PUV Wave Directional Spectra
How PUV Wave Analysis Works

Introduction

The PUV method works by comparing velocity and pressure time series. Figure 1 shows that pressure and velocity (in the direction of the wave) are in phase with each other and correlated. The velocity under the crest of the wave is in the same direction as the wave itself.

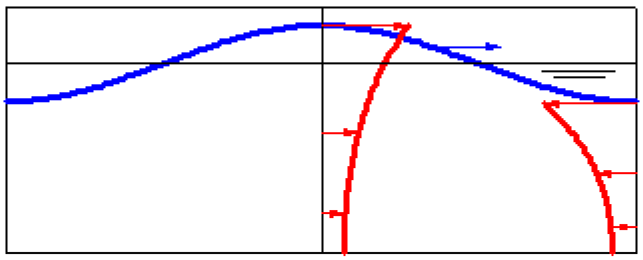

Figure 1. The wave at the left moves in the direction of the blue arrow. The maximum pressure is under the crest, and the maximum velocity, in the direction of the wave, is also under the crest.

Figure 2 shows time series of pressure and velocity under waves traveling toward the east (where they will break on a beach). The east velocity and the pressure are nearly in phase with one another. Since the largest east velocity coincides with the largest pressure, you can tell these waves are heading east, not west. And because the north component is much smaller than the east component, the velocity component to the north is small and the waves travel almost exactly toward the east.

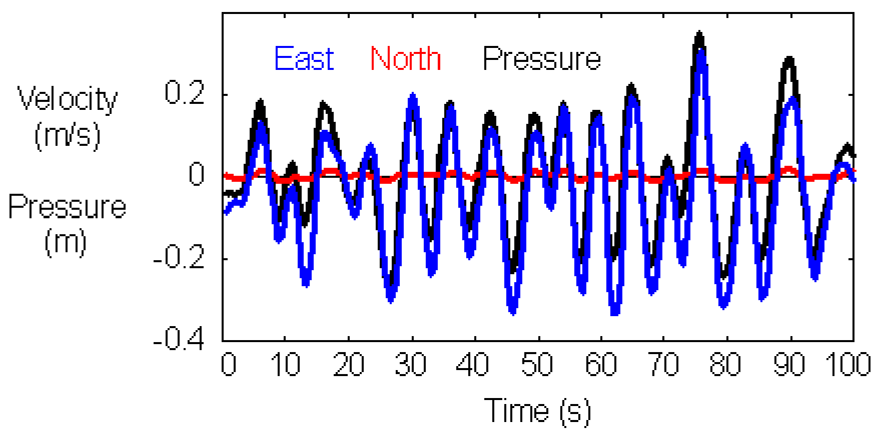

Figure 2. Velocities and pressure under waves traveling east. The mean pressure has been removed from the pressure signal.

Figure 3 shows similar time series, but for waves traveling ENE. Here, the north component is in phase with the pressure just like the east component. The fact that the largest north component coincides with the peak pressure tells us that the waves are heading north, not south. The fact that the east component is larger than the north component tells us that the waves are going more east than the north, hence ENE.

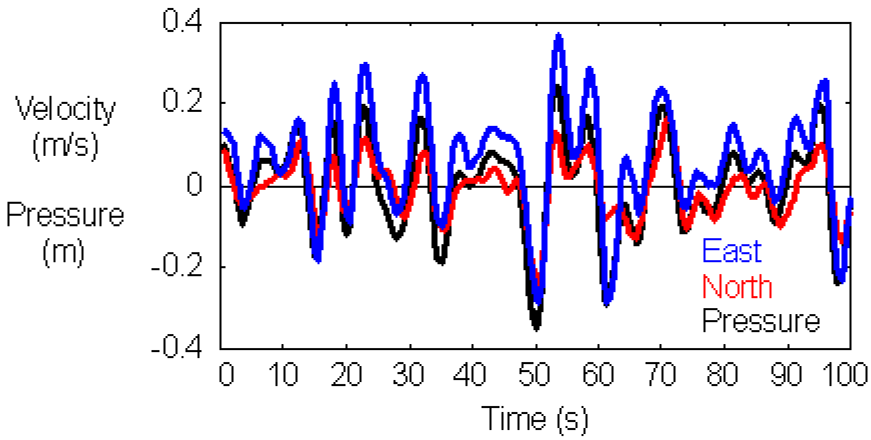

Figure 3. Velocities and pressure under waves traveling ENE. The mean pressure has been removed from the pressure signal.

