Healy HLY10TB/HLY10TC ADCP Evaluation

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Revision History

mid-June, 2010	original, very crude document. submitted on board Healy
July 9, 2010	broken out into part 3 of 3 (“Healy ADCP Evaluation”)
July 19, 2010	revised; remove “draft” designation

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1 Introduction

USCGC Healy presently has two Doppler current profilers made by Teledyne RDI. Both are the Ocean Surveyor model, which uses a single phased-array transducer to generate all four acoustic beams. The two instruments differ in their operating frequency, nominally 75 kHz (OS75) and 150 kHz (OS150). Originally, data acquisition was performed by the manufacturer's software, VmDAS. During the May 2010 Honolulu port call, the UHDAS data acquisition system was installed; it was configured and tested on the subsequent transit HLY10TC from Honolulu to Dutch Harbor. This document describes the processing of the ADCP data from the preceding transit HLY10TB to Honolulu and from HLY10TC, and uses these data sets to characterize the quality of the ADCP data. This leads to suggestions for improving the ADCP installations.

2 UHDAS and CODAS

Documentation for UHDAS and CODAS (the processing component) is accessible

- at sea (http://currents)
- on land (http://currents.soest.hawaii.edu/docs/adcp_doc/index.html)

UHDAS has four components at sea:

- Acquisition
- Processing
- Monitoring
- Access (to data and figures)

CODAS refers to the processing component.

2.1 Codas Processing Overview

This section is available in the CODAS documentation, referenced above.

CODAS (Common Ocean Data Access System) is more than a database. The word has come to be associated with a suite of open-source programs for processing ADCP data. CODAS consists of C, Matlab, and Python scripts that will run on Windows, Linux, SunOS, or Mac OSX, and can process pingdata from a Narrowband ADCP, data collected from a Broadband or Ocean Surveyor data by VmDAS, or data collected by any of those instruments using UHDAS (open source acquisition software that runs RDI ADCPs). Older processing scripts were written in Perl, but we have shifted to Python for the newer versions of these scripts.

Some kind of data treatment is necessary because the acquisition programs write binary files to the disk that are not readable by commercial plotting packages. In fact, there are not actually any ocean velocities stored in the files. A shipboard ADCP reports currents measured along each of its beams. These currents must be transformed into earth coordinates, and the motion of the ship taken out. Ancillary data such as heading and position are used to determine the ocean velocity from the measured velocities.

There are at least four necessary processing steps which are performed by (or made possible) by the CODAS routines. First, an ocean reference layer is used to remove the ship's speed from the measured velocities. By assuming the ocean reference layer is relatively smooth, positions can be nudged to smooth the ship's velocity, which directly results in the smooth reference layer velocity. (This was more important when fixes were rare or jumpy (such as with LORAN) or dithered (such as SA GPS signals prior to 2001).

Second, calibration routines are available to estimate the heading misalignment from either "bottom track" or "water track" data. Watertrack calibration routines use sudden accelerations (such as stopping and starting of the ship when doing station-work) to derive a heading misalignment. For a ship traveling at 10 kts, a 1-degree heading error results in a 10 cm/s cross-track velocity error. It is critical that the misalignment be accounted for if one is to avoid cross-track biases in the velocities.

Third, a GPS-derived heading source (such as Ashtech, POSMV, or Seapath) may provide a more accurate (though often less reliable) heading source than a gyro. Routines are in place for pingdata and UHDAS data to correct the gyro heading with the GPS-derived heading, using a quality-controlled difference in headings. An example is available for VmDAS data. Gyro headings may be reliable but they can vary with oscillations of several degrees over several hours, thus creating spurious fluctuations in the ocean velocity that resemble “eddies” , but which are solely the result of cross-track velocity errors (from the associated gyro heading errors).

Fourth, it is crucial that bad data be edited out prior to use. Traditionally, the data available from the DAS2.48 narrowband data was averaged in 5 minute groups. VmDAS and UHDAS also output time-averaged data,. which can be loaded into the CODAS database for further processing. With CODAS processing, a graphical interface allows identification of the bottom and selection of bad profiles or bad bins based on a variety of criteria. To some extent this can be automated, but for final processing, a person must visually inspect all the averages from a cruise. The graphical interface vastly speeds up editing to the point where it can take only a few minutes of user time per day of data for a typical cruise. On some ships, Healy included, this ideal may only rarely be reached.

CODAS processing has moved beyond averaged data to the realm of single-ping data. Whatever acquisition program was used to record the data also averages it. Prior to averaging, some attempt is made to eliminate bad pings. CODAS processing includes routines that average single-ping data collected by VmDAS or UHDAS. These routines allow the single-ping data to be screened more extensively prior to averaging. Under certain conditions, this may be necessary to avoid subtle underway biases caused by bubbles or ice near the transducer. CODAS processing includes the ability to read single-ping data files and look at the characteristics of the instrument (such as acoustic backscatter or beam velocities) one ping at a time.

