RD Instruments
Acoustic Doppler Solutions

Workhorse ADCP Multi-Directional Wave Gauge Primer

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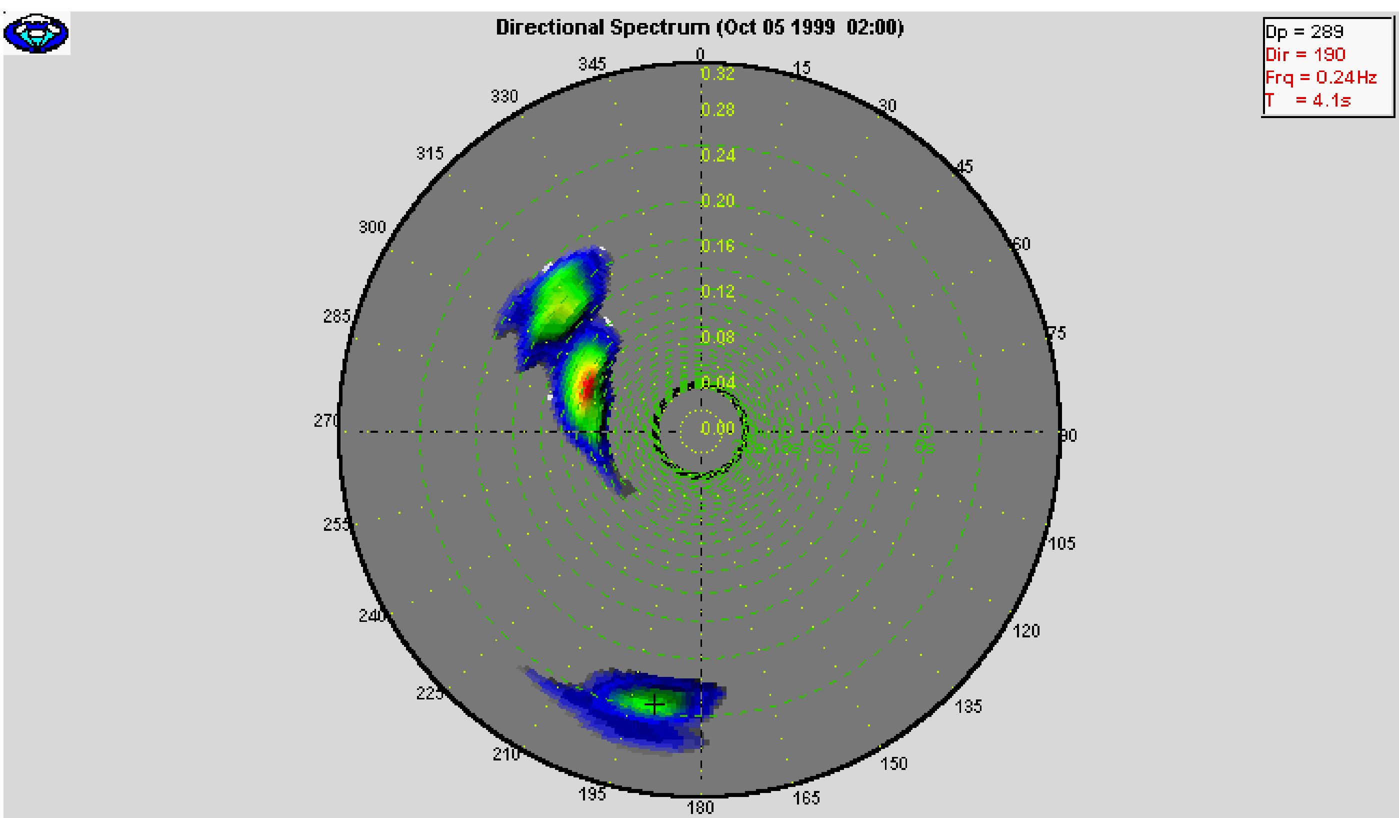

