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DATA PRODUCT SPECIFICATION FOR VELOCITY PROFILE AND ECHO INTENSITY

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Document Control Sheet

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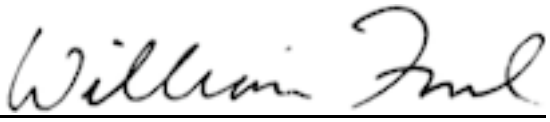
Signature Page

This document has been reviewed and approved for release to Configuration Management.

OOI Senior Systems Engineer: _____

Date:2012-07-20

This document has been reviewed and meets the needs of the OOI Cyberinfrastructure for the purpose of coding and implementation.

OOI CI Signing Authority: 

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1 Abstract

This document describes the computation used to calculate the OOI Level 1 Velocity Profile and OOI Level 1 Echo Intensity core data product, which is calculated using data from Teledyne RDI Workhorse ADCP instruments. This DPS applies to instrument classes of ADCPS, ADCPT, and ADCPA. This document is intended to be used by OOI programmers to construct appropriate processes to create the L1 velocity profile and the L1 echo intensity data products.

2 Introduction

2.1 Author Contact Information

Please contact help@oceanobservatories.org for more information concerning the computation and other items in this document.

2.2 Metadata Information

2.2.1 Data Product Name

The OOI Core Data Product Names for these products are

- VELPROF
- ECHOINT

The OOI Core Data Product Descriptive Names for these products are

- Velocity Profile
- Echo Intensity

The velocity profile core data product (VELPROF) is comprised of 3 parameters:

Identifier	*Name*	*Description*	*L0 Units*	*L1 Units*
VELPROF-VLE	eastward sea water velocity	East component in earth coordinates, magnetic variation accounted	mm/s	m/s
VELPROF-VLN	northward sea water velocity	North component in earth coordinates, magnetic variation accounted	mm/s	m/s
VELPROF-VLU	upward sea water velocity	Upward component in earth coordinates, magnetic variation accounted	mm/s	m/s
VELPROF-EVL	error velocity	error velocity	mm/s	m/s

In addition, the metadata parameter “percent good” is required for quality control.

Identifier	*Name*	*Description*	*Units*
VELPROF-PCG	percent good	percent good	%

The echo intensity core data product (ECHOINT) is comprised of 4 parameters:

Identifier	*Name*	*Description*	*L0 Units*
ECHOINT-B1	Beam #1 Echo intensity	Echo intensity for beam #1	dB
ECHOINT-B2	Beam #2 Echo intensity	Echo intensity for beam #2	dB
ECHOINT-B3	Beam #3 Echo intensity	Echo intensity for beam #3	dB

ECHOINT-B4	Beam #4 Echo intensity	Echo intensity for beam #4	dB

2.2.2 Data Product Abstract (for Metadata)

The OOI Level 1 Velocity Profile core data product (VELPROF) from Workhorse ADCPs provides velocity profile measurements in units of m/s in earth coordinates. ADCPs produce water velocity by measuring relative radial velocity between transducer and sound scatterers. The L1 VELPROF data have been corrected for magnetic variation.

The OOI Level 1 Echo Intensity core data product (ECHOINT) from Workhorse ADCPs provides echo intensity measurements in units of dB. ADCPs produce echo intensity by measuring the signal strength of the echo returning from the ADCP's transmit pulse.

2.2.3 Computation Name

N/A

2.2.4 Computation Abstract (for Metadata)

The OOI Level 1 Velocity Profile core data product and the OOI Level 1 Echo Intensity core data product are computed by decoding *data ensembles* in either hexadecimal-ASCII or binary format from ADCP family of instruments into velocity profile.

2.2.5 Instrument-Specific Metadata

Instrument-specific metadata fields that must be part of the L1 output data, both VELPROF and ECHOINT, are listed in Section 4.4. Echo intensity is stored as a separate L1 core data product (ECHOINT) and it has the same metadata with the associated L1 VELPROF data product.

The PD0 output is composed of header, fixed leader data, variable leader data, velocity, correlation magnitude, echo intensity, percent good, bottom track data, and a data-validity checksum. Fixed leader and variable leader data need to be decoded to obtain instrument-specific configuration data including serial number, coordinate system configuration, bin size, and blanking distance. Details of the PD0 output data format are explained in the TRDI manual, Workhorse commands and output data format (TRDI 2010b).

Depth of transducer, speed of sound, and water temperature are required to perform sound speed corrections if data product users request.

Pitch, roll and heading representing ADCP rotation are required to correct the ADCP data when beam coordinate velocity data are converted into earth coordinates.

Data ensembles include four different kinds of profile data: velocity, echo intensity, correlation magnitude, and percent good. "Velocity" data are used to produce the L1 VELPROF data product. "Echo intensity" data are the L1 ECHOINT data product. "Correlation magnitude" and "Percent good" data in each data ensemble need to be stored as metadata with the L1 VELPROF data product and with the L1 ECHOINT data product. Correlation magnitude is between 0 and 255 and it represents quality of data. Percent good is the fraction of data that has passed data quality criteria such as low correlation, large error velocity, and false target threshold. Both correlation and percent good are measures of data quality, and they will be used for QA/QC procedures.

Table 1. Required metadata for the L1 VELPROF data product and the L1 ECHOINT data product.

Metadata name	**Field**	**PD0 data types**	**Unit**	**Note**
Instrument frequency	System configuration	Fixed leader	Hz	
CPU firmware version	CPU F/W VER.	Fixed leader	N/A	
CPU firmware revision	CPU F/W REV.	Fixed leader	N/A	
Beam pattern	System configuration	Fixed leader	N/A	Concave or convex
Instrument orientation	System configuration	Fixed leader	N/A	Up- or down-facing beam
Number of beams	Number of beams	Fixed leader	count	The number of beams used to calculate velocity data (not physical beams)
Number of cells	Number of cells	Fixed leader	count	
Pings per ensemble	Pings per ensemble	Fixed leader	count	
Depth cell length	Depth cell length	Fixed leader	cm	The length of one depth cell.
Blank after transmit	Blank after transmit	Fixed leader	cm	
Coordinate transform	Coord Transform	Fixed leader	N/A	Earth or beam coordinates
Distance to the first bin	Bin 1 distance	Fixed leader	cm	
Instrument serial number	Serial #	Fixed leader	N/A	
Beam angle	Beam angle	Fixed leader	degrees	
Ensemble number	Ensemble number	Variable leader	count	
Real-time clock year	RTC year	Variable leader	years	
Real-time clock month	RTC month	Variable leader	months	

Real-time clock day	RTC day	Variable leader	days	
Real-time clock hour	RTC hour	Variable leader	hours	
Real-time clock minute	RTC minute	Variable leader	minutes	
Real-time clock second	RTC second	Variable leader	seconds	
Real-time clock hundredths	RTC hundredths	Variable leader	hundredths	
Speed of sound	Speed of sound	Variable leader	m/s	
Depth of transducer	Depth of transducer	Variable leader	decimeters	
Heading	Heading	Variable leader	0.01 degrees	
Pitch	Pitch (Tilt 1)	Variable leader	0.01 degrees	
Roll	Roll (Tilt 2)	Variable leader	0.01 degrees	
Salinity	Salinity	Variable leader		This value may be a manual setting or a reading from the optional ADCP conductivity sensor
Temperature	Temperature	Variable leader		
Pressure	Pressure	Variable leader	deca-pascal	
Correlation magnitude	Field 1, 2, 3, and 4 for each depth cell	Correlation magnitude	N/A	A linear scale between 0 and 255
Percent good	Field 1, 2, 3, and 4 for each depth cell	Percent good	%	

2.2.6 Data Product Synonyms

Synonyms for the Velocity Profile data product are

- Ocean Current
- Velocity

2.2.7 Similar Data Products

VELTURB from VADCP

2.3 Instruments

The Data Processing Flow document (DCN 1342-00750) for Workhorse ADCP instruments including ADCPA, ADCPS, and ADCPT describes instrument classes and make/models, and describes the flow of velocity profile data from ADCPs through all of the relevant QC, calibration, and data product computations and procedures. The QA/QC section of the Data Processing Flow document applies to mobile platform data from ADCPA class instruments as well.

Please see https://oceanobservatories.org/instruments/ for specifics of instrument locations and platforms.

2.4 Literature and Reference Documents

The electronic files of the reference documents are stored on Alfresco under *OOI > Reference Archive > Data Product Specification Artifacts > 1341-00750_VELPROF_ECHOINT*

Teledyne RD Instruments (2009) Workhorse Long Ranger data sheet.
Teledyne RD Instruments (2009) Workhorse Sentinel data sheet.
Teledyne RD Instruments (2009) Workhorse Quartermaster data sheet.
Teledyne RD Instruments (2010a). ADCP Coordinate Transformation. P/N 951-6079-00.
Teledyne RD Instruments (2010b). Workhorse commands and output data format. Teledyne RD Instruments (2011). Acoustic Doppler current profiler principles of operation: A practical primer.

2.5 Terminology

2.5.1 Definitions

Definitions of general OOI terminology are contained in the Level 2 Reference Module in the OOI requirements database (DOORS). The following terms are defined here for use throughout this document.

(Radial) beam coordinates: “These are the raw velocity measurements measured independently by each transducer, in units of millimeters per second. The sense is positive when the motion is towards the transducer. These axes are not orthogonal.” (TRDI, 2010a, p.16).

Earth axes (geographic or geodetic) coordinates: “Velocity is converted into north, east and up components.” (TRDI, 2011)

Instrument coordinates: This is a coordinate oriented relative to the transducer head. ADCPs have four transducers and they are labeled clockwise in the order 3-1-4-2 (TRDI, 2010a, Fig. 3, p.17). “The X-axis lies in the direction from transducer 1 towards transducer 2 and the Y-axis lies in the direction from transducer 4 toward transducer 3. The Z-axis lies along the axis of symmetry of the four beams, pointing away from the water towards the pressure case.” (TRDI, 2010a, p.16).

Data ensemble: “A data ensemble consists of the data collected and averaged during the ensemble interval. A data ensemble can contain header, leader, velocity, correlation magnitude, echo intensity, percent-good, and status data.” (TRDI, 2010b)

Correlation data: “A measure of data quality, and its output is scaled in units such that the expected correlation (given high signal/noise ratio, S/N) is 128.” (TRDI, 2011)

Percent-good data: “A fraction of data passed a variety of criteria. Rejection criteria include low correlation, large error velocity and fish detection. Default thresholds differ for each ADCP; each threshold has an associated command.” (TRDI, 2011)

2.5.2 Acronyms, Abbreviations and Notations

General OOI acronyms, abbreviations and notations are contained in the Level 2 Reference Module in the OOI requirements database (DOORS).

2.5.3 Variables and Symbols

None

3 Theory

3.1 Description

Velocity profile is measured by Workhorse ADCP instruments including ADCPS, ADCPT, and ADCPA. These three instrument classes will be referred to generically as ADCP. The L0 input format from ADCPS and ADCPT are identical. The ADCPA instrument class, which is on the gliders, produces L1 ECHOINT directly. Velocity Profile data from ADCPA instruments requires only magnetic variance correction as described in Step 8 of the processing flow. See the Coastal Glider DPS (DCN 1341-20001) for more details.) An ADCP has four acoustic beams and each beam can measure a single velocity component parallel to the beam using the Doppler Effect. Three beams are necessary to obtain three dimensional velocity profiles. The fourth beam is added to compute a second vertical velocity component to estimate error velocity.

Output data format of Workhorse ADCPs including Quartermaster, Sentinel, and Long Ranger, can be either hexadecimal-ASCII or binary. The standard PD0 format is selected to be used by OOI. PD0 is a binary output format, which uses less storage space and has a faster transmission time than the Hex-ASCII format. The binary L0 velocity profile data product output from the Workhorse ADCP driver, which consists of data ensembles, must be converted into decimal format to obtain an L1 velocity profile data product in mm/s.

The two ADCPT Sentinels on Endurance Inshore Submersible Moorings will be used to measure surface waves, not just mean currents. Raw wave data are in the same PD0 format as current data, so VELPROF and ECHOINT data products may be calculated from these data in the same way as other PD0 data. The difference in the raw currents and waves data are that the currents ADCP data are saved as ensemble averages (e.g., average values over a few minutes of water pings) while the waves data stores information from every ping so that wave orbital velocities can be calculated in post-processing. Typical surface wave periods are 5-20 seconds, so the ADCP must sample for wave orbital velocities every few seconds or more often, which is why every ping is saved instead of ensemble averages. The WAVSTAT DPS (DCN 1341-00450) delineates how to calculate waves statistics from these data.