2.2 Processed Data Conventions:

1. CODAS database times are all UTC.

2. The **decimal day** is a zero-based value. Noon January 1 UTC is 0.5, not 1.5. This is the best convention when dealing with data that may cross over a year boundary. (if your cruise does cross over a year boundary, the decimal days will just keep increasing past 365). This convention is used in naming the raw data files as well.

3. Data averaged over a period of time have an associated time and position. These represent the values at the end of the ensemble. Other scalars associated with a given ensemble (temperature, heading) are presented with two choices: 'averaged' (over the interval) and 'last' (to match the timestamps)

4. Pitch and roll (if available) are recorded if available, but are not used in the data processing.

5. Processing parameters (paths, transducer depth, transducer alignment angle, and serial messages used for position and heading) are contained in two MATLAB files in each processing directory.

    - `config/HLY10TC_cfg.m`
    - `config/HLY10TC_proc.m`

3 ADCP processed data

Errors in ADCP data (ocean velocities) can come from a variety of sources. Two of the most common are:

1. errors in the original ADCP velocity estimates;
2. errors in ship's position and attitude measurements used to transform the measured velocity of the water relative to the ship, in instrument coordinates, into the velocity of the water over the ground, in geographic coordinates.

Relative velocity errors can come from acoustic noise, electrical noise, bubbles, interference from other sonars, and failure of the ADCP itself. Future data sets may be optimized by minimizing sources of noise, etc., but once the data have been collected, the only option is to detect and edit out whatever errors are present. More often than not, such errors appear as a bias towards zero velocity relative to the ship; an example will be described in 3.1.

The most critical part of the position and attitude measurement is the heading; specifically, the heading of the transducer, which requires an accurate measurement of the ship's heading together with an accurate estimate of the (constant) alignment angle between the transducer and the ship's heading reference, nominally the keel. On the Healy the alignment angle is well-known, and the headings are obtained from the POSMV, which is stable, reliable, and closely monitored.

3.1 Introduction to “bias towards zero”

An ADCP measures the Doppler frequency shift in the beams, translating that into a velocity component along each beam. Using the orientation of the transducer relative to the ship's keel and the beam geometry, velocities measured along the beams can be translated into flow of the water past the ship (measured velocity in ship coordinates).

If the ocean had no flow, the sum of the measured velocity and the ship's velocity should be zero (Figure 1). Bias towards zero usually occurs in all 4 beams; the estimated velocity component along each beam is smaller than it should be, so the estimated horizontal velocity components of the water relative to the ship are also smaller than they should be. When the ship's velocity is added, the estimated velocity of the water over the ground is therefore biased in the direction of the ship's motion (Figure 1). This bias in the direction of motion is the “red flag” in processed ADCP data. The bias is proportional to the ship's speed; when the bias is small, it may not become apparent unless there are large changes in the ship's speed or heading.

