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Title: QA/QC Parameters for Acoustic Doppler Current Profilers

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**Introduction:**

The following Application Note describes how to create QA/QC thresholds to evaluate any data collected using Teledyne RD Instruments (TRDI) Acoustic Doppler Current Profilers (ADCP).

TRDI has been manufacturing ADCPs since 1981 and with over 25 years of experience with our customers' deployments we are proud to be able to provide a QA/QC threshold evaluation tool. This application note provides specific parameter thresholds to be used to QA/QC ADCP data, details the method for setting these thresholds, and the background to understand the specific parameters.

TRDI ADCPs are used in a variety of applications and have a variety of unique QA/QC parameters. The following document is written to be used in conjunction with an associated EXCEL™ QA/QC Model (ADCP DATA QA-QC MODEL.XLS). The QA/QC Model provides you the specific thresholds for screening your ADCP data. Since ADCPs are used in a wide variety of applications the thresholds for each application will vary slightly. The QA/QC Model allows you to enter a few specific items about your system and your particular application. The QA/QC Model calculates the specific thresholds for your data.

**ADCP Application Background**

TRDI divides all applications into 2 overall types: moving and stationary.

**Moving applications** will be TRDI ADCPs that are mounted on vessels (or other moving platforms such as AUVs, gliders, etc.) that collect data while the vessel moves. These types of applications typically use external power and can either be unlimited power (such as shore or ship power) or limited power (such as onboard batteries). The typical types of ADCPs used depend on the area where the application originates:

**Coastal Research Vessels –** These applications typically use the WorkHorse (WH) 1200, 600, 300, and 150kHz ADCPs (WHVM1200, WHVM600, WHVM300, and WHVM150) manufactured by TRDI. The goal of this is to allow earth coordinate TRDI ADCP data collected either internally to the ADCP or through a real time connection to be quickly and easily screened for outliers, surface or bottom interference, and for measurement noise (standard deviation).

**Open Ocean Research Vessels –** These applications typically use the Ocean Surveyor (OS) 150, 75, and 38kHz ADCPs (OSII38, OSII75, OSII150) manufactured by TRDI.

**Stationary applications** will be TRDI ADCPs that are mounted on a mooring (surface, bottom, or sub-surface) or from an oil platform in coastal or open ocean applications. The system is stationary and thus collects data at a single location over time. The ADCPs mounted on moorings will typically use internal battery power and as a result have limited power. In some cases, such as on ocean observatories, the system will have external power that is unlimited (shore power). The ADCPs mounted from oil platforms will typically have external unlimited power supplied the platform itself. The typical types of ADCPs used depend on the area where the application originates:

**Offshore Oil -** These applications typically use the Ocean Observer 38kHz ADCP (OOII38) and WorkHorse (WH) Long Ranger 75kHz ADCP (WHLS75) products manufactured by TRDI.

**Coastal -** These applications typically use the WH 1200, 600, and 300 kHz ADCPs (WHS1200, WHM1200, WHS600, WHM600, WHS300, WHM300) manufactured by TRDI.

**Open Ocean QA/QC Parameters -** These applications typically use the WH 150, and 75kHz ADCPs (WHS150, WHM150, WHLS75, WHLM75) manufactured by TRDI.

**QA/QC Methodology:**
There are 4 major areas where QA/QC checks can be applied which we have named Tiers. Our intention with this Application Note is to describe the user parameters to be use for QA/QC, the input required to obtain to set the thresholds for these parameters.

This document currently focuses on how to screen data for the first 2 tiers of screening data; each tier will provide one of 3 QA/QC status indicators. Tier 1 will evaluate each of the individual depth cells within a profile and provide a QA/QC status indicator for each depth cell. Tier 2 will evaluate the entire profile based on the evaluation results in Tier 1. In each step we will use the same 3 QA/QC status indicators:

- **Green** = good data; data that can be with confidence known to be valid
- **Yellow** = data is suspect in some way but is not necessarily invalid
- **Red** = data that is either invalid or does not meet the screening thresholds and therefore should not be used without additional data analysis

**Tier 1 – Evaluating the individual depth cells within a profile:**
These QA/QC evaluations are intended to identify extreme outliers based on empirical thresholds. Parameters will be screened in an order that will systematically analyze the data and result in only the data with the highest confidence to be marked as a GREEN value. The basic parameters to be used in screening are as follows:

1. **Built in Test (BIT) Failures** – this will ensure the general "health" of the instrument
2. **Error Velocity** – this will ensure that the flow being measured is homogeneous and that all 4 beams are measuring a consistent water flow.
3. **Percent Good** – this will ensure that the minimum number of samples and minimum theoretical standard deviation is met in the data
4. **Correlation Magnitude** – this will ensure that the highest quality of velocity data is being used
5. **Vertical Velocity** – this will ensure that vertical velocities above a specific threshold are flagged
6. **Horizontal Velocity** – this will ensure that horizontal velocities above a specific threshold are flagged

**Tier 2 – Evaluating the entire profile:**
These QA/QC evaluations are intended to define the valid range within the profile and evaluate if the ensemble should be rejected as a whole or not.

7. **Echo Intensity** – this will ensure that data inside of contaminated areas such as the surface or bottom and from possible interference from any obstructions is flagged as YELLOW or RED.
8. **Overall QA/QC Parameter** – this will ensure that an ensemble with a high number of suspect (YELLOW) or invalid (RED) will be marked as such in entirety.

**Tier 3 – Evaluating the velocity data:** ***(NOT DEFINED AT THIS TIME; Descriptions provided as reference only)***
These QA/QC evaluations are intended to identify anomalous velocity data within the profile that merit further evaluation and investigation to understand their validity.