The PUV wave analysis compares pressure and velocity to determine the wave direction. However, instead of performing the analysis with the original time series as we have just done, it uses Fourier transforms to separate the signals into different frequency bands so that it can determine direction separately for each band. This means that if you have a long-period swell coming from one direction, and shorter wind waves coming from another, you can tell the direction for each of them separately.

The PUV analysis makes one intrinsic assumption:

Assumption

Standard PUV wave analyses assume that waves at a given frequency come from one primary direction

If waves with approximately equal size come from more than one direction, then the computed wave direction will be different from the direction of either wave set, likely somewhere in between. There is an example of what this looks like in the next section.

The PUV analysis must provide an accurate estimate of the wave elevation spectra in addition to the direction and the directional spreading. Figure 1 shows that the velocity decreases with depth below the surface. The pressure decreases as well. The rate of decrease is well understood and modeled by linear wave theory. This allows us to measure the pressure and the velocity near the bottom, and to rescale the measurements to obtain the wave elevation spectrum at the surface. And if you know the surface elevation spectrum, then you can compute the significant wave height as well.

The equations for scaling pressure and velocity to obtain the surface wave spectra, plus the equations used to compute wave direction and spreading are documented in our Waves2001 paper, and implemented in our Matlab Wave Directional Spectrum tools.

Example Results

This section shows data collected by a Vector Velocimeter, which was deployed for two days in about 8 m of water at Torrey Pines Beach, California. The Vector was deployed next to an Aquadopp Current Profiler both sampling at 2 Hz. The Vector collected 7100-sample bursts every hour, while the Aquadopp collected 2048-sample bursts every 40 minutes. The Waves2001 paper compares the overlapping segments from both instruments. The illustrations below are largely from the Vector, but with more detail because all of the Vector data are used (not just the parts that overlap the Aquadopp data).

Figure 4 shows the surface wave spectrum, averaged over the deployment. It shows a dominant peak at around 0.9 Hz (11 s period).

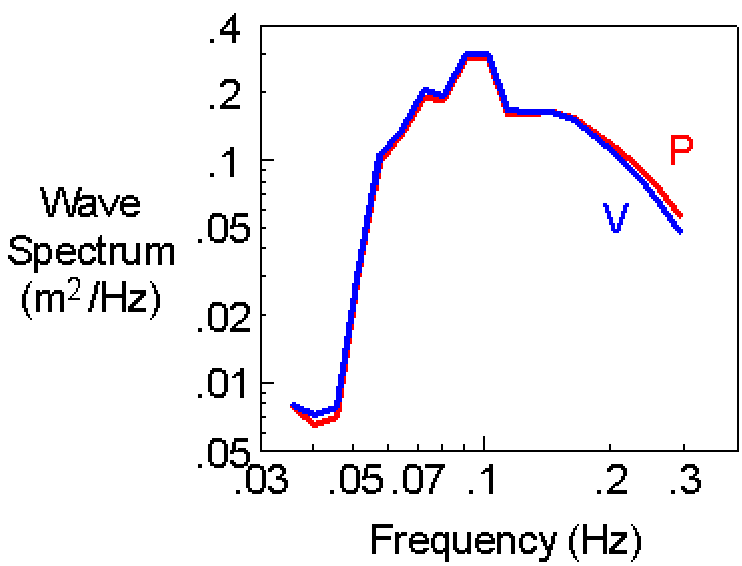

Figure 4. Average surface wave elevation spectrum, based on the velocity (V) and pressure (P) data.

Figure 5 shows the detailed evolution of the wave spectra as well as the wave direction and spreading. The wave spectra computed using the pressure sensor and the velocity sensor are nearly identical, as they should be. The wave direction and spreading, in the lower two panels, are only displayed for the more energetic parts of the spectra, that is where the wave spectrum rises above 0.1 m^2/Hz.

