Formatting Guidelines for Submission of Spectral Wave Data Collected by an RDI Waves ADCP to CDIP

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I.   ADCP Setup Requirements

A. This document assumes text files of processed waves data are available or can be created. The *directional wave spectrum* file (DSpec*.txt) is the only data file used in the following guidelines for submitting ADCP spectral wave data to CDIP. Additional metadata is obtained from the ADCP's setup and physical setting.

B. This documentation also assumes that *heading corrections* for magnetic variations have been applied to the data such that all headings are relative to true north. Corrections can either be done at the time of data collection or in post processing.

C. Directional spectra must be saved in *'Power X Power'* so that the directional spectrum has units[*] of $mm^2\ Hz^{-1}\ deg^{-1}$ and can be integrated to obtain the non-directional spectrum (Expert 1 tab of WavesMon software).
    [*]*There is an additional factor of 360 degrees in the directional spectrum. However, all calculations reported in this document assume this factor has not been removed.*

II.   Data Submission Form

A. CDIP's format for submitting spectral data is available at
    http://cdip.ucsd.edu/?nav=documents&sub=index&xitem=product&xtxt=sp_submission

III.   Metadata

A. The following pieces of metadata corresponding to CDIP's data submission format are obtained from the ADCP's setup in WavesMon:

1. *Sample Rate* is the time between ensembles in the Expert 1 tab of WavesMon. For waves processing, this should be set to 2Hz (or 50 100[ths] of a second in the Expert 1 tab of WavesMon software). Other values may be used for deployments in unique environments.

2. *Sample Length* is given by the FFT length divided by the sampling rate determined above (in Hertz). The FFT length can be found in the Processing tab of WavesMon software. Note that the FFT length is normally equal to or less than the samples/burst but only the FFT length of samples are used for waves processing. Extra samples in the samples/burst are used as a data buffer in case of dropouts during data transmission (for example, an FFT length of 2048 may have the number of samples/burst set to 2400).

3. *Frequency thresholds*, while not explicitly needed for CDIP's metadata, these values are used to determine the valid range of frequencies in the directional wave spectra. The frequency thresholds are ultimately up to the users discretion to determine. Frequency thresholds are either calculated automatically by WavesMon or supplied by a user in the Processing tab but these

values are not applied to the directional wave spectra since data for all frequencies are reported. Since the frequency cutoffs are not reported in the directional spectra file, the user must determine a reasonable range of cutoff frequencies to use. The lower cutoff frequency is usually 0.01 Hz (waves with 100 second periods) but the upper cutoff frequency is dependent upon the wave field, water depth & ADCP orientation. As a guideline, the upper cutoff frequency should be less than or equal to the frequency for waves of wavelengths smaller than two times the distance between adjacent transducer beams at mid-water depth. See Appendix 1 for details.

B. Metadata that do not apply to Waves ADCP data

1. The *Check Factor* and *Sensor Depth* are not applicable to ADCP Waves data. Report –9999.9 for these fields.

IV.   Spectral Data

A. It is important to note that the non-directional wave spectrum, mean direction and Fourier coefficients for each frequency bin are submitted to CDIP, not entire directional wave spectrum. The directional wave spectrum is re-created by CDIP (see Appendix 2 for details). Therefore, the non-directional wave spectrum, mean directions and Fourier coefficients must be computed and reported over valid frequency ranges only.

B. The number of frequencies and bandwidth are both reported in the header of the DSpec file. The *bin centers for each frequency* (F_n) are given by:

$$B \quad = \text{ bandwidth for each frequency bin}$$
$$N \quad = \text{ number of frequency bins}$$
$$F_n \quad = B - nB, \text{ where } n = 1, 2, \ldots , N$$

For example, frequency bins for 128 frequencies of bandwidth 1/128 would be [0, 1/128, 2/128, … , 127/128]

C. *Directional bin centers* start at the first direction slice reported in the DSpec header and increment clockwise by (360 / number of directions). For example, for 90 Directions and the first direction slice at 283 degrees, the directional bin centers are [283, 287, 291, … , 279]

D. Calculations for data submission

a. The *non-directional spectrum* (D(f)) is simply the sum of power over all directions for each frequency divided by the number of directions[*]:

$$M \quad = \text{ number of directional bins}$$
$$D(f, \theta) = \text{ directional wave spectrum}$$
$$D(f) \quad = \text{ non-directional wave spectrum}$$
$$= 1/M \sum_{m=1}^{M} D(f, \theta_m) \quad (\text{mm}^2 \text{ Hz}^{-1})$$

Convert the non-directional wave spectrum to units of m^2 Hz^{-1} by multiplying by 1 x 10^{-6}. These values are reported to CDIP for frequencies between the frequency thresholds.