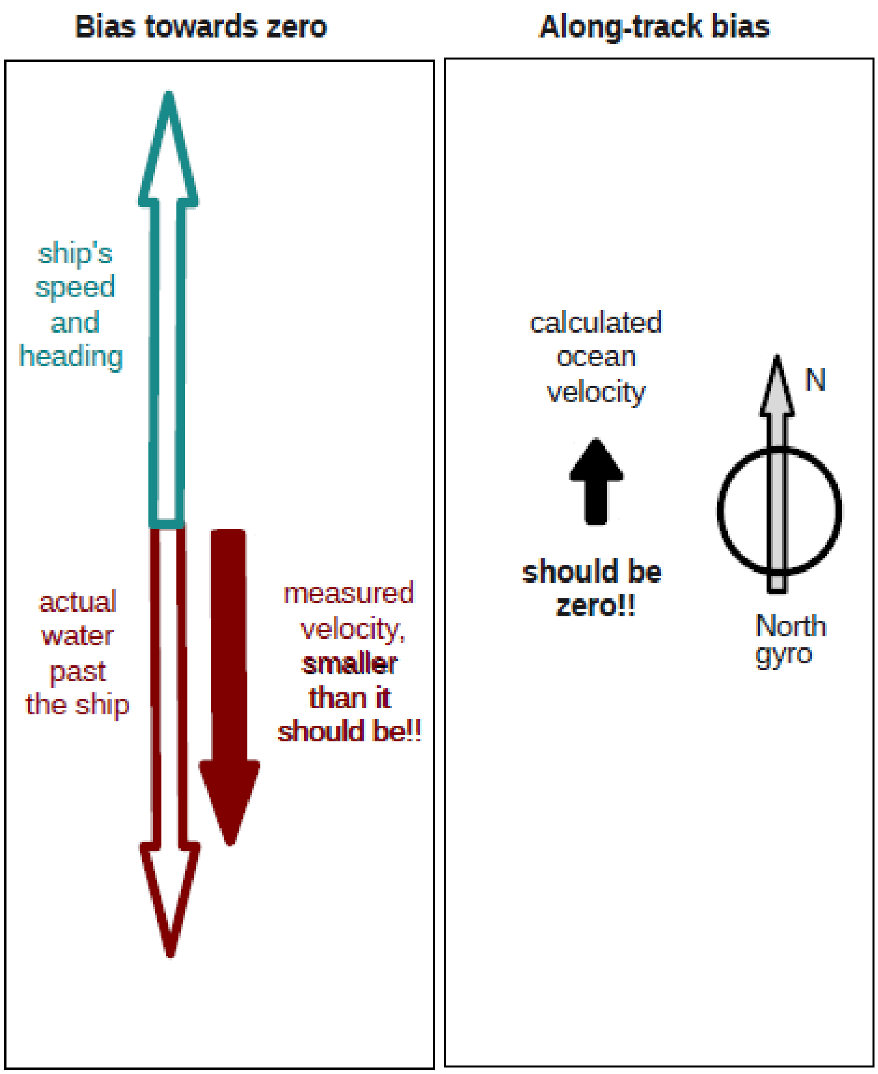

Figure 1: Cartoon illustrating "bias towards zero"

A common cause of bias towards zero is a blanking interval that is inadequate for the installation and the scattering conditions. In that case, the received sound is dominated or biased by the reverberation of the outgoing ping; because the reverberation is at the transmitted frequency, the measured Doppler shift biased towards zero. This is known as "ringing", and typically affects only the top of the velocity profile. Figure 2 shows the biased beam velocity components, and the correspondingly biased ocean velocity estimates, from a ship—not the Healy—with a particularly bad case of ringing caused by poor window and well design. Although the Healy has not shown problems with ringing, it is affected by other sorts of bias, with magnitude increasing with depth rather than being concentrated at the top of the profile.