3.2 Mathematical Theory

The transformation matrix A (TRDI, 2010a, p.11) from beam coordinates to instrument coordinates is

$$A = \begin{bmatrix} c*a & -c*a & 0 & 0 \\ 0 & 0 & -c*a & c*a \\ b & b & b & b \\ d & d & -d & -d \end{bmatrix}, \qquad \text{(Equation 1)}$$

where * denotes multiplication. The constants in Equation 1 are defined as

a=1/[2*sin(θ)]
b=1/[4*cos(θ)]
c=+1 for a convex transducer head, -1 for concave
d=a/sqrt(2),

where / denotes division. Both Workhorse Long Ranger and Workhorse Quartermaster have convex transducer head, thus c=+1. The θ is a beam angle, which is fixed at 20° for both Workhorse Long Ranger and Workhorse Quartermaster.

The rotation matrix M (TRDI, 2010a, p.19) transforms velocity profiles from instrument coordinates to earth coordinates (Equation 2).

$$M = \begin{bmatrix} \cos H & \sin H & 0 \\ -\sin H & \cos H & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos P & -\sin P \\ 0 & \sin P & \cos P \end{bmatrix} * \begin{bmatrix} \cos R & 0 & \sin R \\ 0 & 1 & 0 \\ -\sin R & 0 & \cos R \end{bmatrix}, \qquad \text{(Equation 2)}$$

where * denotes matrix multiplication. H, R, and P are the heading, roll, and pitch angles. Note that R and P in Equation 2 may not be the same as the measured roll and the measured pitch depending on the ADCP orientation configuration. If the ADCP has upward-looking orientation, 180° must be added to the roll angle measured by internal tilt sensor (Equation 3) before applying the matrix M. And the pitch angle needs to be modified using Equation 4.

$$R = \begin{cases} \textbf{\textit{Tilt2}} & \text{for downward-looking ADCP} \\ \textbf{\textit{Tilt2}} + 180° & \text{for upward-looking ADCP} \end{cases} \qquad \text{(Equation 3)}$$

$$P = \arctan[\tan(\textbf{\textit{Tilt1}})*\cos(\textbf{\textit{Tilt2}})], \qquad \text{(Equation 4)}$$

where ***Tilt1*** is the measured pitch and ***Tilt2*** is the measured roll recorded in data ensembles.

The rotation matrix B rotates a vector by θ degrees clockwise (Equation 5).

$$B = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}. \qquad \text{(Equation 5)}$$

3.3 Known Theoretical Limitations

Too few or too many scattering particles can limit the range of the ADCP. The ADCP cannot measure current if scatterers move only perpendicular to each beam, although this is practically not an issue since each beam is 20 degree apart.

3.4 Revision History

The DPA for the ADCP was updated in November 2019 to add functionality for a three-beam solution in the event that one of the four beams has failed or is compromised (further details provided in Section 5 below).

4 Implementation

4.1 Overview

The L0 input format from instrument classes ADCPS, ADCPT is identical and these classes will be referred to generically as ADCP. (The instrument class ADCPA, on the gliders, produces L1 ECHOINT directly. Velocity Profile data from ADCPA instruments requires only magnetic variance correction as described in Step 8 of the processing flow. See the Coastal Glider DPS (DCN 1341-20001) for more details.) Decoding ADCP hexadecimal data ensembles converts the L0 velocity profile data product into an L1 velocity profile data product in units of m/s. The example MatLAB code written by Professor Rich Pawlowicz (http://www.eos.ubc.ca/~rich/#RDADCP, rich@eos.ubc.ca) is provided in Appendix A with his permission. Note that this is research code and is provided as an example for processing ADCP data, but does not handle bad data well as noted in the code comments. Not all functions in the example code apply to the creation of the OOI core data product VELPROF.

After each data collection cycle, the WorkHorse ADCP immediately sends a data ensemble that always includes header, fixed leader data, and variable leader data by default, and that may include velocity profile, correlation profile, echo intensity profile, percent good profile, status profile, bottom track data, MicroCAT data, etc. by user's choice.

Velocity profile L0 data product output can be either raw single-ping data or multi-ping averaged data in either radial beam coordinates or earth coordinates. Single-ping and multi-ping data are treated identically and are not differentiated in this processing specification. However, single-ping data will not go through the QA/QC steps using percent good data because percent good is not available for single-ping data. The L1 velocity profile data product is created by converting the L0 data product to decimal in units of m/s. In addition, if the L0 data product is in beam coordinates, it is transformed using matrices in section 3.2.to obtain North-South, East-West and vertical velocities in earth coordinates after decoding raw binary ADCP data files.

4.2 Inputs

Inputs are:

- L0 VELPROF velocity data product output from the ADCP driver

Input Data Format:

The most common standard data format is PD0, which provides all available information possible. PD0 is the format provided by ADCPA, ADCPS, and ADCPT instrument classes. However, ADCPs with inductive modems (ADCP Series G in ADCPT class and ADCP Series L in ADCPS class) will have the PD12 output format in the near real time telemetry to reduce the record size. PD12 data have the same decoding process steps as PD0 data, but the QA/QC steps are not the same since PD12 data do not provide echo intensity, correlation magnitude, and percent good data. See the ADCP Processing Flow document (DCN 1342-00750) and associated QC lookup tables for details of the QA/QC steps. The near real time PD12 data have no ECHOINT data product. However, the internally recorded data of those ADCPs with inductive modems are PD0; these data will be available for post-processing once the instrument is recovered.

PD0 standard output format is provided in Figure 1.

ALWAYS OUTPUT	**HEADER** (6 BYTES + [2 x No. OF DATA TYPES])
	FIXED LEADER DATA (59 BYTES)
	VARIABLE LEADER DATA (65 BYTES)
WD-command WP-command	**VELOCITY** (2 BYTES + 8 BYTES PER DEPTH CELL)
	CORRELATION MAGNITUDE (2 BYTES + 4 BYTES PER DEPTH CELL)
	ECHO INTENSITY (2 BYTES + 4 BYTES PER DEPTH CELL)
	PERCENT GOOD (2 BYTES + 4 BYTES PER DEPTH CELL)
BP-command	**BOTTOM TRACK DATA** (85 BYTES)
ALWAYS OUTPUT	**RESERVED** (2 BYTES)
	CHECKSUM (2 BYTES)

Figure 1. PD0 standard output data buffer format (fig. 8 in TRDI 2010b, p. 129)

Example: An ADCP data output with seven data types (Fixed Leader, Variable Leader, Velocity, Correction magnitude, Echo intensity, percent good data, and Bottom track) and 30 depth cells in PD0 standard output format has 841 bytes of data per ensemble. The Velocity data is the L0 VELPROF data product.

```
 20  BYTES OF HEADER DATA (6 + [2 x 7 Data Types])
 59  BYTES OF FIXED LEADER DATA (FIXED)
 65  BYTES OF VARIABLE LEADER DATA (FIXED)
242  BYTES OF VELOCITY DATA (2 + 8 x 30)
122  BYTES OF CORRELATION MAGNITUDE DATA (2 + 4 x 30)
122  BYTES OF ECHO INTENSITY (2 + 4 x 30)
122  BYTES OF PERCENT-GOOD DATA (2 + 4 x 30)
 85  BYTES OF BOTTOM TRACK DATA (FIXED)
  2  BYTES OF RESERVED FOR TRDI USE (FIXED)
  2  BYTES OF CHECKSUM DATA (FIXED)
841  BYTES OF DATA PER ENSEMBLE
```

Data formats of important data types are given in Figure 2 (header) and Figure 3 (velocity). Full description of data format for other data types can be found at TRDI (2010b).

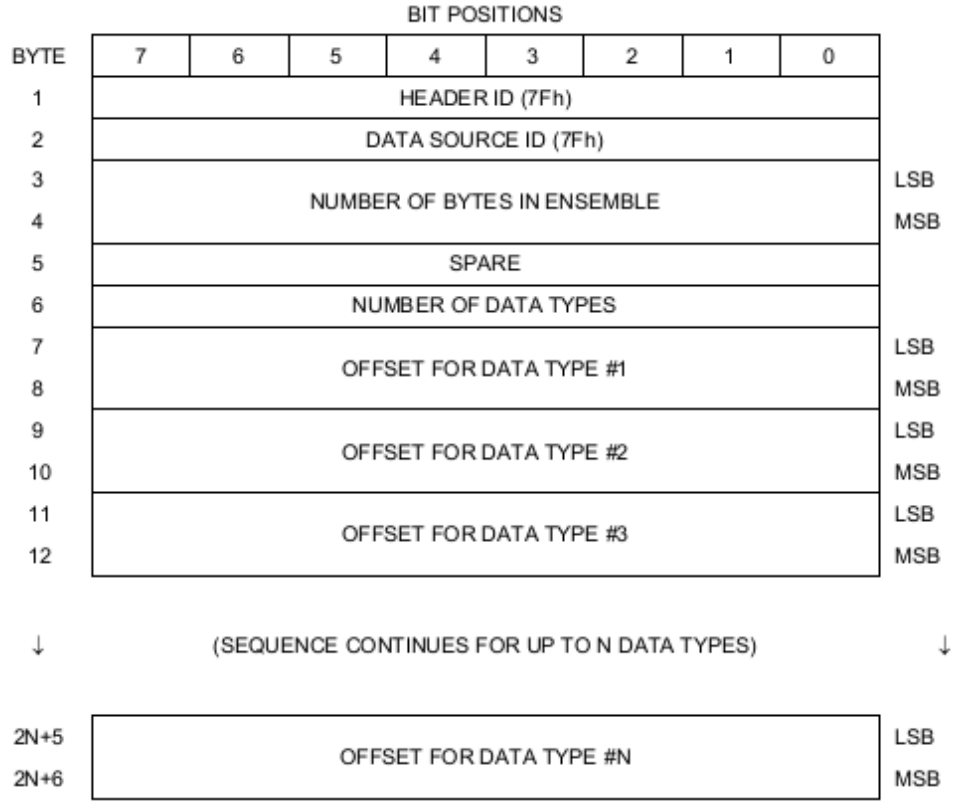

Figure 2. Header data format (figure 9 in TRDI, 2010b)

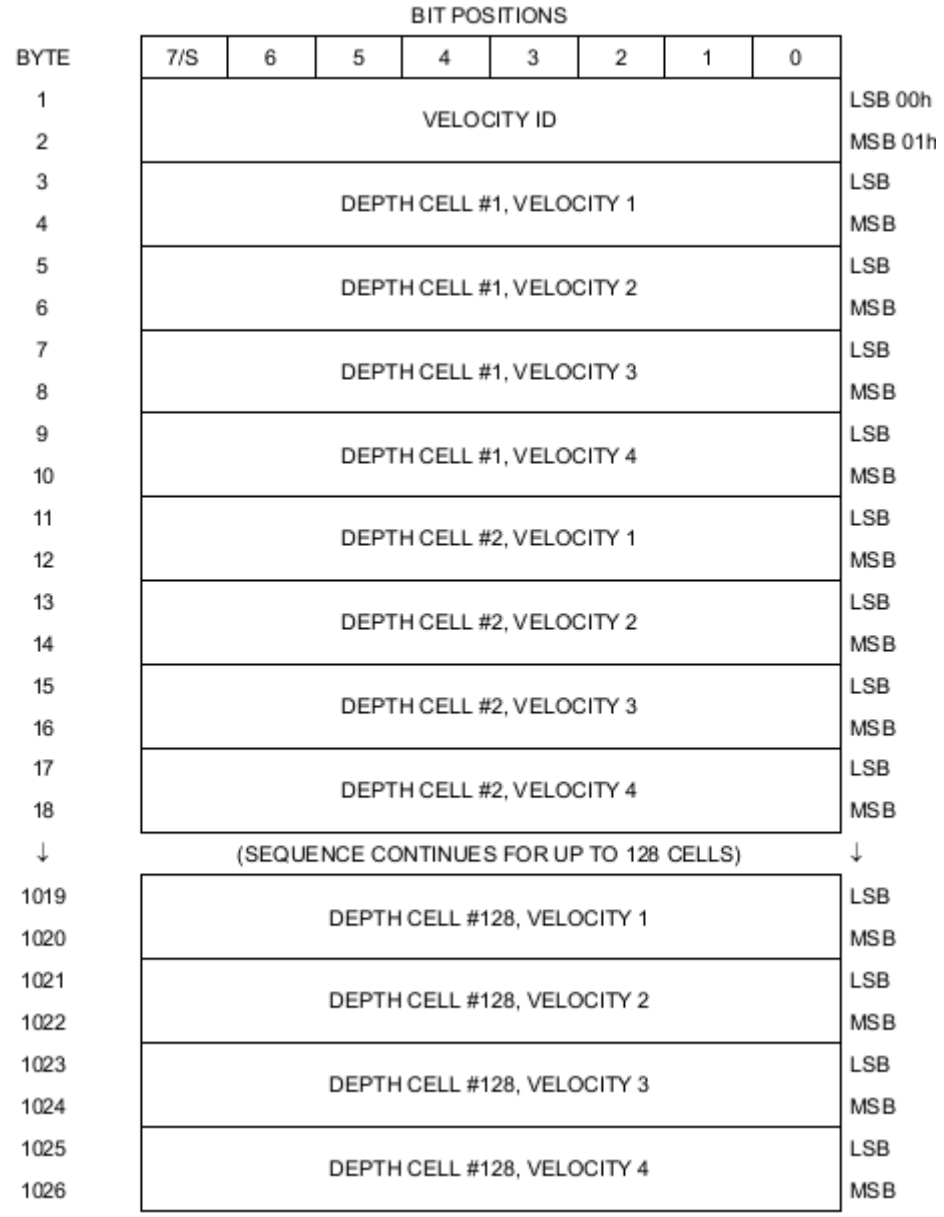

Figure 3. Velocity data format (fig. 12 in TRDI, 2010b)

4.3 Processing Flow

The decoding process recommended by the manufacture is summarized here. Details can be found in TRDI (2010b, p.183, section 7. How to decode an ADCP ensemble) cited in Section 2.4. All the necessary algorithms for data product and QC procedures, and the order that the algorithms need to be applied can be found in the ADCP Processing Flow document (DCN 1342-00750).