Note that division by the number of directions (M) combines multiplying by the angular resolution (Δθ) from integration and removal of the additional 360 degree factor since 1/M = Δθ/360.

b. The *mean direction* for each frequency band ($D_a(f)$) is calculated using a power-weighted average. The calculation is:

M = number of directional bins

$D(f, \theta)$ = directional wave spectrum

$D_a(f)$ = mean direction as a function of frequency

=

$$\arctan\left(\sum_{m=1}^{M} D(f, \theta_m)\sin(\theta_m), \sum_{m=1}^{M} D(f, \theta_m)\cos(\theta_m) \right)$$

where arctan is the four-quadrant arctangent.

c. The *Fourier coefficients* (*a1, b1, a2 & b2*) are computed in a similar manner to the mean direction.

$$a0 = \sum_{m=1}^{M} D(f, \theta_m)$$

$$a1 = \frac{1}{a0} \sum_{m=1}^{M} D(f, \theta_m)\cos(\theta_m)$$

$$b1 = \frac{1}{a0} \sum_{m=1}^{M} D(f, \theta_m)\sin(\theta_m)$$

$$a2 = \frac{1}{a0} \sum_{m=1}^{M} D(f, \theta_m)\cos(2\theta_m)$$

$$b2 = \frac{1}{a0} \sum_{m=1}^{M} D(f, \theta_m)\sin(2\theta_m)$$

As a check, the mean direction for a given frequency ($D_a(f)$) should be obtained by

$$D_a(f) = \arctan (b1, a1)$$

where arctan is the four-quadrant arctangent. See Appendix 2 for details on the accuracy and use of the Fourier coefficients.

V. References

A. How to Get the Non-Directional Spectrum from Directional Spectrum, Brandon Strong.

B. Sampling and Spectra for Waves, Brandon Strong, December 2004.

C. Waves User's Guide, RD Instruments, October 2003.

D. Personal communication with Brandon Strong at RDI.

E. Personal communication with Corey Olfe and Bill O'Reilly at CDIP.

Appendix 1

Determining Guideline for the Upper Cutoff Frequency

As mentioned previously, the upper cutoff frequency should be less than or equal to the frequency for waves of wavelengths smaller than two times the distance between adjacent transducer beams at mid-water depth. First, approximate the distance (d) between adjacent transducers at the mean mid-water depth for a level ADCP deployment:

H_m = mid-water depth   (m)
θ = transducer beam angle from vertical, normally 20 degrees
d   = distance between adjacent transducers
   = $\sqrt{2}\, H_m \sin(\theta)$ (m)

Then use the dispersion relationship for surface gravity waves to determine the frequency (f) corresponding to wavelengths of 2d.

λ = 2d   (m)
f   = 1 / T   (Hz)
H   = $2H_m$ (m)
g   = 9.81   ($m\ s^{-1)}$
k   = $2\pi / \lambda$ ($rad\ m^{-1}$)
w   = $2\pi f$ ($rad\ sec^{-1}$)
w^2 = gk tanh(kH)   ($rad^2\ sec^{-2}$)

Solving for f,

$$f = \frac{\sqrt{gk \tanh(kH)}}{2\pi} \quad (Hz)$$

The upper cutoff frequency is normally less than or equal to this frequency.

Appendix 2

Waves Algorithms & Fourier Coefficients

CDIP does not require any information about the directional bins or bin resolution because directional information is reduced to the directional Fourier coefficients. Only the non-directional spectrum and Fourier coefficients are needed to reproduce the directional spectrum. However, the accuracy of the directional spectrum reproduced by CDIP varies depending on the directional spectrum algorithm used by WavesMon software for producing directional spectra.

Three directional wave spectrum algorithms are available in WavesMon software in Expert tab 1. The two traditional triplet processing algorithms available are the Maximum Entropy Method (MEM) and Extended Maximum Entropy Principle (EMEP). Except for data collected close to the transducers, RDI recommends using the Iterative

Maximum Likelihood Method (IMLM). IMLM corrects for directional spreading caused by conventional MLM and converges to a directional spectrum that matches the data.

The Fourier coefficients submitted to CDIP are exact if the MEM method is used to produce the directional spectra. This is because MEM estimators fit the coefficients exactly in producing the directional spectra and the process is reversible. However, if IMLM is used in producing directional spectra, the process is not reversible for deriving the Fourier coefficients since IMLM allows for some data misfit. The consequence is that directional spectra reproduced by CDIP will not exactly match the original directional spectra if the IMLM algorithm is used.