9. **Error Velocity – *(NOT DEFINED AT THIS TIME)*** a mean value of the error velocity profile is calculated and then each individual cell will be compared to this mean value. A QA/QC threshold will be set to indicate good, or suspect; if suspect then additional data review is required.
10. **Vertical Velocity – *(NOT DEFINED AT THIS TIME)*** a mean value of the vertical velocity profile is calculated and then each individual cell will be compared to this mean value. A QA/QC threshold will be set to indicate good, or suspect; if suspect then additional data review is required.
11. **Horizontal Velocity - *(NOT DEFINED AT THIS TIME)*** a mean value of each component (East and North) of the horizontal velocity profile is calculated and then each individual cell will be compared to

these component mean values.  A QA/QC threshold will be set to indicate good, or suspect; if suspect then additional data review is required.

**Tier 4 – Evaluating for temporal and spatial trend variations:** ***(NOT DEFINED AT THIS TIME; Description provided as reference only)***

These QA/QC evaluations are intended to identify anomalous velocity data within the profile that merit further evaluation and investigation to understand their validity.

12. **Temporal Comparisons** – ***(NOT DEFINED AT THIS TIME)*** Comparisons of each depth cell from ensemble to ensemble are made looking for large changes.  A QA/QC threshold will be set to indicate good or suspect; if suspect then additional data review is required.

**Determining the QA/QC Thresholds:**

The following section describes in detail how to use the QA/QC Model and will describe what was used to determine the thresholds that result. In all instances the thresholds that are calculated match our experience in reviewing 22+ years of ADCP data. If your application pushes the envelope of the system such as when you are operating in waters with high vertical shears or high variability in either time or space, then please contact us at TRDI to ensure that you are not setting thresholds that are too aggressive for your application.

**Step 1 – Select System**

The first step is to select your ADCP type and the basic setup that you will use. The following describes in more detail the names shown in the QA/QC Model

| | |
|---|---|
| **OO38 BB Mode (WP1)** | **Ocean Observer 38kHz operating in Broad Bandwidth mode (high precision mode)** |
| **OO38 NB Mode (NP1)** | **Ocean Observer 38kHz operating in Narrow Bandwidth mode (long range mode)** |
| **OS38 BB Mode (WP1)** | **Ocean Surveyor 38kHz operating in Broad Bandwidth mode (high precision mode)** |
| **OS38 NB Mode (NP1)** | **Ocean Surveyor 38kHz operating in Narrow Bandwidth mode (long range mode)** |
| **OS75 BB Mode (WP1)** | **Ocean Surveyor 75kHz operating in Broad Bandwidth mode (high precision mode)** |
| **OS75 NB Mode (NP1)** | **Ocean Surveyor 75kHz operating in Narrow Bandwidth mode (long range mode)** |
| **OS150 BB Mode (WP1)** | **Ocean Surveyor 150kHz operating in Broad Bandwidth mode (high precision mode)** |
| **OS150 NB Mode (NP1)** | **Ocean Surveyor 150kHz operating in Narrow Bandwidth mode (long range mode)** |
| **WH Long Ranger 75 BB Mode (WB0)** | **WorkHorse 75kHz operating in Broad Bandwidth mode (high precision mode)** |
| **WH Long Ranger 75 NB Mode (WB1)** | **WorkHorse 75kHz operating in Narrow Bandwidth mode (long range mode)** |
| **WH QuarterMaster 150 BB Mode (WB0)** | **WorkHorse 150kHz operating in Broad Bandwidth mode (high precision mode)** |
| **WH QuarterMaster 150 NB Mode (WB1)** | **WorkHorse 150kHz operating in Narrow Bandwidth mode (long range mode)** |
| **WH 300kHz BB Mode (WB0)** | **WorkHorse 300kHz operating in Broad Bandwidth mode (high precision mode)** |
| **WH 300kHz NB Mode (WB1)** | **WorkHorse 300kHz operating in Narrow Bandwidth mode (long range mode)** |
| **WH 600kHz BB Mode (WB0)** | **WorkHorse 600kHz operating in Broad Bandwidth mode (high precision mode)** |
| **WH 600kHz NB Mode (WB1)** | **WorkHorse 600kHz operating in Narrow Bandwidth mode (long range mode)** |
| **WH 1200kHz BB Mode (WB0)** | **WorkHorse 1200kHz operating in Broad Bandwidth mode (high precision mode)** |
| **WH 1200kHz NB Mode (WB1)** | **WorkHorse 1200kHz operating in Narrow Bandwidth mode (long range mode)** |

**Step 2 – Select Power Type**

The number of pings that are possible are directly related to the amount of power you have available for a given deployment. Typically a setup where there is unlimited power the user will want to do as many pings that are possible given the restrictions of travel time in water and the speed at which the ADCP can process data. If a system uses battery power then the power is limited and the user will want to do as many pings that are possible given the deployment length and available power. The number of pings in the case will be reduced. This selection is used so that we can display the TRDI recommended example setup shown in Step 3.

**Step 3 – Enter User Setup**

This step allows you to enter a few critical setup selections that will be used later to determine the QA/QC Model (Step 6).

You must enter the values for:
**Depth Cell Size** = the Depth Cell size in meters you wish to use during your deployment. The QA/QC Model will warn you if you select a depth cell size that is out of recommended sizes for your selected ADCP.

**Ping Interval Time** = this is the time between pings, in seconds, that you intend to use. The QA/QC Model will warn you if you select an interval that is shorter than our recommended minimum time between pings.

**Ensemble Interval Time** = this is the time between ensembles, in seconds, that you intend to use. The QA/QC Model will warn you if you select an interval that is shorter than the product of PING INTERVAL TIME * NUMBER OF PINGS. If you receive an error then you must either increase your Ensemble Interval Time or reduce your total number of pings.

**Minimum Acceptable Averaging Time** = this is your input for the minimum time you want in a given measurement interval. This selection is going to set the minimum thresholds for GREEN values. This means that if the ADCP was not able to collect data for this minimum amount of time then all data will be flagged as either YELLOW or RED.