The processing flow for the velocity profile computation is as follows:

Step 1:
Locate the header data by locating the header ID number. All data types have a specific and unique ID number. The most common IDs are listed in Table 2.

Table 2. Common data format IDs (Table 47 in TRDI, 2010b, p.183)

ID	Description
0x7F7F	Header
0x0000	Fixed Leader
0x0080	Variable Leader
0x0100	Velocity Profile Data
0x0200	Correlation Profile Data
0x0300	Echo Intensity Profile Data
0x0400	Percent Good Profile Data
0x0500	Status Profile Data
0x0600	Bottom Track Data
0x0800	MicroCAT Data

Step 2:
Calculate the “checksum” by summing total number of bytes in the ensemble excluding the 2-byte of checksum. Then read the 2-byte checksum at the end of the ensemble and compare it to the value you calculated. If they match, then the data ensemble is valid. If they do not match, search for the next header ID number occurrence. One example of header data format of PD0 output data format is given below (TRDI, 2010b).

Step 3:
Read the number of data types in the header data. Data types can be fixed leader, variable leader, velocity, echo intensity, correlation, percent good, etc.

Step 4:
Read the offset to each data type in the header data.

Step 5:
Locate the data ID type of velocity and metadata described in section 2.2.5. Then confirm the data ID numbers. ID numbers for all data types need to be identified to decode an ADCP ensemble.

Step 6:
Find what each byte represents in the particular data type. Record the hexadecimal data from the Velocity data type as the L0 VELPROF data product. Record the hexadecimal data from the Echo Intensity data type as the L0 ECHOINT data product. Convert the targeted hexadecimal bytes to decimal to obtain the velocity profile data product in mm/s, the L1 ECHOINT echo intensity data product in dB, and associated metadata. Additional metadata can be found inside of the fixed leader and variable leader as described in section 2.2.5. No further processing is required for the L1 ECHOINT data product.

Step 7:
If the velocity profile data product is in beam coordinates, it needs to be transformed to earth coordinates by applying the transformation matrix A (Equation 1) and the rotation matrix M (Equation 2).

Velocity data for each depth cell consist of VEL1, VEL2, VEL3, and VEL4 that refer to beam1 (b1), beam2 (b2), beam3 (b3), and beam4 (b4) velocity in beam coordinates. Percent good should be used for each beam to determine if three-beam or four-beam solution should be applied (see Section 5).

$$\begin{bmatrix} u \\ v \\ w \\ e \end{bmatrix} = A * \begin{bmatrix} b1 \\ \mathrm{b2} \\ \mathrm{b3} \\ \mathrm{b4} \end{bmatrix},$$

where * denotes matrix multiplication and the matrix A is defined in Equation 1 in Section 3.2.

Now another transformation matrix M (Equation 2) needs to be applied to rotate velocity profiles from instrument coordinates, [u,v,w] to earth coordinates, [uu,vv,ww].

$$\begin{bmatrix} uu \\ vv \\ ww \end{bmatrix} = M * \begin{bmatrix} u \\ v \\ w \end{bmatrix},$$

where * denotes matrix multiplication and the matrix M is defined in Equation 2 in Section 3.2.

Step 8:
Apply magnetic variation correction to velocity profile components using Equation 5. The θ in Equation 5 is magnetic declination estimate, which is provided by the Implementing Organization for each deployment. It also can be calculated at NOAA national geophysical data center website (http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp). Positive magnetic variation means that magnetic north is east of true north and negative one means that magnetic north is west of true north. Inputs are horizontal velocity profiles in earth coordinates (uu,vv).

$$\begin{bmatrix} U \\ \mathrm{V} \end{bmatrix} = B * \begin{bmatrix} uu \\ \mathrm{vv} \end{bmatrix},$$

where * denotes matrix multiplication and the matrix B is defined in Equation 5 in Section 3.2.

4.4 Outputs

The output of the velocity profile computation is

- L1 VELPROF Velocity profile in mm/s in earth coordinates with magnetic variation correction applied
- L1 ECHOINT Echo intensity in dB

The metadata that must be included with the L1 VELPROF and with the L1 ECHOINT data product are listed below. See section 2.2.5 for details.

- Instrument frequency
- Beam pattern (concave or convex)
- Instrument orientation (up- or down- facing)
- Number of beams
- Number of cells
- Pings per ensemble
- Depth cell length
- Blank after transmit
- Coordinate transform
- Distance to the first bin
- Instrument serial number
- Beam angle
- Ensemble number
- RTC year, RTC month, RTC day, RTC hour, RTC minute, RTC second, RTC hundredths
- Speed of sound
- Depth of transducer
- Heading, pitch (Tilt1), roll (Tilt2)

- Salinity
- Temperature
- Pressure
- Correlation magnitude
- Percent good data

Automated QC algorithms are performed using correlation magnitude, percent good data and error velocity, which will generate QC flags for VELPROF (see DCN 1342-00750 Data Processing Flow Diagram for ADCP).

No automated QC is required for the L1 ECHOINT data product.

Note that the ADCPA instrument class produces L1 VELPROF and L1 ECHOINT directly. This data product must still be associated with the metadata described here, and have the automated QC processing steps applied.

See Appendix B for a discussion of the accuracy of the output.
http://www.teos-10.org/

4.5 Computational and Numerical Considerations

4.5.1 Numerical Programming Considerations

There are no numerical programming considerations for this computation. No special numerical methods are used.

4.5.2 Computational Requirements

None.

4.6 Code Verification and Test Data Set

A raw binary ADCP output file (mooredwh-bbdf.000) and MatLAB code (adcpdemo.m) written by Professor Rich Pawlowicz are placed on Alfresco at
OOI > Reference Archive > Data Product Specification Artifacts > 1341-00750_VELPROF_ECHOINT > VELPROF_Code_adcp_matlab.zip
for code verification and test. This code is implemented into the processing stream of NEPTUNE Canada (“regional-scale underwater ocean observatory network”, http://www.neptunecanada.ca/).

The raw binary ADCP output has been decoded and saved on Alfresco (adcp_demo_allEns.mat), which includes velocity profiles in beam coordinates, echo intensity and metadata. The velocity profiles in beam coordinates are transformed into instrument coordinates first using the Matlab function beam2ins (Equation 1), and then into earth coordinates using the Matlab function ins2earth (Equation 2). The output file is placed on Alfresco (adcp_demo_beam2earth.mat).

The test binary file (mooredwh-bbdf.000) has been read by the example code (adcpdemo.m). It includes 256 ensembles (ensemble number from 300 to 555) and 85 depth cells. The output data (adcp_demo_allEns.mat) have been read using Matlab and every field of the data is listed below.

```
    name: 'adcp'
  config: [1x1 struct]
   mtime: [1x256 double]
  number: [1x256 double]
   pitch: [1x256 double]
```

roll:	[1x256 double]
heading:	[1x256 double]
pitch_std:	[1x256 double]
roll_std:	[1x256 double]
heading_std:	[1x256 double]
depth:	[1x256 double]
temperature:	[1x256 double]
salinity:	[1x256 double]
pressure:	[1x256 double]
pressure_std:	[1x256 double]
east_vel:	[85x256 double]
north_vel:	[85x256 double]
vert_vel:	[85x256 double]
error_vel:	[85x256 double]
corr:	[85x4x256 double]
status:	[85x4x256 double]
intens:	[85x4x256 double]
bt_range:	[4x256 double]
bt_vel:	[4x256 double]
bt_corr:	[4x256 double]
bt_ampl:	[4x256 double]
bt_perc_good:	[4x256 double]
perc_good:	[85x4x255 double]

The example code stores four components of velocity profiles in the output file, i.e. east_vel, north_vel, vert_vel, and error_vel. They refer to eastward velocity, northward velocity, vertical velocity, and error velocity in earth coordinates and beam 1, beam 2, beam 3, beam 4 velocities in beam coordinates. In both cases, they are in units of m/s.

The velocity profiles in beam coordinates of the first ensemble (ensemble number 300) from the first to the tenth depth cells are shown below extracted from adcp_demo_allEns.mat in units of m/s.

Beam1 (m/s)	Beam2 (m/s)	Beam3 (m/s)	Beam4 (m/s)
-0.0300	0.1800	-0.3980	-0.2160
-0.2950	-0.1320	-0.4360	-0.6050
-0.5140	0.2130	-0.1310	-0.0920
-0.2340	0.3090	-0.4730	-0.0580
-0.1880	0.2910	-0.4430	0.4840
0.2030	0.0490	0.1880	-0.0050
-0.3250	0.1880	-0.1680	0.3380
0.3050	0.3730	0.2910	0.1750
-0.2040	-0.0020	-0.1790	-0.0800
-0.2940	0.1720	0.0080	-0.5490

The velocity profiles in beam coordinates are transformed using the Matlab functions, beam2ins and ins2earth (provided below). Output data are stored in adcp_demo_beam2earth.mat in units of m/s.

uu (m/s)	vv (m/s)	ww (m/s)
0.2175	-0.3367	0.1401
-0.2814	-0.1815	0.3977
-0.1002	-1.0522	0.1870
0.4831	-0.8676	0.1637
1.2380	-0.8919	0.0091
-0.2455	0.2585	-0.1290

0.6218	-0.8497	0.0334
-0.1807	-0.0873	-0.3017
0.0992	-0.3073	0.1384
-0.9063	-0.5461	0.1966

To apply magnetic variation correction described in step 8 (section 4.3) to horizontal velocity vectors, obtain magnetic variation from the Implementing Organization for each platform and for each deployment. The NOAA magnetic field calculators (http://www.ngdc.noaa.gov/geomag-web/#declination) can also provide magnetic variation. Inputs for the website are date, latitude and longitude.

For instance, horizontal velocity vector in earth coordinate in ensemble number 303 of the example data file (adcp_demo_beam2earth.mat) is (uu,vv) = (0.4413,0. 1719) in m/sec. If we apply magnetic variation at Station Papa (50°N, 145°W), which is 16.9604° on May 1st, 2012, horizontal velocity vector is transformed to (U,V) = (0.4722, 0.0357) in m/sec (Figure 4) using the Matlab function mag_var.