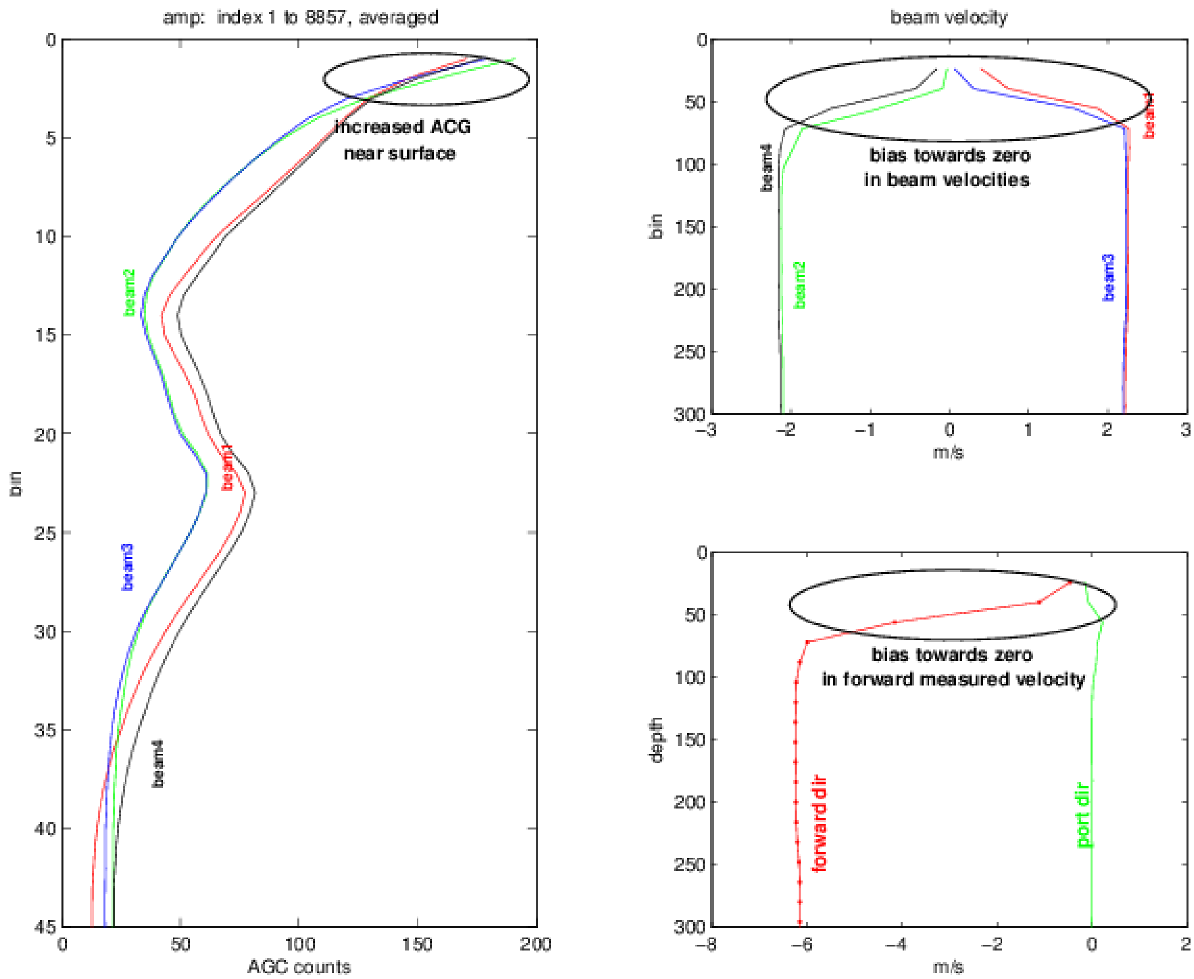

Figure 2: Example of ringing, showing bias towards zero in beam velocities and in measured velocities (fwd direction)

3.2 ADCP data from HLY10TB

ADCP data from HLY10TB (Seattle to Honolulu) were collected with both the OS150 and OS75 set to “ping as fast as possible” and to acquire data in narrowband mode only, with 8-m and 16-m bins, respectively. Data were then processed in two ways: first, using the VmDAS pre-averaged files (*.LTA, or “long term averages”), with a 5-minute averaging period; and second, using CODAS to generate the 5-minute averages from the single-ping *.ENX files recorded by VmDAS. The difference is in the single-ping editing provided by CODAS processing.

3.2.1 Bias towards Zero and CODAS processing

The effect of acoustic interference is obvious in the OS150 ocean velocity data processed using the LTA (unedited, averaged) data. With CODAS single-ping editing, the interference is effectively removed (Figure 3).