Principles of ADCP Wave Measurement

The basic principle behind wave the measurement, is that the wave orbital velocities below the surface can be measured by the highly accurate ADCP. The ADCP is bottom mounted, upward facing and has a pressure sensor for measuring tide and mean water depth. Time series of velocities are accumulated and from these time series, velocity power spectra are calculated. To get a surface height spectrum the velocity spectrum is translated to surface displacement using linear wave kinematics. The depth of each bin measured and the total water depth are used to calculate this translation. To calculate directional spectra phase information must be preserved. Each bin in each beam is considered to be an independent sensor in an array. The cross-spectrum is then calculated between each sensor and every other sensor in the array. The result is a cross-spectral matrix that contains phase information in the path between each sensor and every other sensor at each frequency band. The cross-spectrum at a particular frequency is linearly related to the directional spectrum at a particular frequency. By inverting this forward relation we solve for the directional spectrum.

1. Background

The use of Doppler sonar to measure ocean currents is by now well established, and is documented in the RDI publication Acoustic Doppler Current Profilers, Principles of Operation (RD Instruments, 1989). Conventional acoustic Doppler current profilers (ADCPs) typically use a Janus configuration consisting of four acoustic beams, paired in orthogonal planes (Figure 1), where each beam is inclined at a fixed angle to the vertical (usually 20 - 30 degrees). The sonar measures the component of velocity projected along the beam axis, averaged over a range cell whose along-beam length is roughly half that of the acoustic pulse. Since the mean current is assumed to be horizontally uniform over the beams, its components can be recovered by subtracting the measured velocity from opposing beams. This procedure is relatively insensitive to contamination by vertical currents and/or unknown instrument tilts (RD Instruments, 1989).

The situation regarding waves is more complicated. At any instant of time the wave velocity varies across the array. As a result, except for waves that are highly coherent during their passage from one beam to another, it is not possible to separate the measured along-beam velocities into their horizontal and vertical components. However, the wave field is statistically steady in time and homogeneous in space, so that the cross-spectra of velocities measured at various range cells (either between different beams or along each beam) depend on wave direction. This fact allows us to apply array processing techniques to estimate the frequency-direction spectrum of the waves. In other words, each depth cell of the ADCP can be considered to be an independent sensor that makes a measurement of one component of the wave field velocity. The ensemble of depth cells along the four beams constitutes an array of sensors from which magnitude and directional information about the wave field can be determined.

2. ADCP Performance As a Wave Gauge

The ADCP can use its profiling ability (bins and beams) as an array of sensors. Because the ADCP can profile the water volume all the way to the surface, it can be mounted in much deeper water than a traditional pressure (PUV triplet) based device. Higher frequency waves attenuate more quickly with depth below the surface. The ADCP can measure much higher frequency waves than a PUV and do so in deeper water, because it can make measurements higher up in the water column. Additionally, the ADCP has many independent sensors (bins-beams) so even when sampling at a 2Hz sample rate the data is as quiet as if it had been sampled at 200Hz by a single point meter (example uses 25 bins and 4 beams). To achieve the best possible solution for wave height spectrum the height spectrum and the noise spectrum are fit to the bin-beam data using a least squares fit. See Height Spectrum for details. In addition to the orbital velocity technique for measuring wave spectra, the ADCP can measure wave height spectra from its pressure sensor (with frequency/depth limitations) and from echo ranging the surface. Within the frequency range of the pressure sensor the pressure height spectrum is an old reliable reference for data comparison. The surface track measurement of wave height is reliable most but not all of the time. The advantage of the surface track derived height spectrum is that it is a direct measurement of the surface and can measure wave energy at very high frequencies. Higher than 0.9 Hz in some installations. Having three completely independent measures of wave height spectrum that all agree very closely is a solid argument for data quality.