You will want to set this time to a period that will with confidence allow you to represent the Ensemble Interval Time you selected. As an example if you are spreading your pings over an Ensemble Interval Time of 3600 seconds (1 hour) you may decide that you need at least 900 seconds (15 mins) of measurements to reasonably represent the entire 3600 seconds. In some cases you may decide it can be less or more time. Changing this setting along with Step 4 set to NUMBER OF SAMPLES will provide you with the value shown in the Lowest Accepted Standard Deviation.

**Minimum Acceptable Number of Samples (pings)** = this is your input for the minimum number of samples you want in a given measurement interval. This selection is going to set the minimum thresholds for GREEN values. This means that if the ADCP was not able to collect data for this minimum amount of time then all data will be flagged as either YELLOW or RED.

This works much like the Minimum Acceptable Averaging Time but instead of selecting a minimum time you are selecting a minimum number of samples required to represent the velocities you are trying to measure. Changing this setting along with Step 4 set to NUMBER OF SAMPLES will provide you with the value shown in the Lowest Accepted Standard Deviation.

**The following are the values that are calculated for you in Step 3:**
**Number of Pings** = this is the calculated maximum number of pings (samples) that you will acquire during an ensemble. This value is used to calculate the Best Possible Standard Deviation. The number of pings is important for 2 reasons:

1. It will set the theoretical standard deviation
2. You must set the number of pings to a number large enough to over sample the currents you wish to measure.

Do not use only the theoretical standard deviation as your only tool to set the number of pings. Make sure that you are sampling often enough to provide a valid statistical measurement of your currents.

The QA/QC Model will warn you if the number of pings will result in a number of samples that is less than what TRDI recommends. You may continue with your setup but our recommendation is to increase your total number of pings by increasing your sampling interval.

**Best Possible Standard Deviation** = this provides you the best theoretical standard deviation possible at any given depth cell when 100% of your pings are valid in the ensemble. This value will increase as your percent good decreases. This value is shown so that you understand the “noise” standard deviation your data could have.

**Maximum Expected Water Velocity** = this is an entry set by you as the maximum possible velocity you will encounter during your deployment. You will always enter the maximum water current you expect to see. If you are on a moving vessel do NOT include the vessel speed. Enter in only the true maximum water speed you expect to encounter. This value will be used to set the QA/QC thresholds for the horizontal velocity.

**Lowest Acceptable Standard Deviation** = this is a calculated value based on your setting of Step 4 and your input in either the Minimum Acceptable Averaging Time or Minimum Acceptable Number of Samples (pings). This value shows you the lowest acceptable standard deviation and will be used for the thresholds calculated for Tier 1 QA/QC thresholds.

**Recommended ADCP Error Velocity Setting** = this provides a TRDI recommended setting for the Error Velocity (WE command) in your ADCP when collecting data. This setting will be much higher than the QA/QC Threshold Calculations in Step 5 because this threshold is applied on each ping within an ADCP ensemble. This means that the ADCP will mark invalid data before it is included in the average ensemble. Since this is threshold is applied to a single ping the error velocity threshold must be set much higher to avoid throwing out valid data. Typically WH and OS/OO ADCPs have this particular internal threshold command set to a value that effectively disables this check. We provide this as another method to screen data at the lowest possible level; thus providing the best possible data.

**Step 4 – Select Method for Minimum Acceptable Criteria**
The QA/QC Model will set thresholds based on your selection in this step. You must decide if the minimum averaging time or the minimum number of samples (pings) is most important for your particular deployment. Each of these selections will set a minimum acceptable standard deviation. It is this minimum acceptable standard deviation that sets the thresholds for all Tier 1 QA/AC parameters (except for BIT).

**How to Use the QA/QC Thresholds**
**Step 5 - Tier 1 QA/QC Thresholds:**

1. **(BIT) QA/QC Thresholds:**

Flag each ensemble with a GREEN or YELLOW based on the BIT errors. The reason for the RED setting to be Not Applicable is because the BIT will just warn of a health issue while the rest of the checks will confirm if there is a serious issue that warrants throwing out the ensembles data.

**BIT QA/QC Thresholds Values:**

a. GREEN = a value of 0 (indicates there were no BIT failures)
b. YELLOW = any value other than 0
c. RED = N/A

2. Error Velocity **QA/QC Thresholds at each depth cell:**

Using the Error Velocity reported at each depth cell you will flag each bin with either a GREEN, YELLOW, or RED value depending on the thresholds set here.

The Error Velocity QA/QC values are determined as follows:

a. GREEN = error velocities that are less than 5 times the minimum acceptable standard deviation value at each depth cell.
b. YELLOW = error velocities that are greater than 5 times but less than 10 times the minimum acceptable standard deviation value at each depth cell.
**c.** RED = error velocities that are greater than 10 times the minimum acceptable standard deviation value at each depth cell.

NOTE: In some conditions, such as in very turbulent waters or areas of high shear it may be necessary to increase these values to avoid throwing away valid data. This QA/QC check using the mean value of error velocity is left as a later Tier 3 screening method and is not incorporated into this procedure.

3. Correlation Magnitude **QA/QC Thresholds at each depth cell:**

Using the Correlation Magnitude reported at each depth cell you will flag each bin with either a GREEN, YELLOW, or RED value depending on the thresholds set here.

The Correlation Magnitude QA/QC values are determined as follows:

a. GREEN = at least 3 of the 4 four beams in the depth cell have an average value greater than the value shown in the QA/QC Model
b. YELLOW = only 2 of the 4 beams in the depth cell have an average value greater than the value shown in the QA/QC Model
c. RED = 1 or none of the 4 beams in the depth cell has an average value greater than the value shown in the QA/QC Model

The thresholds used for correlation magnitude are being applied to the averaged data. This results in a more aggressive screening than what is used on a ping by ping basis. This extra screening is ensuring only the highest quality data is being accepted.