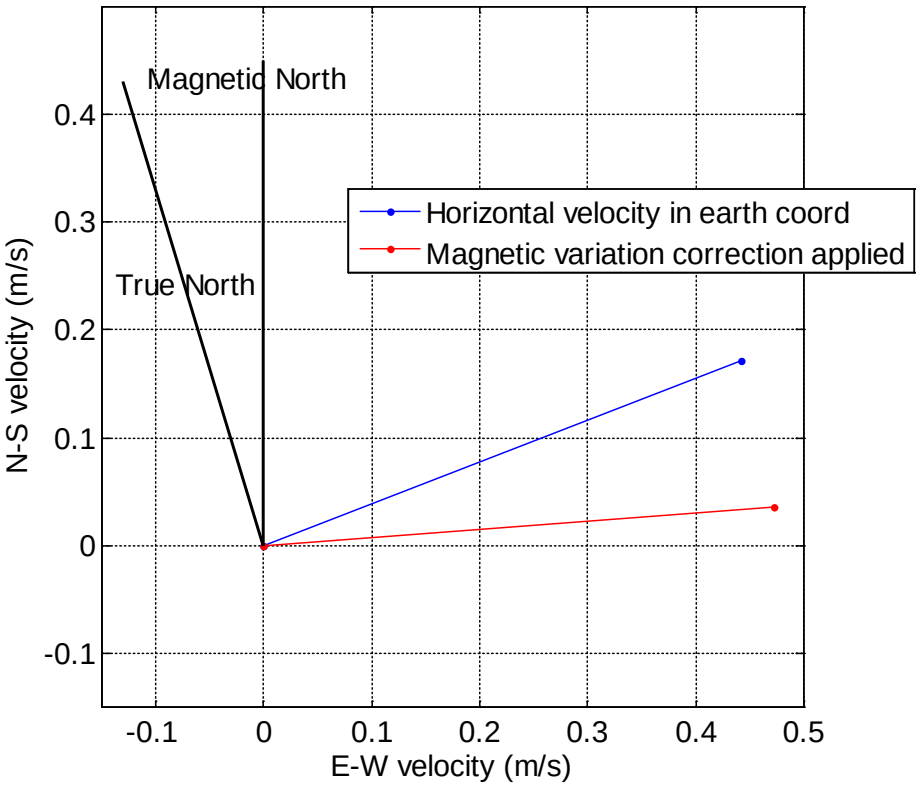

Figure 4. An example of applying the magnetic variation correction.

```
function [u,v,w,e] = beam2ins(b1,b2,b3,b4)
%
% input:
%   b1, b2, b3, b4: velocity profiles in beam coordinates
%
% output:
%   velocity profiles (u,v,w,e) in instrument coordinates
```

```
%
%

theta = 20/180*pi;% 20 deg
a = 1./(2.*sin(theta));
b = 1./(4.*cos(theta));
c = 1;% convex (Long Ranger & Quartermaster)
d = a./sqrt(2);

u = c.*a.*(b1-b2);
v = c.*a.*(b4-b3);
w = b.*(b1+b2+b3+b4);
e = d.*(b1+b2-b3-b4);

function [uu,vv,ww] = ins2earth(u,v,w,H,tilt1,tilt2,adcpmode)
%
% USAGE
% [uu,vv,ww] = ins2earth(u,v,w,H,tilt1,tilt2,adcpmode)
%
%
% input
%   u,v,w: velocity profile in instrument coordinates
%   tilt1: measured pitch, degree
%   tilt2: measured roll, degree
%   adcpmode: 0 for downward looking ADCP, 1 for upward looking ADCP
%
% output
%   uu,vv,ww: velocity profile earth coordinates
%

if adcpmode,
    R = tilt2+180;
else
    R = tilt2;
end

Rrad    = deg2rad(R);
Hrad    = deg2rad(H);
t1rad   = deg2rad(tilt1);
t2rad   = deg2rad(tilt2);

P = atan(tan(t1rad).*cos(t2rad));% rad

M1 = [cos(Hrad) sin(Hrad) 0; -sin(Hrad) cos(Hrad) 0;0 0 1];
M2 = [1 0 0;0 cos(P) -sin(P); 0 sin(P) cos(P)];
M3 = [cos(Rrad) 0 sin(Rrad); 0 1 0; -sin(Rrad) 0 cos(Rrad)];

for i=1:length(u),
    vel(i,:) = M1*M2*M3*[u(i);v(i);w(i)];
end

uu = vel(:,1);
vv = vel(:,2);
ww = vel(:,3);
```

```
function radvalue = deg2rad(degvalue)
radvalue = degvalue./180*pi;
```

5 Three-Beam Solution

5.1 Overview

In the event that a single beam fails, as determined by the percent good variable for that beam falling below 25%, a three-beam solution can be implemented if the percent good for the other three beams exceeds 25%. The three-beam solution, as described in TRDI, 2010a, p. 14, implements this solution by "replacing the bad radial beam velocity with a valuel calculated from the last row of the instrument transformation matrix so as to force the error velocity to zero….The X,Y, and Z components in the instrument coordinates are then calculated in the usual way using the first three rows of the instrument transformation matrix."

The following example, excerpted from TRDI, 2010a, p. 14, provides the necessary equations for a three-beam solution assuming Beam 4 has failed.

"As aforementioned, since we only have 3 beams available we cannot compute the error velocity as we do not have redundancy in the data anymore. Therefore, we can zero the error velocity:"

$e = 0$ (Equation 6)

Replacing the error velocity in the last row of the transformation matrix (TRDI, 2010a, p. 11, Equation 9):

$b_4 = b_1 + b_2 + b_3$ (Equation 7)

With the bad beam now expressed as a function of the other beams, the transformation matrix can be expressed as:

$$\begin{bmatrix} X \\ Y \\ Z \\ e \end{bmatrix} = \begin{bmatrix} ca(b_1 - b_2) \\ ca(b_1 + b_2 + 2b_3) \\ 2b(b_1 + b_2) \\ 0 \end{bmatrix}$$ (Equation 8)

5.2 Implementation

The three-beam solution was implemented in the data product algorithm for the ADCP in the "adcp_functions.py" script in the OOI ion-functions library. The code was based on the above recommendations from Teledyne RD Instruments, as noted in TRDI, 2010a, p.14. Input to functions is now required to include percent good for each beam in order to evaluate whether a four-beam or three-beam solution is possible. This code also includes logic to determine if more than one beam is bad per depth cell, and if so returns NaN.

Relevant code, excerpted from adcp_beam2ins:

x, y, z, e = adcp_beam2ins(b1, b2, b3, b4, pg1, pg2, pg3, pg4)

where

x = x axis velocity profiles in instrument coordinates [mm s-1]
y = y axis velocity profiles in instrument coordinates [mm s-1]

```
z = z axis velocity profiles in instrument coordinates [mm s-1]
e = error velocity profiles [mm s-1]

b1 = beam 1 velocity profiles in beam coordinates [mm s-1]
b2 = beam 2 velocity profiles in beam coordinates [mm s-1]
b3 = beam 3 velocity profiles in beam coordinates [mm s-1]
b4 = beam 4 velocity profiles in beam coordinates [mm s-1]
pg1 = percent good estimate for beam 1 [percent]
pg2 = percent good estimate for beam 2 [percent]
pg3 = percent good estimate for beam 3 [percent]
pg4 = percent good estimate for beam 4 [percent]

# raw beam velocities, set to correct shape
b1 = np.atleast_2d(b1)
b2 = np.atleast_2d(b2)
b3 = np.atleast_2d(b3)
b4 = np.atleast_2d(b4)

# percentage of good pings for each beam per depth cell, set to correct shape
pg1 = np.atleast_2d(pg1)
pg2 = np.atleast_2d(pg2)
pg3 = np.atleast_2d(pg3)
pg4 = np.atleast_2d(pg4)

# using the vendor specified percent good floor of 25%, create masked arrays with fill values set to compute a 3-beam solution, if applicable.
ma1 = np.ma.masked_where(pg1 < 25, b1)
bm1 = ma1.filled((b2 - b3 - b4) * -1)
ma2 = np.ma.masked_where(pg2 < 25, b2)
bm2 = ma2.filled((b1 - b3 - b4) * -1)
ma3 = np.ma.masked_where(pg3 < 25, b3)
bm3 = ma3.filled(b1 + b2 - b4)
ma4 = np.ma.masked_where(pg4 < 25, b4)
bm4 = ma4.filled(b1 + b2 - b3)

# sum across the masked arrays to determine if more than 1 beam is bad per depth cell, if so we cannot compute a 3-beam solution and need to set the fill value to a NaN.
mad = np.ma.dstack((ma1, ma2, ma3, ma4))    # stack the masked arrays in depth
mas = np.ma.count_masked(mad, axis=2)       # count the number of depth cells masked in  the depth stacked array

# using the above, reset the raw beams. fill with 3-beam if applicable, otherwise use a NaN
bm1 = np.ma.filled(np.ma.masked_where(mas > 1, bm1), ADCP_FILLVALUE)
bm2 = np.ma.filled(np.ma.masked_where(mas > 1, bm2), ADCP_FILLVALUE)
bm3 = np.ma.filled(np.ma.masked_where(mas > 1, bm3), ADCP_FILLVALUE)
bm4 = np.ma.filled(np.ma.masked_where(mas > 1, bm4), ADCP_FILLVALUE)

bm1, bm2, bm3, bm4 = replace_fill_with_nan(ADCP_FILLVALUE, bm1, bm2, bm3, bm4)
```

