A New Wave Directional Spectrum Measurement Instrument

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Abstract - An instrument for high accuracy measurement of wave directional spectra was designed and implemented. The instrument, called the 3D-ACM WAVE, combines an acoustic current meter and a high accuracy micromachined pressure sensor into a single instrument. The instrument measures two orthogonal horizontal components of current velocity and the pressure at the deployment depth. Data is collected, and sequences of these three measurements are used to determine wave spectra, based on readily available spectral analysis techniques. The sampling rate of the 3D-ACM WAVE is 5.36 Hz, allowing a wide spectral range for wave characterization. Field results from ocean deployments show that the data collected by the instrument can be successfully used to calculate wave directional spectra. The field results, which are presented in this paper, compare favorably with results acquired using other proven techniques.

1. INTRODUCTION

Both the scientific and the commercial community have a great interest in measuring wave directional and point spectra. The measurement of ocean and higher frequency coastal wave spectra has been previously done by various instruments [1]. Often the measurements were done solely with pressure sensors. Ideally the wave spectral information could also be computed from current meter data, by using the vertical water displacement information. However, acoustic current meters [2] cannot provide high precision measurements of vertical water displacement. This is a problem, especially when the amplitude of the waves of interest is small (several *cm*).

In [3] a new technique for wave direction and spectrum measurement was proposed. The technique, which is used by the 3D-ACM WAVE, combines acoustic current meter measurements with measurements from a subsurface pressure sensor in order to acquire high precision measurement of wave direction and spectra.

2. INSTRUMENT HARDWARE

Figure 1 shows the 3D-ACM WAVE in a protective frame. The instrument has four acoustic “fingers”. These fingers house eight acoustic transceivers (two per finger). The current meter uses the eight acoustic transceivers to create four acoustic paths. The flow velocity is measured by observing the phase shift of the sound along three of the four acoustic paths. One path is always disregarded - this is the path that is contaminated by the wake from the center support strut.

Figure 1 *3D-ACM WAVE in protective frame*

The 3D-ACM WAVE electronics is shown in Figure 2 in block diagram form. The system is built around a Siemens 80C167 16-bit microncontroller. The microcontroller communicates with the user or an external controller. It is also connected to a programmable real-time clock. Using the real-time clock the 3D-ACM WAVE can be programmed to acquire data for a certain duration of time and then shut itself off. After a preprogrammed time, the instrument can "wake up" again and take data, shut itself off again, and keep repeating this cycle until told otherwise by the user.

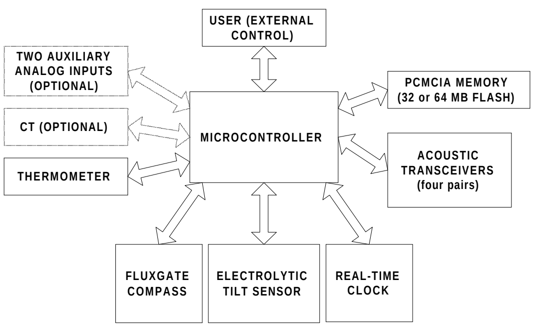

Figure 2 *3D-ACM WAVE hardware outline*

The instrument also includes a *3-axis* fluxgate compass, which measures the Earth's magnetic field, and a *2-axis* electrolytic tilt sensor, which measures the instrument's angle to the vertical. Using the compass and the tilt sensor we can determine the heading of the instrument, and consequently estimate the flow direction in Earth-coordinates.

The instrument measures pressure using a Silicon machined *0.01% F.S.* (*F.S.=344.78 kPa)* precision pressure sensor. The pressure sensor provides wave height information. Averaging wave height information one can acquire tide information.

Data is stored on one or two PCMCIA flash memory cards. The memory capacity is 32 MB for one card, and 64 MB for two cards. Using non-volatile flash memory allows the instrument to be shut off without losing recorded data. Also, recorded data will not accidentally be lost due to loss of battery power.

The instrument measures temperature using a thermistor. It is capable of communicating with a CT instrument in order to acquire high accuracy conductivity and temperature information. Finally, the instrument can sample two analog inputs (these inputs can come from user supplied instruments).

3. INSTRUMENT OPERATION

During deployment the instrument can be fixed in a frame mounted on the ocean floor, as shown in Figure 3. The current meter measurements provide the horizontal wave and current direction information. The pressure sensor data in combination with the current meter data is used to determine the wave spectrum, based on readily available spectral analysis techniques [4]. The high precision pressure sensor also allows for collecting accurate tide information. Vector averaging of the acoustic current sensor data also yields mean flow speed and direction. Note that, since the instrument has a tilt sensor, it does not have to be mounted in a vertical position. The tilt angle can be measured and corrected for.