The directional spectrum is much truer and of higher quality than any sort of triplet (PUV, UVW, PRH) and is almost as good as large home-built arrays. The Maximum Likelihood Method used for inversion allows one to independently resolve the wave field in each direction. The full circle (360 degrees) is arbitrarily divided into as many slices as one chooses (up to 360 slices of 1 degree width). Because of this the RDI directional spectra algorithm can resolve two separate swells arriving from different directions at similar frequency. This feat is impossible using traditional triplet algorithms. The ADCP measures a sparse array and as such it cannot achieve the aperture of expensive home built arrays, (eg. Duck Is.) however the aperture of the beams gives the ADCP a significant improvement in directional accuracy over single point measurements. A traditional triplet algorithm uses only the first three terms in a Fourier series so it can identify a single directional peak particularly at longer wavelengths. However, bouys, PUV's other triplets cannot accurately represent the multiple directional peaks or even the true directional distribution. In the ADCP wave algorithm there are many sensors giving an array with many degrees of freedom and some aperture. The Maximum Likelihood Method used to calculate the directional spectrum has a smearing kernal associated with the inversion. By using the Iterative Maximum Likelihood Method the spreading of the directional spectrum can be corrected. The process is repeated until the directional spectrum converges to what the data actually supports. The spectrum will get narrower and sweep up directionally spread power into the peak as long as the measured data supports it. The result is a directional spectrum that more accurately represents the true directional distribution.

ADCP Wave Gauge Software.