Appendix A Example Code

This Appendix contains MatLAB code for reading raw binary ADCP data files written by Professor Rich Pawlowicz (http://www.eos.ubc.ca/~rich/#RDADCP, rich@eos.ubc.ca). This code has been used extensively by the oceanographic community. A copy of the code (rdradcp.m) has been placed on Alfresco at
OOI > Reference Archive > Data Product Specification Artifacts > 1341-00750_VELPROF_ECHOINT > VELPROF_Code_adcp_matlab.zip. The demo input file, mooredwh-bbdf.000 is in beam coordinates in **PD0** data format. Note that output of this example code is always named east_vel, north_vel, vert_vel, and error_vel regardless of the coordinate system. Thus, if velocity profile is in beam coordinates, actual meaning of those velocity profile variable names is beam1, beam2, beam3, and beam4 radial velocity.

```
function [adcp,cfg,ens,hdr]=rdradcp(name,varargin);
% RDRADCP  Read (raw binary) RDI ADCP files,
%  ADCP=RDRADCP(NAME) reads the raw binary RDI BB/Workhorse ADCP file NAME and
%  puts all the relevant configuration and measured data into a data structure
%  ADCP (which is self-explanatory). This program is designed for handling data
%  recorded by moored instruments (primarily Workhorse-type but can also read
%  Broadband) and then downloaded post-deployment. For vessel-mount data I
%  usually make p-files (which integrate nav info and do coordinate transformations)
%  and then use RDPADCP.
%
%  This current version does have some handling of VMDAS, WINRIVER, and WINRIVER2 output
%  files, but it is still 'beta'. There are (inadequately documented) timestamps
% of various kinds from VMDAS, for example, and caveat emptor on WINRIVER2 NMEA data.
%
%  [ADCP,CFG]=RDRADCP(...) returns configuration data in a
%  separate data structure.
%
%  Various options can be specified on input:
%  [..]=RDRADCP(NAME,NUMAV) averages NUMAV ensembles together in the result.
%  [..]=RDRADCP(NAME,NUMAV,NENS) reads only NENS ensembles (-1 for all).
%  [..]=RDRADCP(NAME,NUMAV,[NFIRST NEND]) reads only the specified range
%   of ensembles. This is useful if you want to get rid of bad data before/after
%   the deployment period.
%
%  Notes- sometimes the ends of files are filled with garbage. In this case you may
%         have to rerun things explicitly specifying how many records to read (or the
%         last record to read). I don't handle bad data very well. Also - in Aug/2007
%         I discovered that WINRIVER-2 files can have a varying number of bytes per
%         ensemble. Thus the estimated number of ensembles in a file (based on the
%         length of the first ensemble and file size) can be too high or too low.
%
%       - I don't read in absolutely every parameter stored in the binaries;
%         just the ones that are 'most' useful. Look through the code if
%         you want to get other things.
%
%       - chaining of files does not occur (i.e. read .000, .001, etc.). Sometimes
%         a ping is split between the end of one file and the beginning of another.
%         The only way to get this data is to concatentate the files, using
%           cat file1.000 file1.001 > file1   (unix)
%           copy file1.000/B+file2.001/B file3.000/B     (DOS/Windows)
%
%         (as of Dec 2005 we can probably read a .001 file)
%
%       - velocity fields are always called east/north/vertical/error for all
%         coordinate systems even though they should be treated as
%         1/2/3/4 in beam coordinates etc.
%
%  String parameter/option pairs can be added after these initial parameters:
```

```
%
%  'baseyear'    : Base century for BB/v8WH firmware (default to 2000).
%
%  'despike'    : [ 'no' | 'yes' | 3-element vector ]
%               Controls ensemble averaging. With 'no' a simple mean is used
%               (default). With 'yes' a mean is applied to all values that fall
%               within a window around the median (giving some outlier rejection).
%               This is useful for noisy data. Window sizes are [.3 .3 .3] m/s
%               for [ horiz_vel vert_vel error_vel ] values. If you want to
%               change these values, set 'despike' to the 3-element vector.
%
% R. Pawlowicz (rich@eos.ubc.ca) - 17/09/99

% R. Pawlowicz - 17/Oct/99
%        5/july/00 - handled byte offsets (and mysterious 'extra" bytes) slightly better, Y2K
%        5/Oct/00 - bug fix - size of ens stayed 2 when NUMAV==1 due to initialization,
%                   hopefully this is now fixed.
%        10/Mar/02 - #bytes per record changes mysteriously,
%                    tried a more robust workaround. Guess that we have an extra
%                    2 bytes if the record length is even?
%        28/Mar/02 - added more firmware-dependent changes to format; hopefully this
%                    works for everything now (put previous changes on firmer footing?)
%        30/Mar/02 - made cfg output more intuitive by decoding things.
%                  - An early version of WAVESMON and PARSE which split out this
%                    data from a wave recorder inserted an extra two bytes per record.
%                    I have removed the code to handle this but if you need it see line 509
%       29/Nov/02  - A change in the bottom-track block for version 4.05 (very old!).
%       29/Jan/03  - Status block in v4.25 150khzBB two bytes short?
%       14/Oct/03  - Added code to at least 'ignore' WinRiver GPS blocks.
%       11/Nov/03  - VMDAS navigation block, added hooks to output
%                    navigation data.
%       26/Mar/04  - better decoding of nav blocks
%                  - better handling of weird bytes at beginning and end of file
%                    (code fixes due to Matt Drennan).
%       25/Aug/04  - fixes to "junk bytes" handling.
%       27/Jan/05  - even more fixed to junk byte handling (move 1 byte at a time rather than
%                    two for odd lengths.
%  29/Sep/2005 - median windowing done slightly incorrectly in a way which biases
%                results in a negative way in data is *very* noisy. Now fixed.
%
%   28/Dc/2005  - redid code for recovering from ensembles that mysteriously change length, added
%                 'checkheader' to make a complete check of ensembles.
%     Feb/2006  - handling of firmware version 9 (navigator)
%   23/Aug/2006 - more firmware updates (16.27)
%   23/Aug2006  - ouput some bt QC stiff
%   29/Oct/2006 - winriver bottom track block had errors in it - now fixed.
%   30/Oct/2006 - pitch_std, roll_std now uint8 and not int8 (thanks Felipe pimenta)
%   13/Aug/2007 - added Rio Grande (firmware v 10),
%                 better handling of those cursed winriver ASCII NMEA blocks whose
%                 lengths change unpredictably.
%                 skipping the inadequately documented 2022 WINRIVER-2 NMEA block
%   13/Mar/2010 - firmware version 50 for WH.


num_av=5;   % Block filtering and decimation parameter (# ensembles to block together).
nens=-1;   % Read all ensembles.
century=2000;  % ADCP clock does not have century prior to firmware 16.05.
vels='no';   % Default to simple averaging

lv=length(varargin);
if lv>=1 & ~isstr(varargin{1}),
  num_av=varargin{1}; % Block filtering and decimation parameter (# ensembles to block together).
```

```
  varargin(1)=[];
  lv=lv-1;
  if lv>=1 & ~isstr(varargin{1}),
    nens=varargin{1};
    varargin(1)=[];
    lv=lv-1;
  end;
end;

% Read optional args
while length(varargin)>0,
 switch varargin{1}(1:3),
              case 'bas',
                century = varargin{2};
              case 'des',
                if isstr(varargin{2}),
                 if strcmp(varargin{2},'no'), vels='no';
                 else vels=[.3 .3 .3]; end;
                else
                 vels=varargin{2};
                end;
              otherwise,
                error(['Unknown command line option  ->' varargin{1}]);
   end;
   varargin([1 2])=[];
end;



% Check file information first

naminfo=dir(name);

if isempty(naminfo),
  fprintf('ERROR******* Can''t find file %s\n',name);
  return;
end;

fprintf('\nOpening file %s\n\n',name);
fd=fopen(name,'r','ieee-le');

% Read first ensemble to initialize parameters

[ens,hdr,cfg,pos]=rd_buffer(fd,-2); % Initialize and read first two records
if ~isstruct(ens) & ens==-1,
  disp('No Valid data found');
  adcp=[];
  return;
end;
fseek(fd,pos,'bof');              % Rewind

if (cfg.prog_ver<16.05 & cfg.prog_ver>5.999) | cfg.prog_ver<5.55,
  fprintf('***** Assuming that the century begins year %d (info not in this firmware version) \n\n',century);
else
  century=0;  % century included in clock.
end;

dats=datenum(century+ens.rtc(1,:),ens.rtc(2,:),ens.rtc(3,:),ens.rtc(4,:),ens.rtc(5,:),ens.rtc(6,:)+ens.rtc(7,:)/100
);
t_int=diff(dats);
fprintf('Record begins at %s\n',datestr(dats(1),0));
```

```
fprintf('Ping interval appears to be  %s\n',datestr(t_int,13));


% Estimate number of records (since I don't feel like handling EOFs correctly,
% we just don't read that far!)


% Now, this is a puzzle - it appears that this is not necessary in
% a firmware v16.12 sent to me, and I can't find any example for
% which it *is* necessary so I'm not sure why its there. It could be
% a leftoever from dealing with the bad WAVESMON/PARSE problem (now
% fixed) that inserted extra bytes.
% ...So its out for now.
%if cfg.prog_ver>=16.05, extrabytes=2; else extrabytes=0; end; % Extra bytes
extrabytes=0;

nensinfile=fix(naminfo.bytes/(hdr.nbyte+2+extrabytes));
fprintf('\nEstimating %d ensembles in this file\n',nensinfile);

if length(nens)==1,
  if nens==-1,
    nens=nensinfile;
  end;
  fprintf('   Reading %d ensembles, reducing by a factor of %d\n',nens,num_av);
else
  fprintf('   Reading ensembles %d-%d, reducing by a factor of %d\n',nens,num_av);
  fseek(fd,(hdr.nbyte+2+extrabytes)*(nens(1)-1),'cof');
  nens=diff(nens)+1;
end;

% Number of records after averaging.

n=fix(nens/num_av);
fprintf('Final result %d values\n',n);

if num_av>1,
  if isstr(vels),
     fprintf('\n Simple mean used for ensemble averaging\n');
  else
     fprintf('\n Averaging after outlier rejection with parameters [%f %f %f]\n',vels);
  end;
end;


% Structure to hold all ADCP data
% Note that I am not storing all the data contained in the raw binary file, merely
% things I think are useful.

switch cfg.sourceprog,
  case 'WINRIVER',
    adcp=struct('name','adcp','config',cfg,'mtime',zeros(1,n),'number',zeros(1,n),'pitch',zeros(1,n),...
            'roll',zeros(1,n),'heading',zeros(1,n),'pitch_std',zeros(1,n),...
            'roll_std',zeros(1,n),'heading_std',zeros(1,n),'depth',zeros(1,n),...
            'temperature',zeros(1,n),'salinity',zeros(1,n),...
            'pressure',zeros(1,n),'pressure_std',zeros(1,n),...
            'east_vel',zeros(cfg.n_cells,n),'north_vel',zeros(cfg.n_cells,n),'vert_vel',zeros(cfg.n_cells,n),...
            'error_vel',zeros(cfg.n_cells,n),'corr',zeros(cfg.n_cells,4,n),...
            'status',zeros(cfg.n_cells,4,n),'intens',zeros(cfg.n_cells,4,n),...
                  'bt_range',zeros(4,n),'bt_vel',zeros(4,n),...
                       'bt_corr',zeros(4,n),'bt_ampl',zeros(4,n),'bt_perc_good',zeros(4,n),...
                       'nav_mtime',zeros(1,n),...
             'nav_longitude',zeros(1,n),'nav_latitude',zeros(1,n));
```

```
 case 'VMDAS',
  adcp=struct('name','adcp','config',cfg,'mtime',zeros(1,n),'number',zeros(1,n),'pitch',zeros(1,n),...
          'roll',zeros(1,n),'heading',zeros(1,n),'pitch_std',zeros(1,n),...
          'roll_std',zeros(1,n),'heading_std',zeros(1,n),'depth',zeros(1,n),...
          'temperature',zeros(1,n),'salinity',zeros(1,n),...
          'pressure',zeros(1,n),'pressure_std',zeros(1,n),...
          'east_vel',zeros(cfg.n_cells,n),'north_vel',zeros(cfg.n_cells,n),'vert_vel',zeros(cfg.n_cells,n),...
          'error_vel',zeros(cfg.n_cells,n),'corr',zeros(cfg.n_cells,4,n),...
          'status',zeros(cfg.n_cells,4,n),'intens',zeros(cfg.n_cells,4,n),...
                'bt_range',zeros(4,n),'bt_vel',zeros(4,n),...
                     'bt_corr',zeros(4,n),'bt_ampl',zeros(4,n),'bt_perc_good',zeros(4,n),...
                'nav_smtime',zeros(1,n),'nav_emtime',zeros(1,n),...
                'nav_slongitude',zeros(1,n),'nav_elongitude',zeros(1,n),...
                'nav_slatitude',zeros(1,n),'nav_elatitude',zeros(1,n),'nav_mtime',zeros(1,n));
 otherwise
  adcp=struct('name','adcp','config',cfg,'mtime',zeros(1,n),'number',zeros(1,n),'pitch',zeros(1,n),...
          'roll',zeros(1,n),'heading',zeros(1,n),'pitch_std',zeros(1,n),...
          'roll_std',zeros(1,n),'heading_std',zeros(1,n),'depth',zeros(1,n),...
          'temperature',zeros(1,n),'salinity',zeros(1,n),...
          'pressure',zeros(1,n),'pressure_std',zeros(1,n),...
          'east_vel',zeros(cfg.n_cells,n),'north_vel',zeros(cfg.n_cells,n),'vert_vel',zeros(cfg.n_cells,n),...
          'error_vel',zeros(cfg.n_cells,n),'corr',zeros(cfg.n_cells,4,n),...
          'status',zeros(cfg.n_cells,4,n),'intens',zeros(cfg.n_cells,4,n),...
                    'bt_range',zeros(4,n),'bt_vel',zeros(4,n),...
                    'bt_corr',zeros(4,n),'bt_ampl',zeros(4,n),'bt_perc_good',zeros(4,n));
end;


% Calibration factors for backscatter data

clear global ens
% Loop for all records
for k=1:n,

 % Gives display so you know something is going on...

 if rem(k,50)==0,  fprintf('\n%d',k*num_av);end;
 fprintf('.');

 % Read an ensemble

 ens=rd_buffer(fd,num_av);

 if ~isstruct(ens), % If aborting...
  fprintf('Only %d records found..suggest re-running RDRADCP using this parameter\n',(k-1)*num_av);
  fprintf('(If this message preceded by a POSSIBLE PROGRAM PROBLEM message, re-run using
%d)\n',(k-1)*num_av-1);
  break;
 end;


dats=datenum(century+ens.rtc(1,:),ens.rtc(2,:),ens.rtc(3,:),ens.rtc(4,:),ens.rtc(5,:),ens.rtc(6,:)+ens.rtc(7,:)/100
);
 adcp.mtime(k)=median(dats);
 adcp.number(k)      =ens.number(1);
 adcp.heading(k)     =mean(ens.heading);
 adcp.pitch(k)       =mean(ens.pitch);
 adcp.roll(k)        =mean(ens.roll);
 adcp.heading_std(k) =mean(ens.heading_std);
 adcp.pitch_std(k)   =mean(ens.pitch_std);
 adcp.roll_std(k)    =mean(ens.roll_std);
 adcp.depth(k)       =mean(ens.depth);
```

```
 adcp.temperature(k) =mean(ens.temperature);
 adcp.salinity(k)    =mean(ens.salinity);
 adcp.pressure(k)    =mean(ens.pressure);
 adcp.pressure_std(k)=mean(ens.pressure_std);

 if isstr(vels),
   adcp.east_vel(:,k)    =nmean(ens.east_vel ,2);
   adcp.north_vel(:,k)   =nmean(ens.north_vel,2);
   adcp.vert_vel(:,k)    =nmean(ens.vert_vel ,2);
   adcp.error_vel(:,k)   =nmean(ens.error_vel,2);