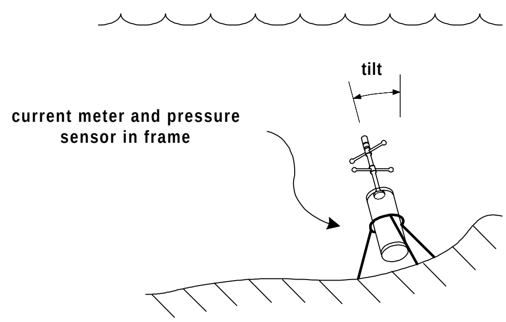

Figure 3 *Instrument positioning*

The instrument can be used in three modes:

- bursting mode,
- vector averaging mode, and
- interleaved mode.

In bursting mode the instrument saves every data point that it acquires into memory. The data can later be processed. In vector averaging mode the instrument performs vector averaging on the sampled data and only stores the vector averages in memory. These averages are later downloaded to a computer and processed. Interleaved mode can be used when the instrument is programmed to shut itself off and wake up periodically. Let us observe *(n+1)* intervals of operation in interleaved mode. During these *(n+1)* intervals the instrument will work in vector averaging mode during *n* periods of operation, and in burst mode in one interval of operation.

4. FIELD MEASUREMENTS

An evaluation of the performance of the 3D-ACM WAVE may be made through examination of results from field measurements. This section presents directional wave spectra, significant wave height, and mean wave direction measurements over extended periods of time. When evaluating a new instrument, it is convenient to provide comparative field measurements with another proven instrument. Accordingly, this section also provides a comparison of directional wave spectra calculated from coincident data measured by a 3D-ACM WAVE unit and an adjacent InterOcean S4DW instrument.

Two 3D-ACM WAVE units where utilized for measuring directional waves and currents, along with a suite of other instruments, in an intensive year-long wave and sediment dynamics study at New Plymouth, New Zealand. The experimental design of the program integrates a wide range of field measurement techniques to provide a unique database for the calibration/validation of numerical simulations of coastal processes. Measurement of the reference boundary wave condition for the study (*Site L1*) employed a 3D-ACM WAVE unit deployed *8.5 m* below the surface on a taut-wire mooring in *23.4 m* water depth. The second unit was deployed on a seabed frame at *9.4 m* depth (*Site L2*) and was used to monitor waves and currents at an inshore sediment tracer release site. At both sites, burst data was collected for *18 minutes* at *6-hourly* intervals, with the instruments being serviced monthly.

This paper uses data collected over *76 days* in 1998 from *Site L1* and from four comparative measurements using an S4DW sited on a seabed frame adjacent to the 3D-ACM-WAVE seabed frame at *Site L2*.

4.1 RESULTS

Figure 4 presents wave directional spectrum plots of one event from data collected by the 3D-ACM WAVE instrument (top plot) and the S4DW instrument (bottom plot). In the plots, the direction of wave advance is represented on the *x-axis* with frequency on the *y-axis.* Both the direction and frequency values are discrete. In each plot a “column” of bins represents the spectrum of the component of the wave going in the direction denoted on the *x-axis*, at discrete frequency values denoted on the *y-axis*. The magnitude of the spectrum for a given direction and frequency bin is given by the shade of the bin – white indicates the smallest magnitude, and black the largest magnitude. Directional spectra were resolved from the two orthogonal horizontal components of current velocity (U and V) and pressure measurements using the MATLAB routine TSERIES [5].

The spectra produced from both instruments were found to be highly similar (Figure 4). However, it was noted that there was a difference of approximately *10*° in the resolved direction of the wave energy.

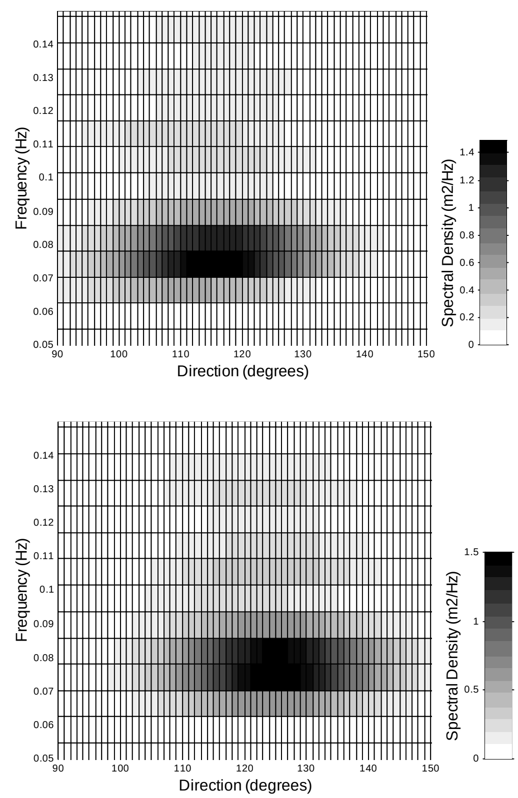

Figure 4 *Directional wave spectrum from 3D-ACM WAVE data (top plot) and from S4DW data (bottom plot)*

Figure 5 is a time-series plot of the mean direction and significant height of the waves as measured by the 3D-ACM WAVE over *76 days* at *Site L1*. This plot illustrates the utility of the instrument in its capacity to measure a highly variable and periodically energetic wave environment.