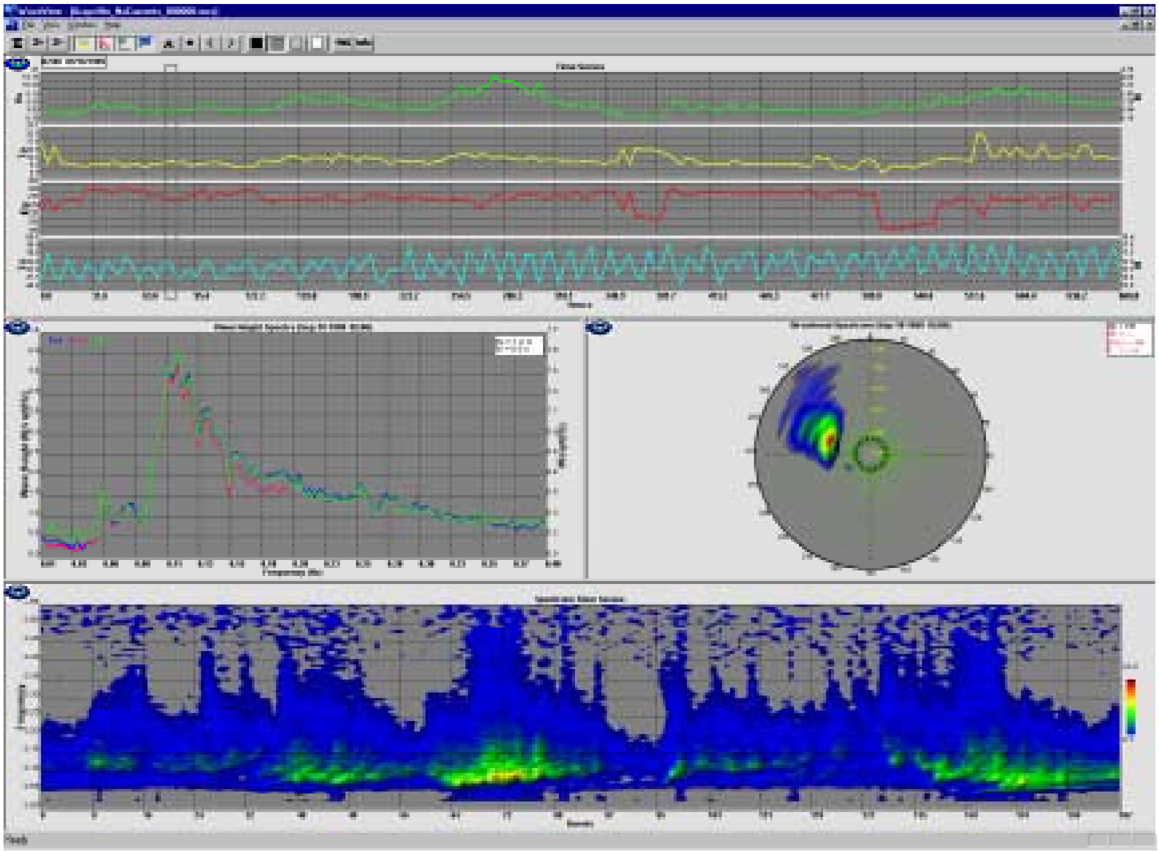

Figure 1. WaveView provides a big picture view of the wave climate as well as details of individual height spectra and directional spectra. Time-series of significant wave height, peak period, peak direction, water level, and height spectra make it easy to find significant events.