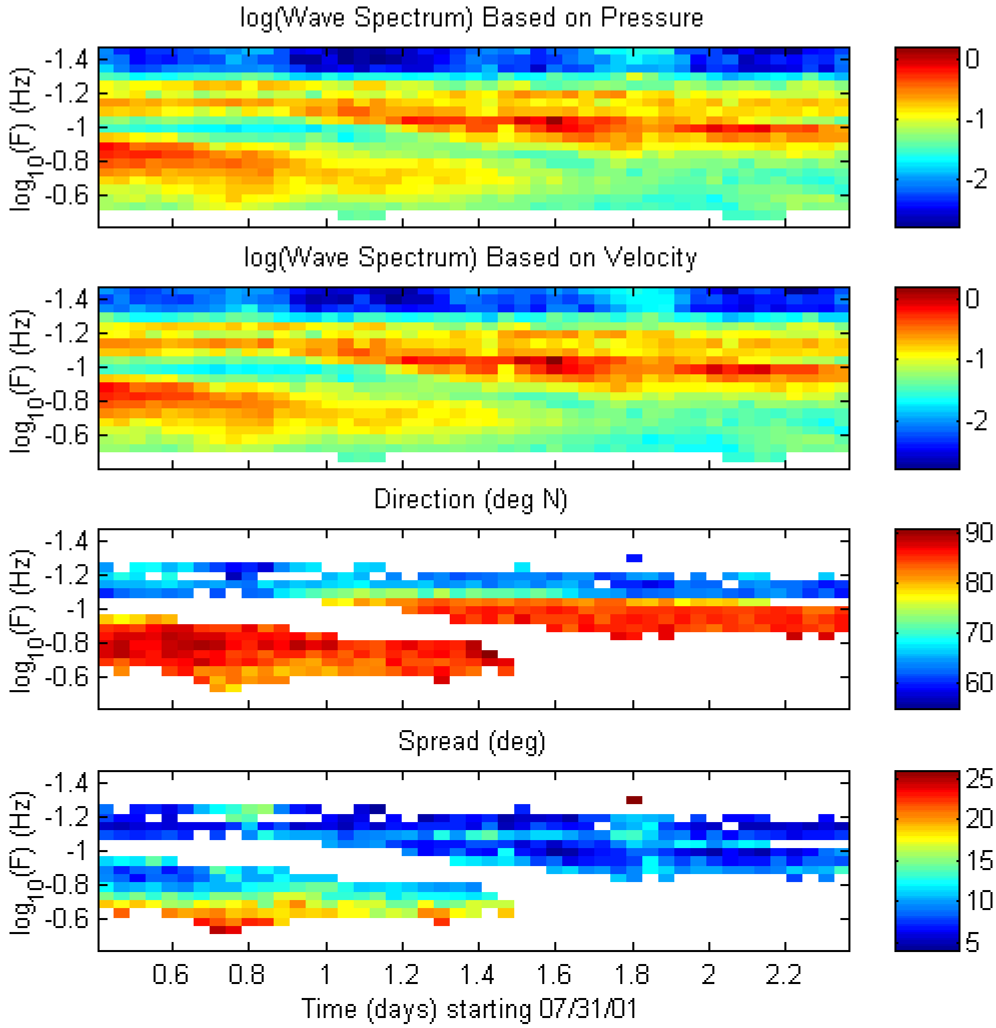

Figure 5. Evolution of the wave spectra, direction and spreading. The top two panels show how the wave spectrum evolves over time. The spectra based on the pressure and velocity look nearly identical. The bottom two panels show corresponding wave directions and spreading. The tics on the log frequency axis at the left correspond to the following wave periods:

-1.4	*25 s*
-1.2	*16 s*
-1.0	*10 s*
-0.8	*6 s*
-0.6	*4 s*

Wave Events

Looking only at the spectra, it appears that there are two wave "events": one covering long periods (8-18 s) for the entire deployment, and a second covering shorter periods (4-10 s) for the first half of the deployment. However, the waves directions tell us that the long period event is really two distinct events. The 16 s waves are going in a different direction than the 10 s waves. In fact, in the middle of the deployment, closer inspection of both spectra and directions tell us that these two long-period events overlap some. We will look at this overlap more closely on the next page. These three events are labeled 1-3 in Figure 6.