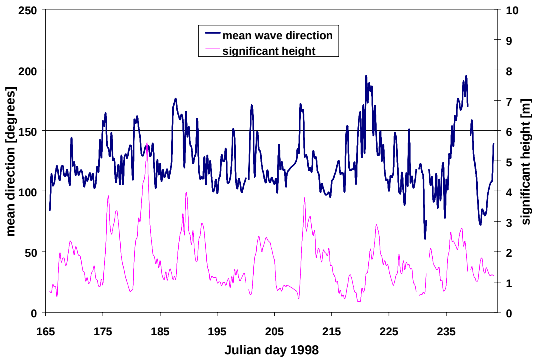

Figure 5 *Mean wave direction and significant wave height measured at Site L1 (**New Plymouth, New Zealand**) over 76 days in 1998.*

This utility is further illustrated by four directional wave spectrum plots (Figure 6), showing sequential events measured over one day (Julian day 182) using the 3D-ACM WAVE at *Site L1*. These events are *6 hours* apart and cover the peak of a migrating storm condition. The plots clearly show the ability of the instrument to resolve the distribution of wave energy across frequency and directional components.

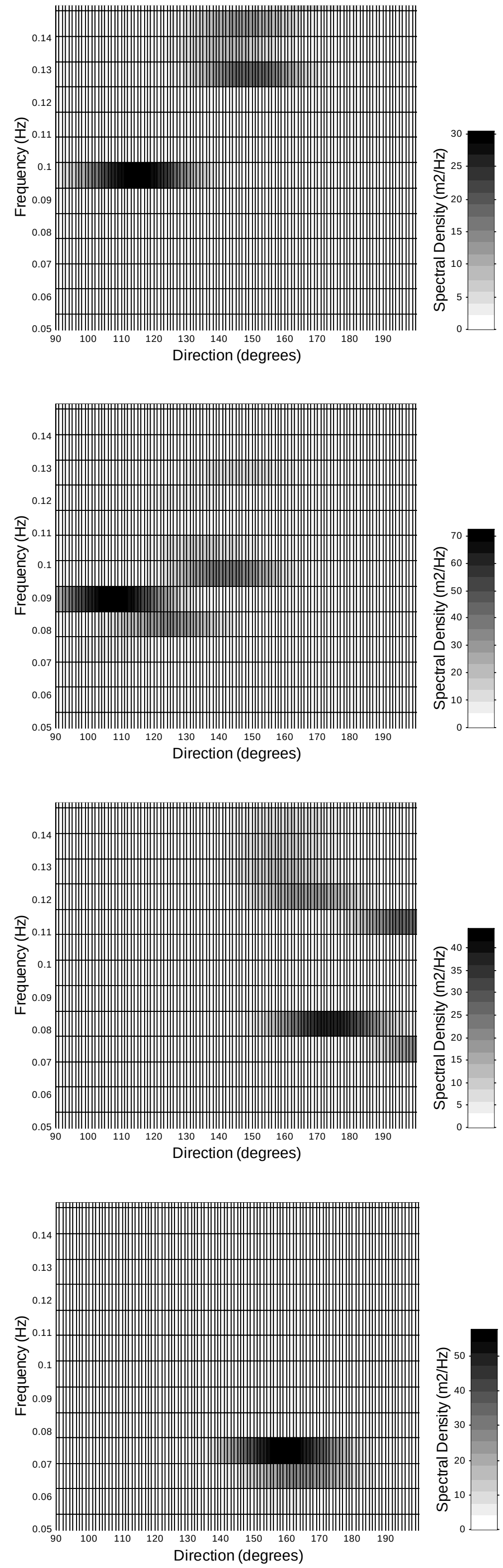

Figure 6 *Directional wave spectra of four sequential events (Julian Day 182, 1998) measured using the 3D-ACM WAVE from Site L1, New Plymouth, New Zealand*

5. CONCLUSION

A new instrument for measuring the directional spectrum of waves was designed and implemented. The instrument, called the 3D-ACM WAVE, is capable of high accuracy wave characterization. The instrument's advanced electronics enables the user to collect data at the rate of *5.36 Hz*. Field data from a *76-day* ocean deployment at New Plymouth, New Zeland show that the instrument can successfully be used to measure directional spectra of highly variable and periodically energetic wave environments. The field results compare favorably with results obtained using another proven instrument.

6. BIBLIOGRAPHY

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