4. Percent Good **QA/QC Thresholds at each depth cell:**
Using the total Percent Good (earth coordinate field 1 and 4 of the percent good data fields) reported at each depth cell you will flag each bin with either a GREEN, YELLOW, or RED value depending on the thresholds set here.

The Percent Good QA/QC values are determined as follows:

a. GREEN = 25% higher than the RED value.
b. YELLOW = all values between the GREEN and RED settings.
**c.** RED = the calculated percent good to comply with the user selection of the Minimum Acceptable Averaging Interval or the Minimum Acceptable Number of Samples (pings).

5. Vertical Velocity **QA/QC Thresholds at each depth cell:**
Using the Vertical Velocity reported at each depth cell you will flag each bin with either a GREEN, YELLOW, or RED value depending on the thresholds set here.

The Vertical Velocity QA/QC values are determined as follows:

a. GREEN = vertical velocity at each depth cell must be less than 10% of the user entered maximum velocity with a minimum value of 5cm/s (for horizontal velocities less than or equal to 50cm/s)
b. YELLOW = ll values between the GREEN and RED settings.
**c.** RED = all vertical velocity at each depth cell greater than 20% of the user entered maximum velocity with a minimum value of 10cm/s (for horizontal velocities less than or equal to 50cm/s)

6. Horizontal Velocity **QA/QC Thresholds at each depth cell:**
Using the Horizontal Velocity components (East and North) reported at each depth cell you will flag each bin with either a GREEN, YELLOW, or RED value depending on the thresholds set here.

The Horizontal Velocity QA/QC values are determined as follows:

a. GREEN = both the East and North velocities are less than 110% of the Maximum Expected Velocity value.
b. YELLOW = both the East and North velocities are greater than 110% but less than twice the Maximum Expected Velocity value.
**c.** RED = either the East or the North velocities are greater than twice the Maximum Expected Velocity value.

**Tier 2 – Final Evaluation of the Overall Profile:**

7. **Bottom or Surface** Echo Intensity **QA/QC Thresholds**[7] **at each depth cell:**

a. GREEN = no rise on any beam after depth cell 15 >30 counts
b. YELLOW = a rise on 1 beam after depth cell 15 >30 counts
c. RED = a rise >30 counts on 2 or more of the four beams after depth cell 15

[7]The thresholds used for echo intensity are based on the fact that the ADCP is installed in deep water and so the bottom or surface will be greater than 120 meters from the Long Ranger ADCP and 240 meters from the OO ADCP.

If no rise on any beam is greater than the threshold of 30 counts is seen then we can safely assume that the bottom or surface is not in range of the system and thus mark all cells as GREEN for this check.

If only 1 beam at a bin is spiking above the 30 count threshold then we might be hitting the bottom or surface on that beam or we might be striking a riser. We therefore recommend that all bins after this point should be flagged with YELLOW as a caution.

If a rise in the echo intensity on 2 or more beams is higher than the threshold at one bin then we are assuming that we have hit the bottom or surface and we must mark the appropriate data as RED. If we have hit the bottom or surface then we do need to mark the data within the side lobe contamination area (the last 15% of range for the OO ADCP and the last 6% of range for the WH Long Ranger) plus one more bin red. This means a range calculation will have to be performed, as an example:

Example: 10m bins, 10m to 1st bin, 400m bottom, rise above threshold is seen in 2 beams at bin 39:

Step 1 - Calculate the range to the bin having the rise in echo intensity data –
range to bin = (bin number * bin size) + range to bin 1
= (39 * 10) + 10
= 400m

Step 2 - Calculate the side lobe contamination starting range –
Side lobe contamination start = (cos(beam angle) * range to bin)
= (cos(20) * 400m)
= 376m

Step 3 - Calculate the starting bin to be marked as red -
Boundary area = ((side lobe contamination start)/(bin size)) **-** 1 bin
= (376/10) **-** 1
= 38 **-** 1
= 37

Step 4 - Mark all bins from bin 37 on as RED

We will now use the evaluations done in Step 1 to provide a status of the entire profile; thus providing the confidence that the entire ensemble profile is valid and can be reviewed further. This evaluation excludes using any of the depth cells flagged as YELLOW or RED because of the Echo Intensity **QA/QC Thresholds** (Tier 2 step 7)**.**

8. **Profile QA/QC Thresholds:**

Values based on the review of the Tier 1 evaluations:

a. GREEN = Tier 1 QA/QC values for each depth cell are flagged as GREEN
b. YELLOW = <50% of Tier 1 QA/QC values at each depth cell are flagged as YELLOW or RED
**c.** RED = >50% of Tier 1 QA/QC values at each depth cell are flagged as YELLOW or RED

This threshold check provides for the final verification for all the data within the profile. This should be considered as the overall evaluation of the entire profile and recorded as the top level QA/QC evaluation with the individual depth cells as the secondary QA/QC evaluation.

Examples; assuming 20 depth cells are collected:

1. All of the Tier 1 checks are green; Tier 2 would be green.
2. All of the Tier 1 checks except step 5 are green and 10 bins of Tier 1 step 5 checks are Red; Tier 2 would be green.
3. Tier 1 checks (steps other than step 5) are yellow on 10 of the bins; Tier 2 would be yellow.
4. Tier 1 checks (steps other than step 5) are red on 10 of the bins; Tier 2 would be yellow.
5. Tier 1 checks (steps other than step 5) are yellow or red on 11 of the bins; Tier 2 would be red.

**Details of the items being suggested for QA/QC parameters:**

**Built in Test (BIT)** – At each ping the WorkHorse (WH) ADCP performs a built in test to check for various types of errors. These checks provide the health of the ADCP for different issues such as: condition of the DSP board, Demodulator board, or transmit circuitry.

The Ocean Surveyor/Ocean Observer (OS/OO) does not perform BIT during the pinging operation and so this check is not required in the OS/OO.