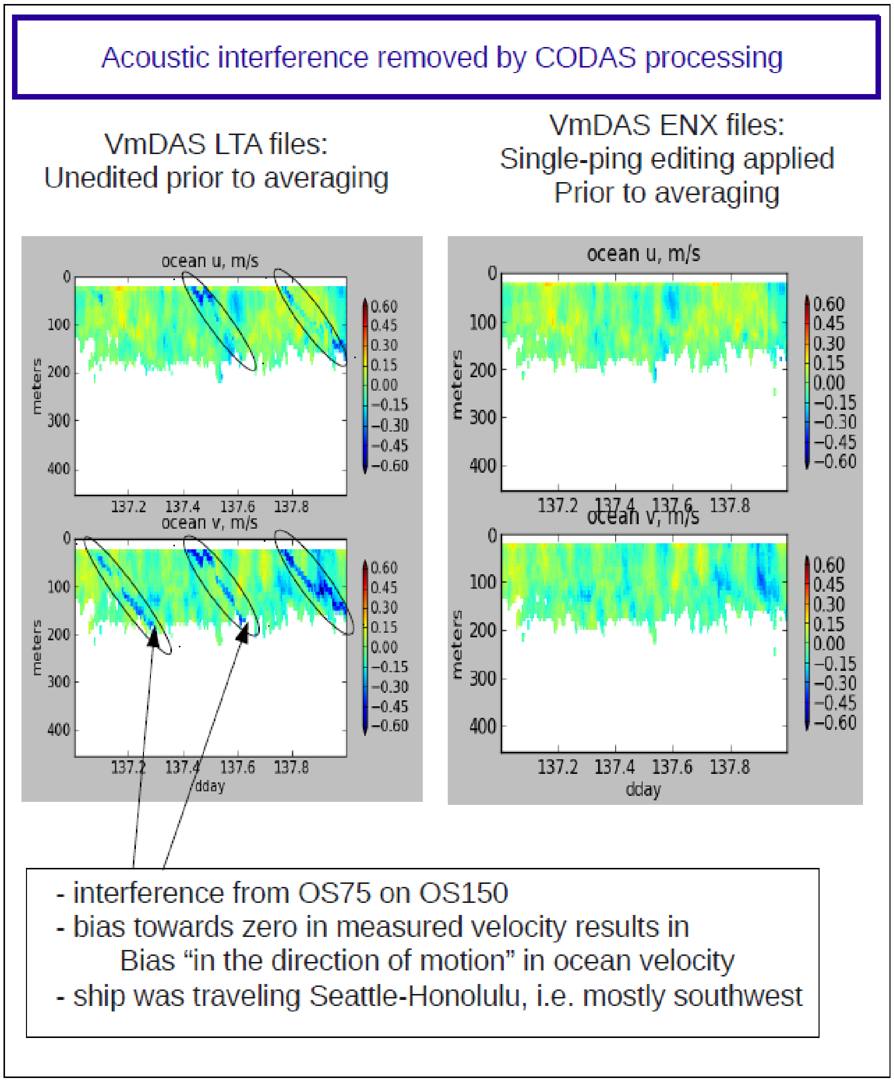

Figure 3: Effect of CODAS single-ping editing

Figure 4 shows the algorithm used to identify and remove the interference from the single-ping data. Note the obvious spikes in the OS150 Echo Intensity (red) and the corresponding contamination of the beam velocity (cyan), The black dots represent the remaining Intensity and beam velocity after the offending bins have been flagged as bad. This single-ping editing is what cleans up the blue stripes in Figure 3.

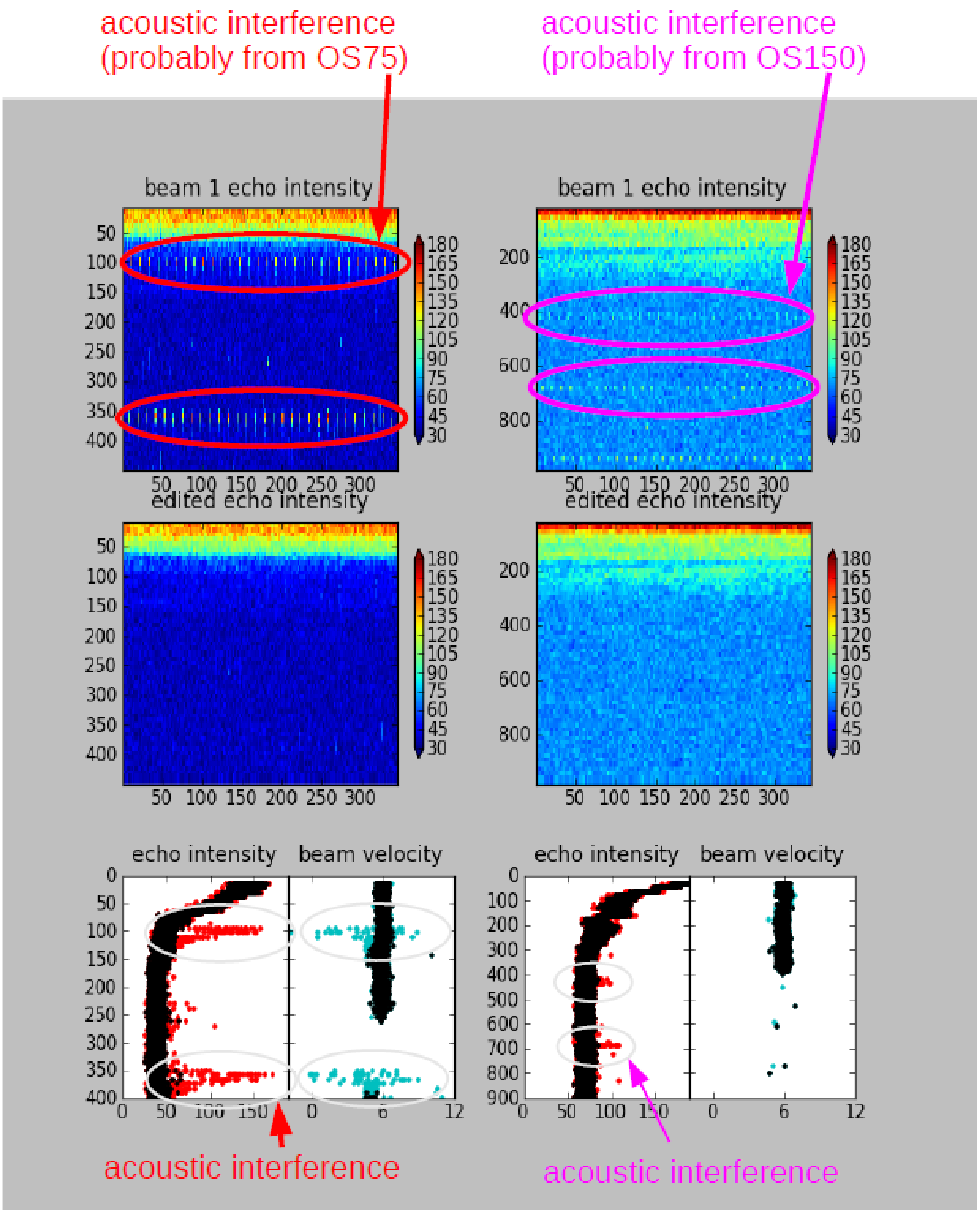

Figure 4: Acoustic interference in the OS150 (left) and the OS75 (right).