 else
  adcp.east_vel(:,k)    =nmedian(ens.east_vel  ,vels(1),2);
  adcp.north_vel(:,k)   =nmedian(ens.north_vel,vels(1),2);
  adcp.vert_vel(:,k)    =nmedian(ens.vert_vel  ,vels(2),2);
  adcp.error_vel(:,k)   =nmedian(ens.error_vel,vels(3),2);
 end;

 adcp.corr(:,:,k)      =nmean(ens.corr,3);       % added correlation RKD 9/00
 adcp.status(:,:,k)=nmean(ens.status,3);

 adcp.intens(:,:,k)     =nmean(ens.intens,3);
 adcp.perc_good(:,:,k)  =nmean(ens.percent,3);  % felipe pimenta aug. 2006


 adcp.bt_range(:,k)   =nmean(ens.bt_range,2);
 adcp.bt_vel(:,k)     =nmean(ens.bt_vel,2);

 adcp.bt_corr(:,k)=nmean(ens.bt_corr,2);          % felipe pimenta aug. 2006
 adcp.bt_ampl(:,k)=nmean(ens.bt_ampl,2);          %  "
 adcp.bt_perc_good(:,k)=nmean(ens.bt_perc_good,2);%  "

 switch cfg.sourceprog,
   case 'WINRIVER',
    adcp.nav_mtime(k)=nmean(ens.smtime);
    adcp.nav_longitude(k)=nmean(ens.slongitude);
    adcp.nav_latitude(k)=nmean(ens.slatitude);
  case 'VMDAS',
    adcp.nav_smtime(k)   =ens.smtime(1);
    adcp.nav_emtime(k)   =ens.emtime(1);
    adcp.nav_slatitude(k)=ens.slatitude(1);
    adcp.nav_elatitude(k)=ens.elatitude(1);
    adcp.nav_slongitude(k)=ens.slongitude(1);
    adcp.nav_elongitude(k)=ens.elongitude(1);
    adcp.nav_mtime(k)=nmean(ens.nmtime);
 end;
end;

fprintf('\n');
fprintf('Read to byte %d in a file of size %d bytes\n',ftell(fd),naminfo.bytes);
if ftell(fd)+hdr.nbyte<naminfo.bytes,
  fprintf('-->There may be another %d ensembles unread\n',fix((naminfo.bytes-ftell(fd))/(hdr.nbyte+2)));
end;

fclose(fd);

%----------------------------------------
function valid=checkheader(fd);

%disp('checking');
valid=0;
numbytes=fread(fd,1,'int16');          % Following the header bytes is numbytes
if numbytes>0,                                 % and we move forward numbytes>0
```

```
  status=fseek(fd,numbytes-2,'cof');
  if status==0,
    cfgid=fread(fd,2,'uint8');
    if length(cfgid)==2,              % will Skip the last ensemble (sloppy code)
      fseek(fd,-numbytes-2,'cof');
   %% fprintf([dec2hex(cfgid(1)) ' ' dec2hex(cfgid(2)) '\n']);
      if cfgid(1)==hex2dec('7F') & cfgid(2)==hex2dec('7F')          % and we have *another* 7F7F
            valid=1;                                               % ...ONLY THEN it is valid.
      end;
    end;
  end;
 else
  fseek(fd,-2,'cof');
 end;


%-------------------------------------
function [hdr,pos]=rd_hdr(fd);
% Read config data
% Changed by Matt Brennan to skip weird stuff at BOF (apparently
% can happen when switching from one flash card to another
% in moored ADCPs).

cfgid=fread(fd,2,'uint8');
nread=0;
while (cfgid(1)~=hex2dec('7F') | cfgid(2)~=hex2dec('7F'))  | ~checkheader(fd),
    nextbyte=fread(fd,1,'uint8');
    pos=ftell(fd);
    nread=nread+1;
    if isempty(nextbyte),  % End of file
        disp('EOF reached before finding valid cfgid');
            hdr=NaN;
        return;
    end
    cfgid(2)=cfgid(1);cfgid(1)=nextbyte;
    if mod(pos,1000)==0
        disp(['Still looking for valid cfgid at file position ' num2str(pos) '...'])
    end
end;

pos=ftell(fd)-2;
if nread>0,
  disp(['Junk found at BOF...skipping ' int2str(nread) ' bytes until ']);
  disp(['cfgid=' dec2hex(cfgid(1)) dec2hex(cfgid(2)) ' at file pos ' num2str(pos)])
end;

hdr=rd_hdrseg(fd);

%-------------------------------------
function cfg=rd_fix(fd);
% Read config data

cfgid=fread(fd,1,'uint16');
if cfgid~=hex2dec('0000'),
 warning(['Fixed header ID ' cfgid 'incorrect - data corrupted or not a BB/WH raw file?']);
end;

cfg=rd_fixseg(fd);



%-------------------------------------
```

```
function [hdr,nbyte]=rd_hdrseg(fd);
% Reads a Header

hdr.nbyte         =fread(fd,1,'int16');
fseek(fd,1,'cof');
ndat=fread(fd,1,'int8');
hdr.dat_offsets    =fread(fd,ndat,'int16');
nbyte=4+ndat*2;

%---------------------------------
function opt=getopt(val,varargin);
% Returns one of a list (0=first in varargin, etc.)
if val+1>length(varargin),
          opt='unknown';
else
  opt=varargin{val+1};
end;

%
%---------------------------------
function [cfg,nbyte]=rd_fixseg(fd);
% Reads the configuration data from the fixed leader

%%disp(fread(fd,10,'uint8'))
%%fseek(fd,-10,'cof');

cfg.name='wh-adcp';
cfg.sourceprog='instrument';  % default - depending on what data blocks are
                      % around we can modify this later in rd_buffer.
cfg.prog_ver       =fread(fd,1,'uint8')+fread(fd,1,'uint8')/100;

% 8,9,16 - WH navigator
% 10 -rio grande
% 15, 17 - NB
% 19 - REMUS, or customer specific
% 11- H-ADCP
% 31 - Streampro
% 34 - NEMO
% 50 - WH, no bottom track (built on 16.31)
% 51 - WH, w/ bottom track
% 52 - WH, mariner

if fix(cfg.prog_ver)==4 | fix(cfg.prog_ver)==5,
   cfg.name='bb-adcp';
elseif fix(cfg.prog_ver)==8 | fix(cfg.prog_ver)==9 | fix(cfg.prog_ver)==10 | fix(cfg.prog_ver)==16 ...
    | fix(cfg.prog_ver)==50 | fix(cfg.prog_ver)==51 | fix(cfg.prog_ver)==52,
   cfg.name='wh-adcp';
elseif fix(cfg.prog_ver)==14 | fix(cfg.prog_ver)==23,  % phase 1 and phase 2
   cfg.name='os-adcp';
else
   cfg.name='unrecognized firmware version'   ;
end;

config        =fread(fd,2,'uint8');  % Coded stuff
cfg.config         =[dec2base(config(2),2,8) '-' dec2base(config(1),2,8)];
 cfg.beam_angle     =getopt(bitand(config(2),3),15,20,30);
 cfg.numbeams       =getopt(bitand(config(2),16)==16,4,5);
 cfg.beam_freq      =getopt(bitand(config(1),7),75,150,300,600,1200,2400,38);
 cfg.beam_pattern   =getopt(bitand(config(1),8)==8,'concave','convex'); % 1=convex,0=concave
 cfg.orientation    =getopt(bitand(config(1),128)==128,'down','up');    % 1=up,0=down
cfg.simflag        =getopt(fread(fd,1,'uint8'),'real','simulated'); % Flag for simulated data
fseek(fd,1,'cof');
```

```
cfg.n_beams       =fread(fd,1,'uint8');
cfg.n_cells       =fread(fd,1,'uint8');
cfg.pings_per_ensemble=fread(fd,1,'uint16');
cfg.cell_size     =fread(fd,1,'uint16')*.01;        % meters
cfg.blank         =fread(fd,1,'uint16')*.01;        % meters
cfg.prof_mode     =fread(fd,1,'uint8');         %
cfg.corr_threshold =fread(fd,1,'uint8');
cfg.n_codereps    =fread(fd,1,'uint8');
cfg.min_pgood     =fread(fd,1,'uint8');
cfg.evel_threshold =fread(fd,1,'uint16');
cfg.time_between_ping_groups=sum(fread(fd,3,'uint8').*[60 1 .01]'); % seconds
coord_sys     =fread(fd,1,'uint8');                 % Lots of bit-mapped info
  cfg.coord=dec2base(coord_sys,2,8);
  cfg.coord_sys     =getopt(bitand(bitshift(coord_sys,-3),3),'beam','instrument','ship','earth');
  cfg.use_pitchroll  =getopt(bitand(coord_sys,4)==4,'no','yes');
  cfg.use_3beam     =getopt(bitand(coord_sys,2)==2,'no','yes');
  cfg.bin_mapping   =getopt(bitand(coord_sys,1)==1,'no','yes');
cfg.xducer_misalign=fread(fd,1,'int16')*.01;    % degrees
cfg.magnetic_var   =fread(fd,1,'int16')*.01;    % degrees
cfg.sensors_src    =dec2base(fread(fd,1,'uint8'),2,8);
cfg.sensors_avail  =dec2base(fread(fd,1,'uint8'),2,8);
cfg.bin1_dist     =fread(fd,1,'uint16')*.01;       % meters
cfg.xmit_pulse    =fread(fd,1,'uint16')*.01;       % meters
cfg.water_ref_cells=fread(fd,2,'uint8');
cfg.fls_target_threshold =fread(fd,1,'uint8');
fseek(fd,1,'cof');
cfg.xmit_lag      =fread(fd,1,'uint16')*.01; % meters
nbyte=40;

if fix(cfg.prog_ver)==8 | fix(cfg.prog_ver)==10 | fix(cfg.prog_ver)==16 ...
    | fix(cfg.prog_ver)==50 | fix(cfg.prog_ver)==51 | fix(cfg.prog_ver)==52,

  if cfg.prog_ver>=8.14,  % Added CPU serial number with v8.14
    cfg.serialnum     =fread(fd,8,'uint8');
    nbyte=nbyte+8;
  end;

  if cfg.prog_ver>=8.24,  % Added 2 more bytes with v8.24 firmware
    cfg.sysbandwidth  =fread(fd,2,'uint8');
    nbyte=nbyte+2;
  end;

  if cfg.prog_ver>=16.05,                 % Added 1 more bytes with v16.05 firmware
    cfg.syspower     =fread(fd,1,'uint8');
    nbyte=nbyte+1;
  end;

  if cfg.prog_ver>=16.27,   % Added bytes for REMUS, navigators, and HADCP
    cfg.navigator_basefreqindex=fread(fd,1,'uint8');
    nbyte=nbyte+1;
    cfg.remus_serialnum=fread(fd,4,'uint8');
    nbyte=nbyte+4;
    cfg.h_adcp_beam_angle=fread(fd,1,'uint8');
    nbyte=nbyte+1;
  end;

elseif fix(cfg.prog_ver)==9,

  if cfg.prog_ver>=9.10,  % Added CPU serial number with v8.14
    cfg.serialnum     =fread(fd,8,'uint8');
    nbyte=nbyte+8;
    cfg.sysbandwidth  =fread(fd,2,'uint8');
```

```
   nbyte=nbyte+2;
 end;

elseif fix(cfg.prog_ver)==14 | fix(cfg.prog_ver)==23,

   cfg.serialnum      =fread(fd,8,'uint8');  % 8 bytes 'reserved'
   nbyte=nbyte+8;

end;

% It is useful to have this precomputed.

cfg.ranges=cfg.bin1_dist+[0:cfg.n_cells-1]'*cfg.cell_size;
if cfg.orientation==1, cfg.ranges=-cfg.ranges; end


%------------------------------
function [ens,hdr,cfg,pos]=rd_buffer(fd,num_av);

% To save it being re-initialized every time.
global ens hdr

% A fudge to try and read files not handled quite right.
global FIXOFFSET SOURCE

% If num_av<0 we are reading only 1 element and initializing
if num_av<0,
 SOURCE=0;
end;
% This reinitializes to whatever length of ens we want to average.
if num_av<0 | isempty(ens),
 FIXOFFSET=0;
 n=abs(num_av);
 [hdr,pos]=rd_hdr(fd);
 if ~isstruct(hdr), ens=-1; cfg=NaN; return; end;
 cfg=rd_fix(fd);
 fseek(fd,pos,'bof');
 clear global ens
 global ens


ens=struct('number',zeros(1,n),'rtc',zeros(7,n),'BIT',zeros(1,n),'ssp',zeros(1,n),'depth',zeros(1,n),'pitch',zeros(
1,n),...
          'roll',zeros(1,n),'heading',zeros(1,n),'temperature',zeros(1,n),'salinity',zeros(1,n),...
          'mpt',zeros(1,n),'heading_std',zeros(1,n),'pitch_std',zeros(1,n),...
          'roll_std',zeros(1,n),'adc',zeros(8,n),'error_status_wd',zeros(1,n),...
          'pressure',zeros(1,n),'pressure_std',zeros(1,n),...
          'east_vel',zeros(cfg.n_cells,n),'north_vel',zeros(cfg.n_cells,n),'vert_vel',zeros(cfg.n_cells,n),...
          'error_vel',zeros(cfg.n_cells,n),'intens',zeros(cfg.n_cells,4,n),'percent',zeros(cfg.n_cells,4,n),...
          'corr',zeros(cfg.n_cells,4,n),'status',zeros(cfg.n_cells,4,n),...
               'bt_range',zeros(4,n),'bt_vel',zeros(4,n),...
               'bt_corr',zeros(4,n),'bt_ampl',zeros(4,n),'bt_perc_good',zeros(4,n),...
          'smtime',zeros(1,n),'emtime',zeros(1,n),'slatitude',zeros(1,n),...
               'slongitude',zeros(1,n),'elatitude',zeros(1,n),'elongitude',zeros(1,n),...
               'nmtime',zeros(1,n),'flags',zeros(1,n));
  num_av=abs(num_av);
end;

k=0;
while k<num_av,

   % This is in case junk appears in the middle of a file.
```

```
  num_search=6000;

  id1=fread(fd,2,'uint8');

  search_cnt=0;
  while search_cnt<num_search & ((id1(1)~=hex2dec('7F') | id1(2)~=hex2dec('7F') ) | ~checkheader(fd) ),
     search_cnt=search_cnt+1;
     nextbyte=fread(fd,1,'uint8');
     if isempty(nextbyte),  % End of file
        disp(['EOF reached after ' num2str(search_cnt) ' bytes searched for next valid ensemble start'])
        ens=-1;
        return;
     end;
     id1(2)=id1(1);id1(1)=nextbyte;
% fprintf([dec2hex(id1(1)) '--' dec2hex(id1(2)) '\n']);
  end;
  if search_cnt==num_search,
      error(sprintf('Searched %d entries...Not a workhorse/broadband file or bad data encountered: ->
%x',search_cnt,id1));
  elseif search_cnt>0
     disp(['Searched ' int2str(search_cnt) ' bytes to find next valid ensemble start'])
  end


  startpos=ftell(fd)-2;  % Starting position.


  % Read the # data types.
  [hdr,nbyte]=rd_hdrseg(fd);
  byte_offset=nbyte+2;
%% fprintf('# data types = %d\n  ',(length(hdr.dat_offsets)));
%% fprintf('Blocklen = %d\n  ',hdr.nbyte);
   % Read all the data types.
  for n=1:length(hdr.dat_offsets),

   id=dec2hex(fread(fd,1,'uint16'),4);
%%   fprintf('ID=%s SOURCE=%d\n',id,SOURCE);

   % handle all the various segments of data. Note that since I read the IDs as a two
   % byte number in little-endian order the high and low bytes are exchanged compared to
   % the values given in the manual.
   %
   winrivprob=0;

   switch id,
    case '0000',   % Fixed leader
     [cfg,nbyte]=rd_fixseg(fd);
     nbyte=nbyte+2;

   case '0080'   % Variable Leader
     k=k+1;
     ens.number(k)        =fread(fd,1,'uint16');
     ens.rtc(:,k)         =fread(fd,7,'uint8');
     ens.number(k)        =ens.number(k)+65536*fread(fd,1,'uint8');
     ens.BIT(k)           =fread(fd,1,'uint16');
     ens.ssp(k)           =fread(fd,1,'uint16');
     ens.depth(k)         =fread(fd,1,'uint16')*.1;   % meters
     ens.heading(k)       =fread(fd,1,'uint16')*.01;  % degrees
     ens.pitch(k)         =fread(fd,1,'int16')*.01;   % degrees
     ens.roll(k)          =fread(fd,1,'int16')*.01;   % degrees
     ens.salinity(k)      =fread(fd,1,'int16');       % PSU
     ens.temperature(k)   =fread(fd,1,'int16')*.01;   % Deg C
```

```
ens.mpt(k)           =sum(fread(fd,3,'uint8').*[60 1 .01]'); % seconds
ens.heading_std(k)    =fread(fd,1,'uint8');     % degrees
ens.pitch_std(k)      =fread(fd,1,'uint8')*.1;   % degrees
ens.roll_std(k)       =fread(fd,1,'uint8')*.1;   % degrees
ens.adc(:,k)          =fread(fd,8,'uint8');
nbyte=2+40;

if strcmp(cfg.name,'bb-adcp'),

   if cfg.prog_ver>=5.55,
      fseek(fd,15,'cof'); % 14 zeros and one byte for number WM4 bytes
         cent=fread(fd,1,'uint8');            % possibly also for 5.55-5.58 but
         ens.rtc(:,k)=fread(fd,7,'uint8');    % I have no data to test.
         ens.rtc(1,k)=ens.rtc(1,k)+cent*100;
         nbyte=nbyte+15+8;
   end;

elseif strcmp(cfg.name,'wh-adcp'), % for WH versions.

   ens.error_status_wd(k)=fread(fd,1,'uint32');
   nbyte=nbyte+4;;

   if fix(cfg.prog_ver)==8 | fix(cfg.prog_ver)==10 | fix(cfg.prog_ver)==16 ...
            | fix(cfg.prog_ver)==50 | fix(cfg.prog_ver)==51 | fix(cfg.prog_ver)==52,

         if cfg.prog_ver>=8.13,  % Added pressure sensor stuff in 8.13
        fseek(fd,2,'cof');
        ens.pressure(k)       =fread(fd,1,'uint32');
        ens.pressure_std(k)   =fread(fd,1,'uint32');
            nbyte=nbyte+10;
         end;

         if cfg.prog_ver>=8.24,  % Spare byte added 8.24
            fseek(fd,1,'cof');
            nbyte=nbyte+1;
         end;


         if ( cfg.prog_ver>=10.01 & cfg.prog_ver<=10.99 ) ...
            | cfg.prog_ver>=16.05,   % Added more fields with century in clock 16.05
            cent=fread(fd,1,'uint8');
            ens.rtc(:,k)=fread(fd,7,'uint8');
            ens.rtc(1,k)=ens.rtc(1,k)+cent*100;
            nbyte=nbyte+8;
         end;

      elseif fix(cfg.prog_ver)==9,

        fseek(fd,2,'cof');
        ens.pressure(k)       =fread(fd,1,'uint32');
        ens.pressure_std(k)   =fread(fd,1,'uint32');
            nbyte=nbyte+10;

         if cfg.prog_ver>=9.10,  % Spare byte added 8.24
            fseek(fd,1,'cof');