The BIT is recorded in the WH Variable Leader data of the ADCP in bytes 13,14. Only 1 BIT error observed during the ensemble can be displayed at a time.

Note an intermittent failure of the BIT is not unacceptable nor an indication of a failure, but a consistent failure of the same value from ensemble to ensemble is an indication of a failure. It is suggested that this threshold will offer a caution to all data in the ensemble, but that the follow on QA/QC parameters will be used as a means to throw out data or to keep the data.

**Percent Good** – data field is a data-quality indicator that reports the percentage (0 to 100) of good data collected for each depth cell of the velocity profile. Rejection criteria include low correlation, large error velocity and fish detection (false target threshold). Default thresholds differ for each ADCP; each threshold has an associated command. The setting of the EX-command (Coordinate Transformation) determines how the percent-good data is recorded.

Table 1 - Percent Good Data Format

| Hex Digit | Binary Byte | Field | Description |
|---|---|---|---|
| 1-4 | 1,2 | ID Code | Stores the percent-good data identification word (00 04h) |
| 5,6 | 3 | Depth cell 1, Field 1 | Stores percent-good data for depth cell #1, field 1 |
| 7,8 | 4 | Depth cell 1, Field 2 | Stores percent-good data for depth cell #1, field 2 |
| 9,10 | 5 | Depth cell 1, Field 3 | Stores percent-good data for depth cell #1, field 3 |
| 11,12 | 6 | Depth cell 1, Field 4 | Stores percent-good data for depth cell #1, field 4 |
| 12-1028 | 7-514 | Depth cell 2-128 (if used) | These fields store percent-good data for depth cells 2 through 128 (depending on the WN-command), following the same format as listed above for depth cell 1 |

The ADCP has the ability to collect velocity data in either beam coordinates (that is the velocity at each depth cell along each of the 4 beams) or in earth coordinates (that is the velocity at each depth cell in east, north, vertical, and error velocity). As a result of these 2 coordinate systems it is necessary to record the percentage good data in different formats:

- If the ADCP was set to collect velocities in BEAM coordinates (EX command of EX00000), then the values show the percentage of pings passing the low correlation threshold (WC-command in the ADCP) and fish rejection thresholds (more details on this latter threshold can be found in the Technical Manual). In this setup:
  - FIELD 1 equals the percentage of valid data for beam 1,
  - FIELD 2 equals the percentage of valid data for beam 2,
  - FIELD 3 for beam 3,
  - FIELD 4 for beam 4.
- If the ADCP was set to collect velocities in EARTH coordinates (EX command of EX11111), then the values show the percentage of pings that could be used to create the earth coordinate velocities. In this setup:
  - FIELD 1 equals the percentage of valid 3-beam earth solutions passing both the low correlation and the fish rejection thresholds.
  - FIELD 2 equals the total percentage of transformations rejected – Shows percent of data rejected because of an error velocity higher than the internal threshold set by the WE-command. The WE command is turned off as a default.

- FIELD 3 – Percentage of more than one beam bad in depth cell – if more than one beam was rejected then no coordinate transformation is possible.
- FIELD 4 – Percentage of valid 4-beam earth solutions passing both the low correlation and the fish rejection thresholds.

NOTE 1 – Typically data is collected and used in Earth coordinates and as such will contain 4 values of percentage good; the QA/QC threshold for total percent good shall be based entirely on the summation of FIELDS 1 and 4. This QA/QC document assumes the use of Earth Coordinate data; if data is collected in beam coordinates then this step must be modified; see note 2.

NOTE 2 – Collecting data in single ping beam coordinates allows for the optimal reprocessing capability. If the data is collected in beam coordinates then it will be necessary to convert the data into Earth Coordinates before applying this QA/QC parameter. TRDI supplies several programs that will perform this conversion. Contact TRDI for further information.

**Selecting the Best Data Format –** Although the percent good QA/QC thresholds are based on Earth coordinates this may not the only data format to collect data. The following discusses the difference between beam and earth coordinates and their uses.

1. The most raw data format - Single ping data is the "rawest" format data you can collect. You can collect either beam or each coordinate data. Beam coordinates is the most raw velocity data you can collect. This data allows you to look at all details and then average in any way that want later (that is perform 3 beam solutions, 4 beam solutions, etc.). Single ping earth coordinate data is the next most raw velocity data you can collect. With single ping data you are able to convert back to beam coordinates but that is not done by any of our software. In either case the downside of collecting single ping data is that there is a lot of data to handle.

2. Averaging data allows you to reduce the amount of data you collect and you can again collect in either beam or earth coordinate data. When averaging data there are now issues related to whether the ADCP is going to be able to rotate or will remain stationary.

    - Rotating ADCP - If the ADCP will rotate then the recommendation is to collect data in Earth coordinates. Collecting data in beam coordinates is not good because the changing heading (and pitch and roll) that occurs ping to ping is not being accounted for. The heading (pitch/roll) will be measured at each ping but it will be averaged independently to the average beam coordinate data and then would be applied at the end. Doing this will result in bias in both velocity and direction.
    - Fixed ADCP - If the ADCP heading (pitch and roll) are fixed then collecting in beam coordinates is OK and there will be no biases to the resulting earth coordinate data that is calculated. Earth coordinate data could be used as well but beam coordinates offers the "rawest" data format you can collect with averaged data.