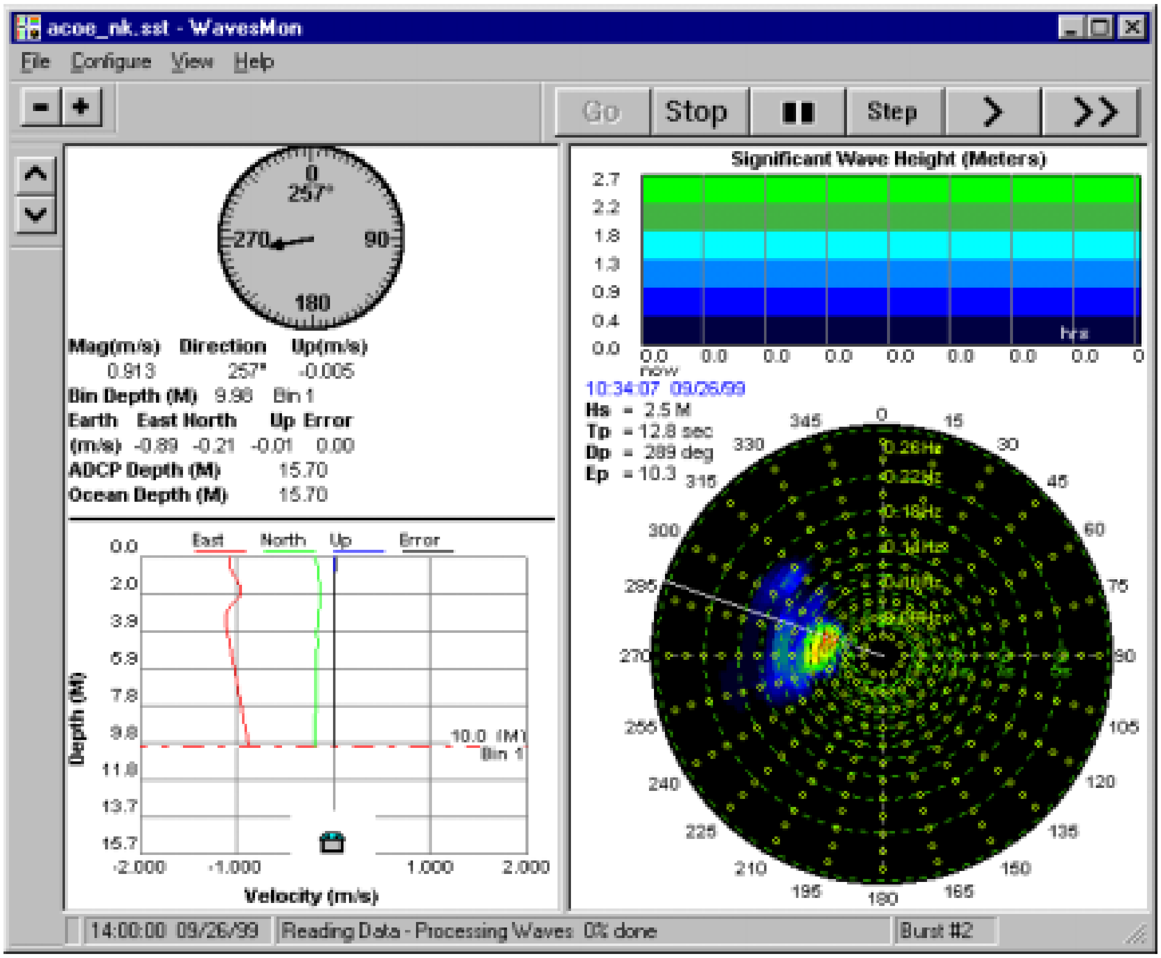

Figure 2. Shown above is WavesMon software. Wavesmon is geared towards real time collection and processing of current and wave data. The displays are designed to make evaluation of the wave field and currents at a glance.

Height Spectrum

The ADCP has three different independent techniques for measuring non-directional wave height spectrum. The pressure sensor derived spectrum is a traditional technique, but is limited because the measurement must be made on the bottom. The orbital velocity can be measured up close to the surface then translated to a surface displacement spectrum. This method provides a much better frequency response because the measurements can be made farther up in the water column where the exponential attenuation of wave energy with depth, has not reduced the signal much.
The surface track is direct measurement of the surface and is not frequency dependent except for the resolution of the echolocation of the surface.

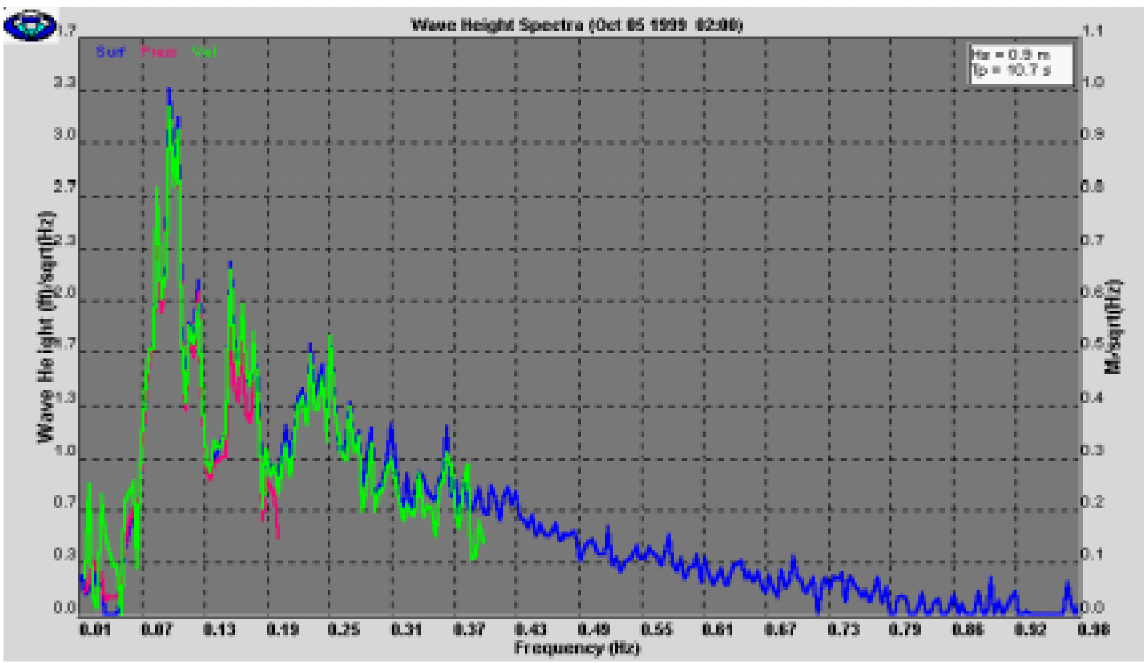

Figure 3. The ADCP has three independent measurements of wave height spectrum. The close agreement between pressure, velocity, and surface track derived spectra demonstrates the integrity of the data. In addition, redundant measurement also allows one to differentiate between measurement noise and environmental noise.