            nbyte=nbyte+1;
         end;

      end;

elseif strcmp(cfg.name,'os-adcp'),
```

```
            fseek(fd,16,'cof'); % 30 bytes all set to zero, 14 read above
            nbyte=nbyte+16;

            if cfg.prog_ver>23,
           fseek(fd,2,'cof');
                nbyte=nbyte+2;
            end;
    end;

   case '0100',  % Velocities
    vels=fread(fd,[4 cfg.n_cells],'int16')'*.001;     % m/s
    ens.east_vel(:,k) =vels(:,1);
    ens.north_vel(:,k)=vels(:,2);
    ens.vert_vel(:,k) =vels(:,3);
    ens.error_vel(:,k)=vels(:,4);
    nbyte=2+4*cfg.n_cells*2;

   case '0200',  % Correlations
    ens.corr(:,:,k)   =fread(fd,[4 cfg.n_cells],'uint8')';
    nbyte=2+4*cfg.n_cells;

   case '0300',  % Echo Intensities
    ens.intens(:,:,k)   =fread(fd,[4 cfg.n_cells],'uint8')';
    nbyte=2+4*cfg.n_cells;

   case '0400',  % Percent good
    ens.percent(:,:,k)   =fread(fd,[4 cfg.n_cells],'uint8')';
    nbyte=2+4*cfg.n_cells;

   case '0500',  % Status
    if strcmp(cfg.name,'os-adcp'),
      fseek(fd,00,'cof');
          nbyte=2+00;
    else
       % Note in one case with a 4.25 firmware SC-BB, it seems like
       % this block was actually two bytes short!
      ens.status(:,:,k)   =fread(fd,[4 cfg.n_cells],'uint8')';
      nbyte=2+4*cfg.n_cells;
    end;

   case '0600', % Bottom track
             % In WINRIVER GPS data is tucked into here in odd ways, as long
             % as GPS is enabled.
    if SOURCE==2,
       fseek(fd,2,'cof');
       long1=fread(fd,1,'uint16');
       fseek(fd,6,'cof');
       cfac=180/2^31;
       ens.slatitude(k)  =fread(fd,1,'int32')*cfac;
            if ens.slatitude(k)==0, ens.slatitude(k)=NaN; end;
%%fprintf('\n k %8.3f',ens.slatitude(k));
    else
       fseek(fd,14,'cof'); % Skip over a bunch of stuff
    end;
    ens.bt_range(:,k)=fread(fd,4,'uint16')*.01; %
    ens.bt_vel(:,k)  =fread(fd,4,'int16');
    ens.bt_corr(:,k)=fread(fd,4,'uint8');      % felipe pimenta aug. 2006
    ens.bt_ampl(:,k)=fread(fd,4,'uint8');      % "
    ens.bt_perc_good(:,k)=fread(fd,4,'uint8'); % "
    if SOURCE==2,
       fseek(fd,2,'cof');
       ens.slongitude(k)=(long1+65536*fread(fd,1,'uint16'))*cfac;
```

```
%%fprintf('\n k %d %8.3f %f ',long1,ens.slongitude(k),(ens.slongitude(k)/cfac-long1)/65536);
        if ens.slongitude(k)>180, ens.slongitude(k)=ens.slongitude(k)-360; end;
             if ens.slongitude(k)==0, ens.slongitude(k)=NaN; end;
             fseek(fd,16,'cof');
             qual=fread(fd,1,'uint8');
             if qual==0,
%%             fprintf('qual==%d,%f %f',qual,ens.slatitude(k),ens.slongitude(k));
              ens.slatitude(k)=NaN;ens.slongitude(k)=NaN;
            end;
        fseek(fd,71-45-21,'cof');
    else
        fseek(fd,71-45,'cof');
    end;
    nbyte=2+68;
    if cfg.prog_ver>=5.3,    % Version 4.05 firmware seems to be missing these last 11 bytes.
     fseek(fd,78-71,'cof');
     ens.bt_range(:,k)=ens.bt_range(:,k)+fread(fd,4,'uint8')*655.36;
     nbyte=nbyte+11;

     if strcmp(cfg.name,'wh-adcp'),

       if cfg.prog_ver>=16.20,   % RDI documentation claims these extra bytes were added in v 8.17
          fseek(fd,4,'cof');  % but they don't appear in my 8.33 data - conversation with
          nbyte=nbyte+4;       % Egil suggests they were added in 16.20
       end;
     end;
    end;

% The raw files produced by VMDAS contain a binary navigation data
% block.

   case '2000',  % Something from VMDAS.
    cfg.sourceprog='VMDAS';
    if SOURCE~=1, fprintf('\n***** Apparently a VMDAS file \n\n'); end;
    SOURCE=1;
    utim  =fread(fd,4,'uint8');
    mtime =datenum(utim(3)+utim(4)*256,utim(2),utim(1));
    ens.smtime(k)     =mtime+fread(fd,1,'uint32')/8640000;
    fseek(fd,4,'cof');  % PC clock offset from UTC
    cfac=180/2^31;
    ens.slatitude(k)  =fread(fd,1,'int32')*cfac;
    ens.slongitude(k) =fread(fd,1,'int32')*cfac;
    ens.emtime(k)     =mtime+fread(fd,1,'uint32')/8640000;
    ens.elatitude(k)  =fread(fd,1,'int32')*cfac;
    ens.elongitude(k) =fread(fd,1,'int32')*cfac;
    fseek(fd,12,'cof');
    ens.flags(k)      =fread(fd,1,'uint16');
    fseek(fd,6,'cof');
    utim  =fread(fd,4,'uint8');
    mtime =datenum(utim(1)+utim(2)*256,utim(4),utim(3));
    ens.nmtime(k)     =mtime+fread(fd,1,'uint32')/8640000;
                    % in here we have 'ADCP clock' (not sure how this
                    % differs from RTC (in header) and UTC (earlier in this block).
    fseek(fd,16,'cof');
    nbyte=2+76;

   case '2022',  % New NMEA data block from WInRiverII

    cfg.sourceprog='WINRIVER2';
    if SOURCE~=2, fprintf('\n***** Apparently a WINRIVER file - Raw NMEA data handler not yet
implemented\n\n'); end;
    SOURCE=2;
```

```
    specID=fread(fd,1,'uint16');
    msgsiz=fread(fd,1,'int16');
    deltaT=fread(fd,8,'uchar');
    nbyte=2+12;

    fseek(fd,msgsiz,'cof');
    nbyte=nbyte+msgsiz;

 %%   fprintf(' %d ',specID);
    switch specID,
      case 100,
           case 101,
           case 102,
           case 103,
     end;


% The following blocks come from WINRIVER files, they aparently contain
% the raw NMEA data received from a serial port.
%
% Note that for WINRIVER files somewhat decoded data is also available
% tucked into the bottom track block.
%
% I've put these all into their own block because RDI's software apparently completely ignores the
% stated lengths of these blocks and they very often have to be changed. Rather than relying on the
% error coding at the end of the main block to do this (and to produce an error message) I will
% do it here, without an error message to emphasize that I am kludging the WINRIVER blocks only!

   case {'2100','2101','2102','2103','2104'}

   winrivprob=1;

   switch id,

     case '2100', % $xxDBT  (Winriver addition) 38
           cfg.sourceprog='WINRIVER';
           if SOURCE~=2, fprintf('\n***** Apparently a WINRIVER file - Raw NMEA data handler not yet
implemented\n\n'); end;
           SOURCE=2;
           str=fread(fd,38,'uchar')';
           nbyte=2+38;

     case '2101', % $xxGGA  (Winriver addition) 94 in manual but 97 seems to work
                % Except for a winriver2 file which seems to use 77.
           cfg.sourceprog='WINRIVER';
           if SOURCE~=2, fprintf('\n***** Apparently a WINRIVER file - Raw NMEA data handler not yet
implemented\n\n'); end;
           SOURCE=2;
           str=setstr(fread(fd,97,'uchar')');
           nbyte=2+97;
           l=strfind(str,'$GPGGA');
           if ~isempty(l),

ens.smtime(k)=(sscanf(str(l+7:l+8),'%d')+(sscanf(str(l+9:l+10),'%d')+sscanf(str(l+11:l+12),'%d')/60)/60)/24;
           end;
 %         disp(['->' setstr(str(1:50)) '<-']);

     case '2102', % $xxVTG  (Winriver addition) 45 (but sometimes 46 and 48)
           cfg.sourceprog='WINRIVER';
           if SOURCE~=2, fprintf('\n***** Apparently a WINRIVER file - Raw NMEA data handler not yet
implemented\n\n'); end;
```

```
            SOURCE=2;
            str=fread(fd,45,'uchar')';
            nbyte=2+45;
  %      disp(setstr(str));

      case '2103', % $xxGSA  (Winriver addition) 60
            cfg.sourceprog='WINRIVER';
            if SOURCE~=2, fprintf('\n***** Apparently a WINRIVER file - Raw NMEA data handler not yet
implemented\n\n'); end;
            SOURCE=2;
            str=fread(fd,60,'uchar')';
  %      disp(setstr(str));
            nbyte=2+60;

      case '2104',  %xxHDT or HDG (Winriver addition) 38
            cfg.sourceprog='WINRIVER';
            if SOURCE~=2, fprintf('\n***** Apparently a WINRIVER file - Raw NMEA data handler not yet
implemented\n\n'); end;
            SOURCE=2;
            str=fread(fd,38,'uchar')';
  %      disp(setstr(str));
            nbyte=2+38;
      end;




    case '0701', % Number of good pings
      fseek(fd,4*cfg.n_cells,'cof');
      nbyte=2+4*cfg.n_cells;

    case '0702', % Sum of squared velocities
      fseek(fd,4*cfg.n_cells,'cof');
      nbyte=2+4*cfg.n_cells;

    case '0703', % Sum of velocities
      fseek(fd,4*cfg.n_cells,'cof');
      nbyte=2+4*cfg.n_cells;

% These blocks were implemented for 5-beam systems

    case '0A00', % Beam 5 velocity (not implemented)
      fseek(fd,cfg.n_cells,'cof');
      nbyte=2+cfg.n_cells;

    case '0301', % Beam 5 Number of good pings (not implemented)
      fseek(fd,cfg.n_cells,'cof');
      nbyte=2+cfg.n_cells;

    case '0302', % Beam 5 Sum of squared velocities (not implemented)
      fseek(fd,cfg.n_cells,'cof');
      nbyte=2+cfg.n_cells;

    case '0303', % Beam 5 Sum of velocities (not implemented)
      fseek(fd,cfg.n_cells,'cof');
      nbyte=2+cfg.n_cells;

    case '020C', % Ambient sound profile (not implemented)
      fseek(fd,4,'cof');
      nbyte=2+4;
```

```
  case '3000',  % Fixed attitude data format for OS-ADCPs (not implemented)
    fseek(fd,32,'cof');
    nbyte=2+32;

   otherwise,
    % This is pretty idiotic - for OS-ADCPs (phase 2) they suddenly decided to code
    % the number of bytes into the header ID word. And then they don't really
    % document what they did! So, this is cruft of a high order, and although
    % it works on the one example I have - caveat emptor....
    %
    % Anyway, there appear to be codes 0340-03FC to deal with. I am not going to
    % decode them but I am going to try to figure out how many bytes to
    % skip.
    if strcmp(id(1:2),'30'),
      % I want to count the number of 1s in the middle 4 bits of the
           % 2nd two bytes.
      nflds=sum(dec2base(bitand(hex2dec(id(3:4)),hex2dec('3C')),2)=='1');
           % I want to count the number of 1s in the highest 2 bits of byte 3
           dfac= sum(dec2base(bitand(hex2dec(id(3)),hex2dec('C')),2)=='1');
           fseek(fd,12*nflds*dfac,'cof');
           nbyte=2+12*nflds*dfac;

     else
      fprintf('Unrecognized ID code: %s\n',id);
      nbyte=2;
    end;
   %% ens=-1;
   %% return;


  end;

  % here I adjust the number of bytes so I am sure to begin
  % reading at the next valid offset. If everything is working right I shouldn't have
  % to do this but every so often firware changes result in some differences.

  %%fprintf('#bytes is %d, original offset is %d\n',nbyte,byte_offset);
  byte_offset=byte_offset+nbyte;

  if n<length(hdr.dat_offsets),
    if hdr.dat_offsets(n+1)~=byte_offset,
      if ~winrivprob, fprintf('%s: Adjust location by %d\n',id,hdr.dat_offsets(n+1)-byte_offset); end;
      fseek(fd,hdr.dat_offsets(n+1)-byte_offset,'cof');
    end;
    byte_offset=hdr.dat_offsets(n+1);
  else
    if hdr.nbyte-2~=byte_offset,
      if ~winrivprob, fprintf('%s: Adjust location by %d\n',id,hdr.nbyte-2-byte_offset); end;
      fseek(fd,hdr.nbyte-2-byte_offset,'cof');
    end;
    byte_offset=hdr.nbyte-2;
  end;
end;

% Now at the end of the record we have two reserved bytes, followed
% by a two-byte checksum = 4 bytes to skip over.

readbytes=ftell(fd)-startpos;
offset=(hdr.nbyte+2)-byte_offset; % The 2 is for the checksum

if offset ~=4 & FIXOFFSET==0,
  fprintf('\n*******************************************************\n');
```

```
   if feof(fd),
     fprintf(' EOF reached unexpectedly - discarding this last ensemble\n');
     ens=-1;
   else
     fprintf('Adjust location by %d (readbytes=%d, hdr.nbyte=%d)\n',offset,readbytes,hdr.nbyte);
     fprintf(' NOTE - If this appears at the beginning of the read, it is\n');
     fprintf('        is a program problem, possibly fixed by a fudge\n');
     fprintf('        PLEASE REPORT TO rich@eos.ubc.ca WITH DETAILS!!\n\n');
     fprintf('      -If this appears at the end of the file it means\n');
     fprintf('       The file is corrupted and only a partial record has  \n');
     fprintf('       has been read\n');
   end;
   fprintf('*******************************************************\n');
   FIXOFFSET=offset-4;
  end;
  fseek(fd,4+FIXOFFSET,'cof');

  % An early version of WAVESMON and PARSE contained a bug which stuck an additional two
  % bytes in these files, but they really shouldn't be there
  %if cfg.prog_ver>=16.05,
  %          fseek(fd,2,'cof');
  %end;

end;

% Blank out stuff bigger than error velocity
% big_err=abs(ens.error_vel)>.2;
big_err=0;

% Blank out invalid data
ens.east_vel(ens.east_vel==-32.768 | big_err)=NaN;
ens.north_vel(ens.north_vel==-32.768 | big_err)=NaN;
ens.vert_vel(ens.vert_vel==-32.768 | big_err)=NaN;
ens.error_vel(ens.error_vel==-32.768 | big_err)=NaN;



%---------------------------------------
function y=nmedian(x,window,dim);
% Copied from median but with handling of NaN different.

if nargin==2,
  dim = min(find(size(x)~=1));
  if isempty(dim), dim = 1; end
end

siz = [size(x) ones(1,dim-ndims(x))];
n = size(x,dim);

% Permute and reshape so that DIM becomes the row dimension of a 2-D array
perm = [dim:max(length(size(x)),dim) 1:dim-1];
x = reshape(permute(x,perm),n,prod(siz)/n);

% Sort along first dimension
x = sort(x,1);
[n1,n2]=size(x);

if n1==1,
 y=x;
else
  if n2==1,
```

```
   kk=sum(isfinite(x),1);
   if kk>0,
     x1=x(fix((kk-1)/2)+1);
     x2=x(fix(kk/2)+1);
     x(abs(x-(x1+x2)/2)>window)=NaN;
   end;
   x = sort(x,1);
   kk=sum(isfinite(x),1);
   x(isnan(x))=0;
   y=NaN;
   if kk>0,
    y=sum(x)/kk;
   end;
  else
   kk=sum(isfinite(x),1);
   ll=kk<n1-2;
   kk(ll)=0;x(:,ll)=NaN;
   x1=x(fix((kk-1)/2)+1+[0:n2-1]*n1);
   x2=x(fix(kk/2)+1+[0:n2-1]*n1);

   x(abs(x-ones(n1,1)*(x1+x2)/2)>window)=NaN;
   x = sort(x,1);
   kk=sum(isfinite(x),1);
   x(isnan(x))=0;
   y=NaN+ones(1,n2);
   if any(kk),
    y(kk>0)=sum(x(:,kk>0))./kk(kk>0);
   end;
  end;
end;

% Permute and reshape back
siz(dim) = 1;
y = ipermute(reshape(y,siz(perm)),perm);

%---------------------------------------
function y=nmean(x,dim);
% R_NMEAN Computes the mean of matrix ignoring NaN
%         values
%   R_NMEAN(X,DIM) takes the mean along the dimension DIM of X.
%

kk=isfinite(x);
x(~kk)=0;

if nargin==1,
  % Determine which dimension SUM will use
  dim = min(find(size(x)~=1));
  if isempty(dim), dim = 1; end
end;

if dim>length(size(x)),
 y=x;             % For matlab 5.0 only!!! Later versions have a fixed 'sum'
else
  ndat=sum(kk,dim);
  indat=ndat==0;
  ndat(indat)=1; % If there are no good data then it doesn't matter what
                 % we average by - and this avoid div-by-zero warnings.

  y = sum(x,dim)./ndat;
  y(indat)=NaN;
end;
```

```
function [U,V] = mag_var(theta,u,v)
% magnetic variation correction
%
% input:
%   theta (degree)
%   u,v: horizontal velocity profile
%
%
% output:
%   U,V
%
theta_rad = deg2rad(theta);

M = [cos(theta_rad) sin(theta_rad);-sin(theta_rad) cos(theta_rad)];

tmp   = M*[u,v]';
U     = tmp(1);
V     = tmp(2);
```