**Beam-to-Instrument Transformation -** The vector of beam velocities is transformed to the vector of velocity components in a coordinate system fixed to the instrument (with error velocity appended) through multiplication by the instrument transformation matrix. The instrument coordinate system is described in the "*Coordinate Transformation Booklet*". The instrument transformation matrix is displayed by the PS3 command. Unless the ADCP has been calibrated to compensate for small beam misalignments, the instrument transformation matrix has the following nominal value:

Table 2 - Instrument Transformation Matrix

| Component | Beam 1 | Beam 2 | Beam 3 | Beam 4 |
|---|---|---|---|---|
| X | c*a | -c*a | 0 | 0 |
| Y | 0 | 0 | -c*a | c*a |
| Z | b | B | b | b |
| E | d | D | -d | -d |

where: c = +1 for a convex transducer head, -1 for concave

$a = 1/[2\sin(\theta)] = 1.4619$ for $\theta = 20°$, $1.0000$ for $\theta = 30°$
$b = 1/[4\cos(\theta)] = 0.2660$ for $\theta = 20°$, $0.2887$ for $\theta = 30°$
$d = a/\sqrt{2} = 1.0337$ for $\theta = 20°$, $0.7071$ for $\theta = 30°$

The first three rows are the generalized inverse of the beam directional matrix representing the components of each beam in the instrument coordinate system (see PS3 command). The last row representing the error velocity is orthogonal to the other three rows and has been normalized so that its magnitude (root-mean-square) matches the mean of the magnitudes of the first two rows. This normalization has been chosen so that in horizontally homogeneous flows, the variance of the error velocity will indicate the portion of the variance of each of the nominally-horizontal components (X and Y) attributable to instrument noise (short-term error).

The velocity now needs an additional rotation to earth coordinates, which is accomplished by multiplying the instrument transformation matrix Table 2 by the rotation matrix M.

**Instrument-To-Earth Transformation -** Unless the first two bits of the EX command are 0/ 0/ (beam coordinates) or 0/ 1 (instrument coordinates), another transformation is needed to rotate the velocities from instrument coordinates to the desired coordinates. This transformation can be considered to be the net result of three successive rotations in this order:

- -R about the Y axis,
- -P about the leveled X axis, and then
- H about the Z axis,

Where R, P, and H are the roll, pitch, and heading angles as traditionally defined so as to represent the orientation of a set of gimbals.

The rotation matrix M is thus:

$$M = \begin{bmatrix} CH & SH & 0 \\ -SH & CH & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & CP & -SP \\ 0 & SP & CP \end{bmatrix} \begin{bmatrix} CR & 0 & SR \\ 0 & 1 & 0 \\ -SR & 0 & CR \end{bmatrix}$$

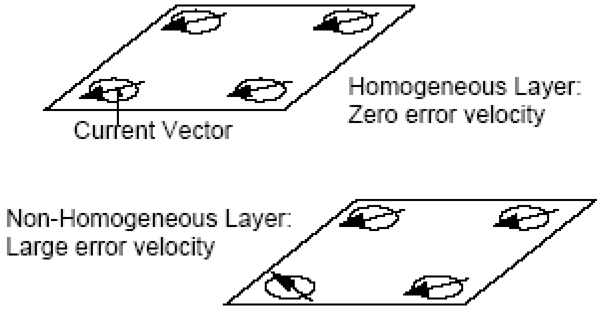
$$= \begin{bmatrix} (CH*CR + SH*SP*SR) & (SH*CP) & (CH*SR - SH*SP*CR) \\ (-SH*CR + CH*SP*SR) & (CH*CP) & (-SH*SR - CH*SP*CR) \\ (-CP*SR) & (SP) & (CP*CR) \end{bmatrix}$$

**Three-Beam Solutions -** If exactly one beam has been marked bad in the screening step due to low correlation or fish detection, and if enabled by the EXxxx1x command, then a three-beam solution is calculated by the ADCP. This is accomplished by replacing the bad radial beam velocity with a value calculated from the last row of the instrument transformation matrix so as to force the error velocity to zero. Of course, the actual error velocity cannot be computed in this case, because there is no longer any redundant information. The X, Y, and Z components in the instrument coordinates are then compared in the usual way using the first three rows of the instrument transformation matrix.

**Error Velocity –** Error velocity is unique to the RDI ADCP and is the result of having a Janus configuration of the beams. The error velocity is the difference between the two estimates of vertical velocity. Error velocity depends on the data redundancy: only three beams are required to compute three dimensional velocities. The fourth ADCP beam is redundant, but not wasted. Error velocity allows you to evaluate whether the assumption of horizontal homogeneity is reasonable. It is an important, built-in means to evaluate data quality.

Figure 1 shows two different situations. In the first situation, the current velocity at one depth is the same in all four beams. In the second, the velocity in one beam is different. The error velocity in the second case will, on average, be larger than the error velocity in the first case. Note that it does not matter whether the velocity is different because the ADCP beam is bad or because the actual currents are different. Error velocity can detect errors due to inhomogeneities in the water, as well as errors caused by malfunctioning equipment.

Figure 1




Error velocity requires that there are 4 beams being used to create an earth coordinate transformation. If a beam has been disabled (to avoid risers) or if a beam has gone bad the error velocity will have a value of -32768. To QA/QC the error velocity the first step should be to review the value of error velocity if it equals -32768 then skip this QA/QC setup and move to the next QA/QC step.

**The Janus Configuration –** The ADCP transducer configuration is called the Janus configuration, named after the Roman god who looks both forward and backward. The Janus configuration is particularly good for rejecting errors in horizontal velocity caused by tilting (pitch and roll) of the ADCP. This is because:

- The two opposing beams allow vertical velocity to cancel when computing horizontal velocity.
- Pitch and roll uncertainty causes single-beam velocity errors proportional to the sine of the pitch and roll error. Beams in a Janus configuration reduce these velocity errors to second order; that is, velocity errors are proportional to the square of the pitch and roll errors.

**Current Homogeneity in a Horizontal Layer -** One problem with using trigonometric relations to compute currents is that the beams make their measurements in different places. If the current velocities are not the same in the different places, the trigonometric relations will not work. Currents must be horizontally homogeneous, that is, they must be the same in all four beams. Fortunately, in the ocean, rivers, and lakes, horizontal homogeneity is normally a reasonable assumption.