Another kind of “bias towards zero” can occur when the weather is bad (sea state is high) and bubbles are entrained under the hull. The bubbles absorb, reflect, and scatter the sound, as well as generating noise, so range is reduced. A bias towards zero at the tops of the profiles, especially pronounced in profiles with severely shortened range, is common, although its precise cause is not clear (Figures 5 and 6). CODAS single-ping editing can eliminate most of the bias, but an additional stage of manual editing of the averaged data is often needed. It can be a difficult judgment call.

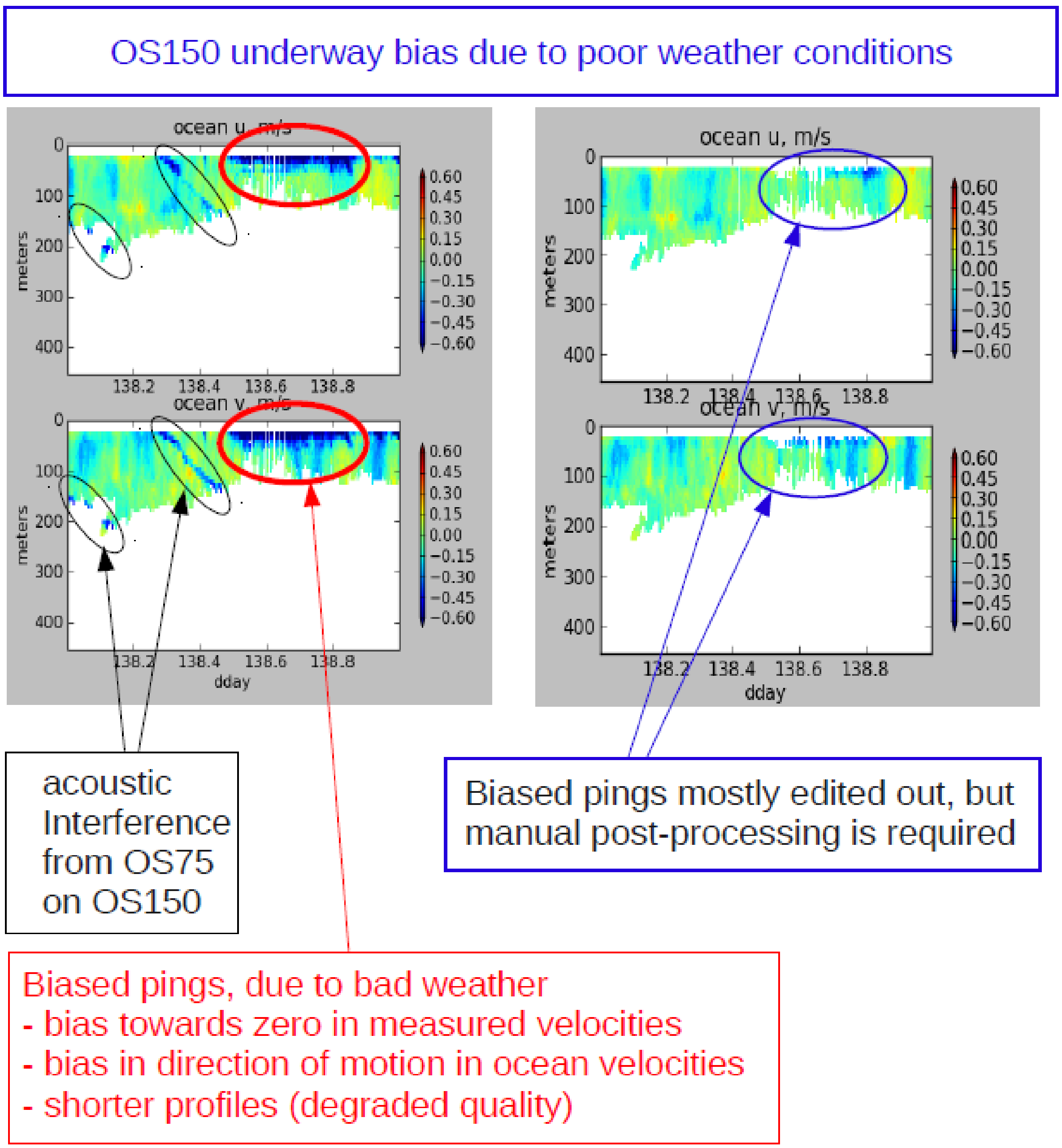

Figure 5: OS150 underway bias from bad weather (left), and the same data after CODAS singleping editing and averaging (right).

