the observations as expected. Single-point in-situ wave measurement is simply incapable of embodying the realistic ocean waves for more than just that one single-point location. The theoretically refined wave prediction model can not be made in accord with the observations at a single point is simply because that the single point observation does not represent the reality the theoretical model is trying to portray. We need the more comprehensive 4D ATSIS ocean wave measurements.

CONCLUGING REMARKS

After six decades of dominating the ocean wave conceptualization as the innate reality, the single-point wave measurements have served well to the general wave studies. However the progress and model refinement has been in stagnate during the last dozen years, we feel it is timely that new system of ocean wave measurement should be initiated and implemented toward rightful reality. Along with this new frontier of ocean wave data measurement system, there will be a whole new realm of wave data analysis system poising to be cultivated. New paradigm and new conceptualizations that has not yet been contemplated should be further explored. For instance, instead of the distance between a trough and an adjacent crest at a single point, what should a wave height in the four-dimensional wave field be? There should never be any shortage of impetus or excitement in this new ocean wave measurement frontier – if one can refrain from insisting on antiquated notion that's on the verge of obsolescence and readily opening up to glaring fresh new perspectives.

ACKNOWLEDGMENTS

This is GLERL contribution no.1465.

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