Appendix B Output Accuracy

The output accuracy for the OOI L1 Velocity Profile core data product calculated by this algorithm is equivalent to the accuracy of the instrument. The manufacturer, TRDI, provides accuracy as stated below.

For fixed assets.

Instrument class	Output	Accuracy
ADCPT: TRDI Workhorse Quartermaster (150kHz ADCP)	≤ ±500 mm/s	± 5 mm/s
	> ±500 mm/s	1%
ADCPS: TRDI Workhorse Longranger (75 kHz ADCP)	≤ ±500 mm/s	± 5 mm/s
	> ±500 mm/s	1%

Relevant requirements from the OOI requirements database (DOORS, L2_Science_Requirements_ReferenceOnly_Baseline_Version_2.22 exported from DOORS SL CCB 2011-11-15) are listed below.

L2-SR-RQ-3137 Velocity profile measurements shall have an accuracy of ±(0.01 m/s + 1% of the measured value).

L2-SR-RQ-3864 Velocity profile measurements shall have an absolute direction accuracy of +/- 2 degrees.

For mobile assets.

Instrument class	Output	Accuracy
ADCPA: TRDI Explorer PA DVL	≤ ±666.67 mm/s	± 2 mm/s
	> ±666.67 mm/s	± 0.3%

Relevant requirement from the OOI requirements is listed below.

L4-CG-IP-RQ-468 Velocity Profile instruments on mobile assets shall have a speed accuracy of 1% of the measured value +/- 1 cm/s.

No accuracy information is known for the OOI L1 Echo Intensity core data product.

Appendix C Sensor Calibration Effects

None.