**Calculation of Velocity with the Four ADCP Beams –** Figure 2 illustrates how we compute three velocity components using the four acoustic beams of an ADCP. One pair of beams obtains one horizontal component and the vertical velocity component. The second pair of beams produces a second, perpendicular horizontal component as well as a second vertical velocity component. Thus there are estimates of two horizontal velocity components and two estimates of the vertical velocity. The vertical velocity recorded is the average of the 2 vertical velocity estimates; providing for a very quite answer. Note Figure 2 shows the beams oriented east/west and north/south, but the orientation is arbitrary.

Figure 2 – Velocity Vector Components

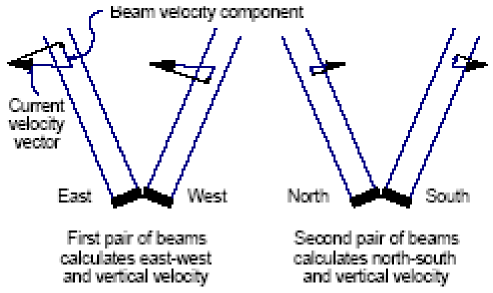



Table 3 – Velocity Data Format

| Hex Digit | Binary Byte | Field | Description |
|---|---|---|---|
| 1-4 | 1,2 | ID Code | Stores the percent-good data identification word (00 01h) |
| 5,6 | 3 | Depth cell 1, Velocity 1 | Stores EAST velocity data for depth cell #1, velocity 1 |
| 7,8 | 4 | Depth cell 1, Velocity 2 | Stores NORTH velocity data for depth cell #1, velocity 2 |
| 9,10 | 5 | Depth cell 1, Velocity 3 | Stores VERTICAL velocity data for depth cell #1, velocity 3 |
| 11,12 | 6 | Depth cell 1, Velocity 4 | Stores ERROR velocity data for depth cell #1, velocity 4 |
| 12-1028 | 7-514 | Depth cell 2-128 (if used) | These fields store velocity data for depth cells 2 through 128 (depending on the WN-command), following the same format as listed above for depth cell 1 |

**Echo Intensity –** Echo intensity is a measure of the intensity (strength) of the backscattered echo for each depth cell. Echo intensity is useful in determining the relative volume of scatterers in each depth cell. You can use echo intensity data to check data quality or to locate the surface, the bottom, or an obstruction (such as a riser).

Table 4 – Echo Intensity Data Format

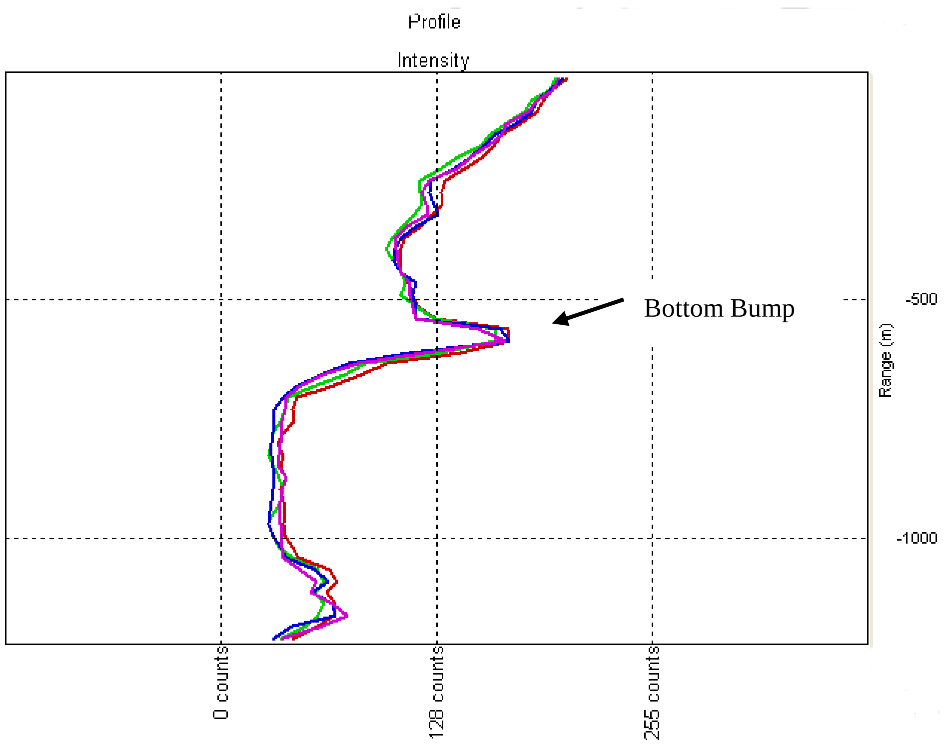
| Hex Digit | Binary Byte | Field | Description |
|---|---|---|---|
| 1-4 | 1,2 | ID Code | Stores the percent-good data identification word (00 03h) |
| 5,6 | 3 | Depth cell 1, Field 1 | Stores echo intensity data for depth cell #1, beam 1 |
| 7,8 | 4 | Depth cell 1, Field 2 | Stores echo intensity data for depth cell #1, beam 2 |
| 9,10 | 5 | Depth cell 1, Field 3 | Stores echo intensity data for depth cell #1, beam 3 |
| 11,12 | 6 | Depth cell 1, Field 4 | Stores echo intensity data for depth cell #1, beam 4 |
| 12-1028 | 7-514 | Depth cell 2-128 (if used) | These fields store echo intensity data for depth cells 2 through 128 (depending on the WN-command), following the same format as listed above for depth cell 1 |

Figure 3 shows a typical bottom bump reflection. In Figure 3 all 4 beams are striking the bottom at the same time and there is a large rapid increase in the echo intensity values in approximately a single depth cells worth and then the signal drops off to a value that is lower than prior to reaching the bump. By using the relative echo intensity value from depth cell to depth cell it is possible to look for and detect the bottom or surface and then locate the end of range.