Directional Spectrum

The directional spectrum algorithm has several features that are important.

A. The ADCP bins and beams are used as a virtual array of sensors. This provides the many degrees of freedom required describing a potentially complex or sharp directional distribution. In contrast, a PUV or triplet type algorithm can only provide 3 degrees of freedom and only the first three terms in the Fourier series are actually derived from measured data.
B. The array of sensors has a substantially greater aperture than a single point measurement (PUV, Bouy). A larger antenna or array aperture is required to measure finer directional resolution and accurately reproduce narrow spectra.

C. The Maximum Likelihood Method (MLM) used to construct the directional spectrum allows us to measure multiple directions arriving at the same frequency. The MLM process smears the directional distribution, however by iteratively applying the technique (IMLM), this smearing can be undone. The IMLM technique converges to a directional spectrum that matches the data for a reasonable number of iterations. Experience has shown 1, 2, or 3 iterations sweeps up most of energy back into the peak. The difference between a directional spectrum that was processed with 3 iterations and 20 iterations is small.

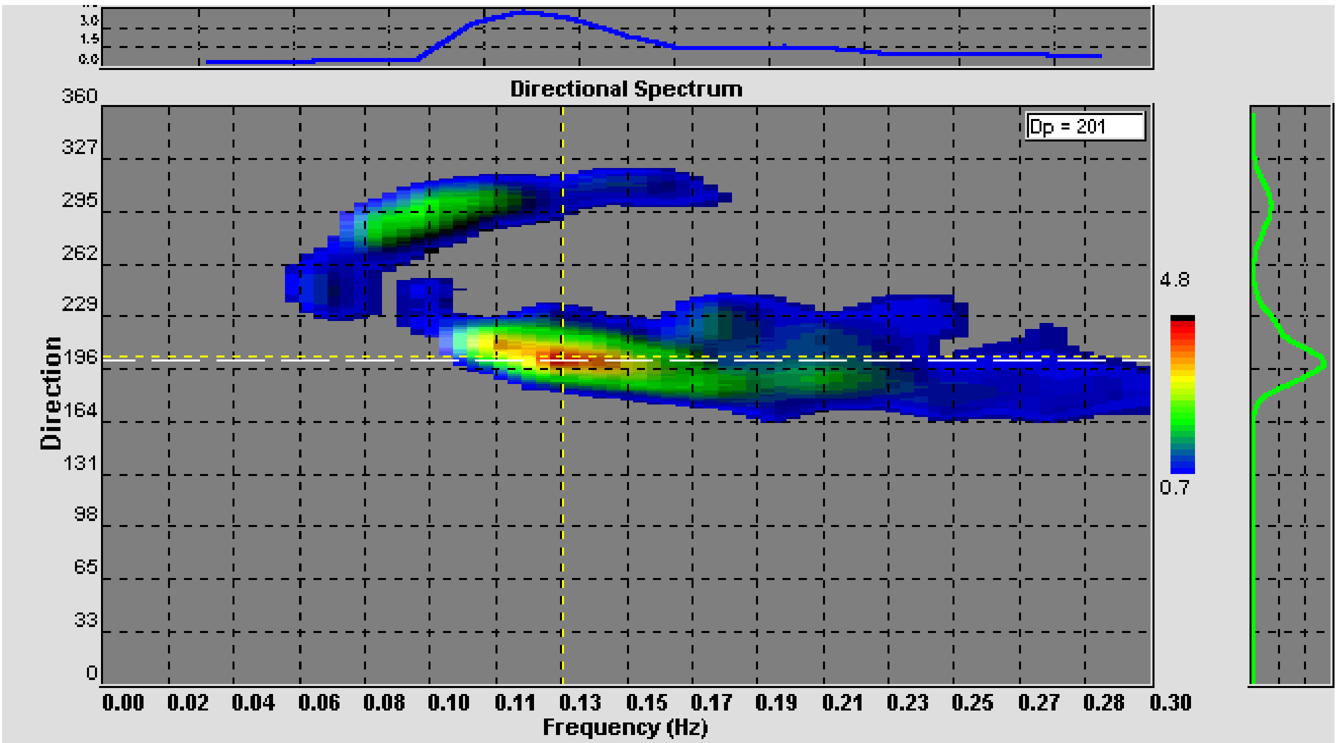

Figure 4. ADCP directional spectrum data shows waves arriving simultaneously from the North and the South. Refraction bends the longest waves to the coastline.

Above is an average directional spectrum from 10/4 to 10/6. Clearly there is swell arriving from both the north and from the south. One can see the refraction in this data. It appears that the longer wavelengths are refracting more parallel to the coastline, and that the direction at higher frequencies is more representative of the deep-water wave direction.

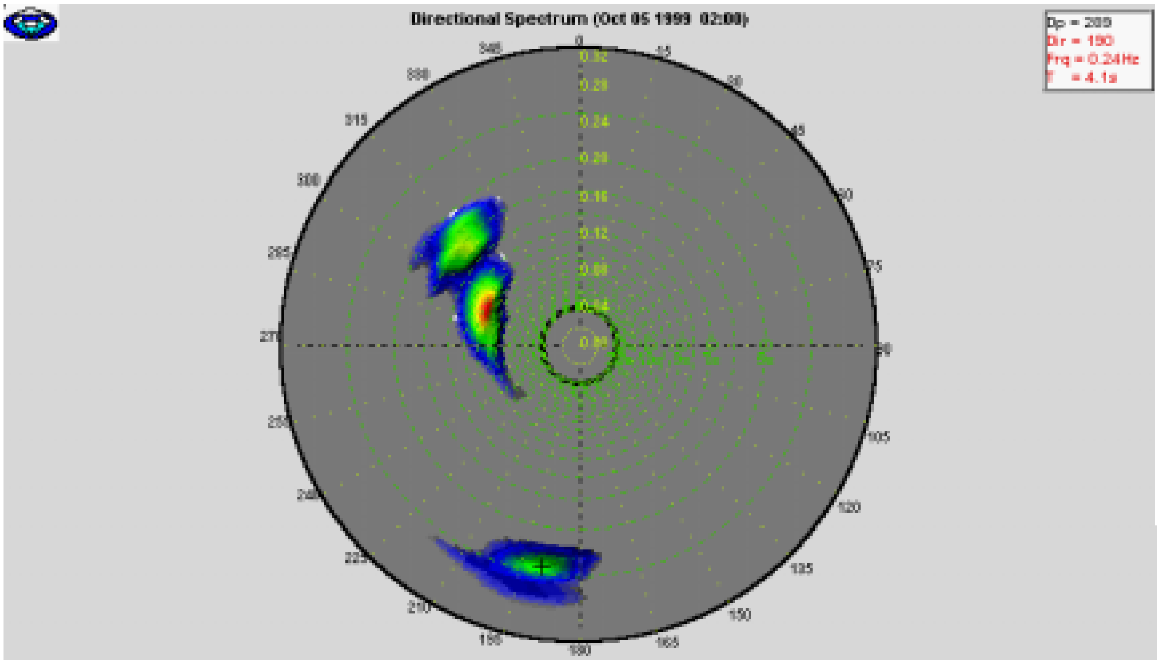

Figure 5. This directional spectrum shows waves arriving from three different directions at the same time.