Although the OS150 was able to capture more bins (Figure 5) than the OS75 (Figure 6), velocity data around decimal day 138.6 are clearly biased (left). The OS75 did a better job of rejecting bad data, but some highly biased pings were not rejected. Reprocessing using single-ping editing (right) resulted in several hours of data are deemed unrecoverable.

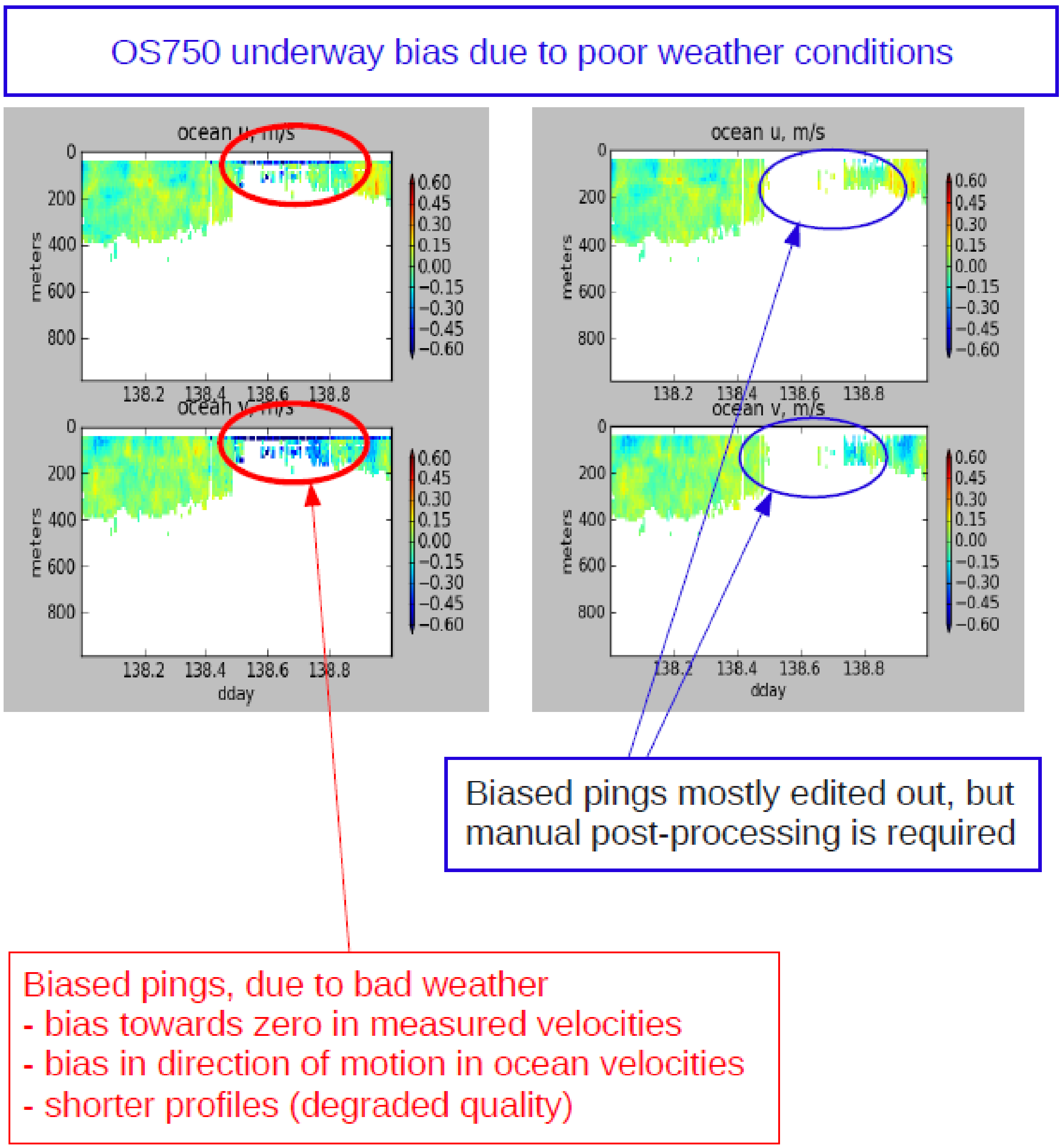

Figure 6: OS75 underway bias due to bad weather (left) and the same data after CODAS singleping editing and averaging (right).