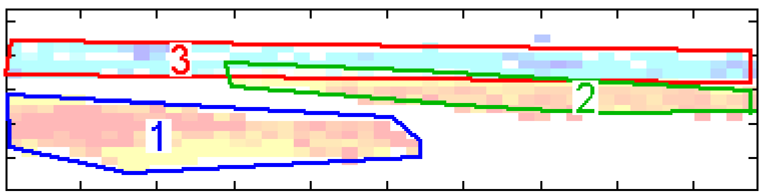

Figure 6. Three events visible in Figure 5. Compare this figure with the third panel showing wave direction in Figure 6. The mean directions of these events are 1: 87°; 2: 85°; 3: 62°.

These wave "events" originate as wind events or storms that occur in some area far from Torrey Pines and lasting for a period of time. Because the generation areas are far out to sea where the water is deep, the waves are dispersive. The long waves travel faster than the short waves and arrive at Torrey Pines first. All three events identified in Figure 7 are dispersive. In each event, the frequency slowly increases--the long waves arrive first followed by progressively shorter waves. The rate of change in the event frequency differs among the three events. Frequency changes slowest in Event 3; its source is the furthest from Torrey Pines. The other two events change more quickly and originate from areas much closer to Torrey Pines.

Events 1 and 2 come from areas that are almost directly offshore, while the waves in Event 3 appear to come from a region further to the south. The long waves in Event 3 are feeling the bottom, and have certainly been refracted as they approach the shore.

Significant Wave Height

Figure 7 plots the significant wave height, and period, direction and spreading, all at the spectral peak.

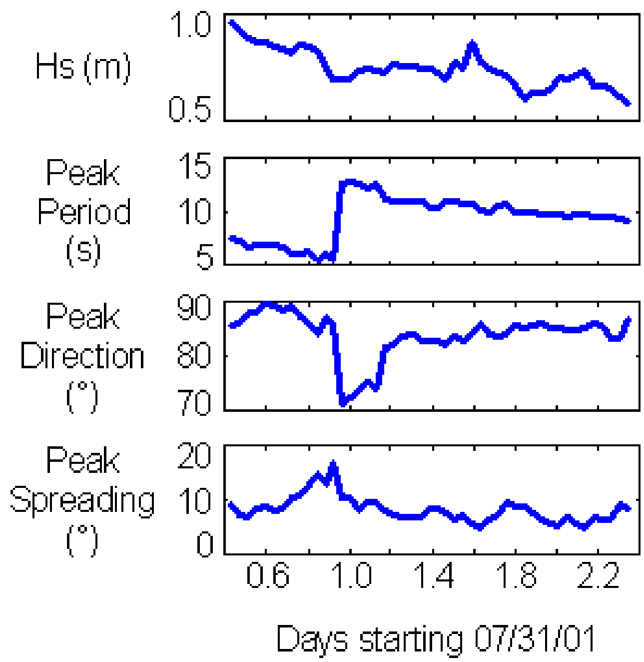

Figure 7. Significant wave height Hs, peak period, peak direction and peak spreading, corresponding to figure 5.

Figure 7 gives examples of "integral" wave parameters. For example, the significant wave height is obtained by integrating to obtain the total standard deviation of the wave elevation over the wave spectrum; Hs is four times the standard deviation. The significant wave height is a common and standard definition, but there are a variety of different integral formulations for period, direction and spreading. The peak direction, in particular, shows that the three events each dominate at different times. The peak direction near 90° in the beginning shows when Event 1 dominates. The shift to 70° indicates that Event 3 takes over briefly, before ceding dominance to Event 2.

Rather than criticizing the merits and faults of different integral parameters, keep in mind that different people measure waves for different purposes. Your best choice of which integral formulation to use depends on what you intend to do with the results.