The best way to know when to cut-off the data when the bottom is range of the system is to use echo intensity data and look for sudden rises in the values. If these values pass a specified threshold for long (2 depth cells) then you most likely have encountered the surface, the bottom, or another hard object. The choice then is to cut off the data using the following formula:

last good depth cell = (COS (beam angle) * (distance from ADCP to bottom)) + (1 depth cell)

Figure 3 - Typical Bottom Bump Echo Intensity Profile




**Correlation Magnitude –** Correlation magnitude is a measure of the pulse-to-pulse correlation in a ping for each depth cell. This information is useful in determining the validity (or confidence) of the data. For a given ADCP setup, the correlation magnitude will have a constant, although slightly variable, value throughout the profile. As the correlation magnitude value decreases, so does the data accuracy. Correlation magnitude data give the magnitude of the normalized echo autocorrelation at the lag used for estimating the Doppler phase change. The correlation data is 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 a given value and a value of zero indicates bad correlation values.

Table 5 – Correlation Data Format

| Hex Digit | Binary Byte | Field | Description |
|---|---|---|---|
| 1-4 | 1,2 | ID Code | Stores the percent-good data identification word (00 02h) |
| 5,6 | 3 | Depth cell 1, Field 1 | Stores correlation magnitude data for depth cell #1, beam 1 |
| 7,8 | 4 | Depth cell 1, Field 2 | Stores correlation magnitude data for depth cell #1, beam 2 |
| 9,10 | 5 | Depth cell 1, Field 3 | Stores correlation magnitude data for depth cell #1, beam 3 |
| 11,12 | 6 | Depth cell 1, Field 4 | Stores correlation magnitude data for depth cell #1, beam 4 |
| 12-1028 | 7-514 | Depth cell 2-128 (if used) | These fields store correlation magnitude data for depth cells 2 through 128 (depending on the WN-command), following the same format as listed above for depth cell 1 |

WH Long Ranger expected correlation value on each beam for each depth cell is 128 counts. Values below this mean that the signal to noise ratio is decreasing (and can be seen as a related drop in the echo intensity data).

The Ocean Observer expected correlation value depends on the water profiling mode you are using (N commands versus W commands). If using N commands (Narrow Bandwidth profiling for extended range) then the threshold is 110 counts. If using W commands (Wide Bandwidth profiling for improved short term accuracy) then the threshold is 190 counts.

**Relationship Between Echo Intensity, Correlation, and Percent Good -** In a perfect world, all data collected in every depth cell would be valid. In reality, at some point the data collected is invalid. The relationship between the echo intensity, correlation, and percent good values can help you to determine why range is limited or why range is extended. The correlation values alone only tell you the last good depth cell to use as long as the bottom is not in range. When the bottom is in range the echo intensity will increase the correlation can increase at this time too. This would provide a false indication if you screened on correlation alone. There are times that you will never reach the noise floor of the system as the bottom is too close. The echo intensity values alone can tell you where the bottom or surface is but cannot tell you if the data has good confidence to itself. And finally percent good can help you determine the expected noise (standard deviation) of your data but cannot tell if you are at the surface, bottom, or if the data has good confidence. Rather it takes all 3 to determine data quality.

A good rule of thumb or first pass cut-off of the data is to look first at the correlation values. Any time the correlation goes below a given threshold counts for any beam then you should cut-off the data at that point. It is possible to get bad correlations on a beam in an upper depth cell.

When looking at the data you can confirm if the ADCP's range was limited because of signal strength; i.e. echo intensity data. The echo intensity data gives you information as to what the signal strength appears as to the ADCP. When the echo intensity becomes a constant value for several depth cells (what we refer to as "flattening out") then you have reached the *noise floor* of the ADCP. The signal-to-noise ratio is very low in this area and the ADCP cannot pick out the signal.

It is at this point your ADCP will stop collecting valid data. By comparing the echo intensity to the correlation you will see that they both fall off (drop to a low value) at approximately the same rate. In fact, when the instruments echo intensity "flattens out" you should see that the correlation values have fallen below 64 counts.

Comparing both the echo intensity value and the correlation values to percent good you will notice that it too will fall off. The percent good data should drop to zero at about the same time the echo intensity flattens out and the correlation falls below 64 counts.

This becomes the range of the system. The signal has become too weak to process and the ADCP is unable to work any deeper. It should be noted that noisy environments will raise the noise floor of the system. Noisy environments include;

- Moving platforms such as ships.
- Areas where there is background noise such as on dynamically positioned oil rigs.

Noise from waves may cause the background noise to rise. The higher the background noise the less range the system will be able to profile. The reason being is the signal to noise ratio will be decreased with higher background noise. When the echo intensity flattens out, you have an indication of the relative background noise and know that the signal now equals noise.

**Internal ADCP Screening**

The ADCP performs four kinds of screening on velocity data: the correlation test, the fish rejection algorithm, the error velocity test, and the percent good test. The correlation test compares the correlation level of each of the four beams to the threshold set by the BC or WC command. If less, that beam velocity is marked bad. Low correlation may be caused by poor signal-to-noise ratio or by excess speed when the ambiguity velocity is low (see BZ, BM, WZ, and WM-commands).

The fish rejection algorithm compares the echo intensity measurements among the beams and may mark one or all beams as bad (see the WA-command). This algorithm does not apply to bottom-track velocities.

The error velocity is a test that compares the error velocity to the threshold set by the BE or WE-command. If greater, all four velocities are marked bad. If after the first three screening tests, only one beam velocity in a particular depth cell is marked bad, a three-beam solution is still possible if enabled. In all other cases of bad data, none of the velocity components will be included from the ping in the ensemble average for the particular range cell or bottom-track velocity.

The percent good test is enabled only for radial beam velocity output (EX00xxx command). After ensemble averaging, the percentage of good values in the average is compared to the threshold set by the BG or WG commands. If less then the velocity is marked bad. This test operates independently for each beam and for each depth cell.

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