3.3 ADCP data from HLY10TC

3.3.1 Data Collection

The ship sailed May 31, with UHDAS data collection commencing at 20:05 UTC. During the cruise, UHDAS and the ADCP installation were tested with a variety of instrument and processing settings. Uniformly reprocessed data are in the directory called 'HLY10TC_rationalized". The reprocessed data used the same settings that are now in place for the at-sea processing on Healy:

- position and attitude from POSMV
- averaging interval: 5 minutes
- heading alignment (referenced to POSMV)
  - OS150 : beam 3 = 28.4 deg starboard of fwd
  - OS75 : beam 3 = 43.4 deg starboard of fwd
- transducer depth = 8m

During much of HLY10TC, the seas were remarkably calm. The ADCPs were able to return valid data for most the (17kt) transit to Dutch Harbor until the northern section. There, as the wind picked up and there was some chop on the water, the ADCP data were mostly decimated by bubbles. After a brief stop in Dutch Harbor, several multibeam surveys provided additional opportunities for evaluating the ADCP data quality with various settings. Based on these tests, default ADCP setup parameters for the Healy were chosen.

During the first part of the cruise, the OS150 was run in interleaved mode (that is, alternating broadband and narrowband pings) with instrument default settings for depth bin size and blanking interval. The OS75 was run in narrowband mode only.

Partway through the transit, OS75 broadband mode was turned on. For most of the transit, the ADCPs were run with RDI-recommended bin size. During the surveys south of Dutch Harbor, reduced bin size (half the recommended default) was tested.

3.3.2 Results from Multibeam survey north of Oahu

North of Oahu, a deep-water multibeam survey allowed the collection of many short ADCP transits in different directions in a region of relatively weak currents. This kind of cruise track is ideal for watertrack calibration (transducer angle and scale factor) and is useful for discovering bias in the velocity estimates.

During this survey, the OS150 was set to ping in interleaved mode (broadband and narrowband pings) with instrument defaults (4m bins for broadband, 8m bins for narrowband). The OS75 was set to instrument defaults, narrowband mode only (16m bins) .

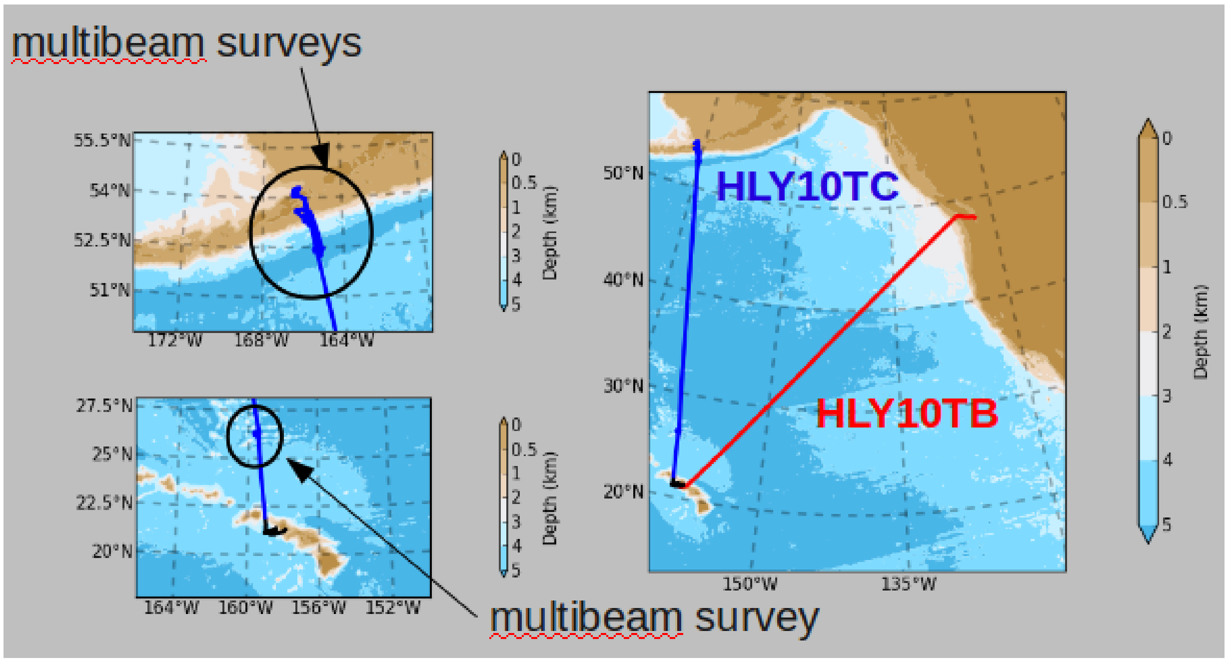

Figure 7: cruise track and location of surveys

Observations

OS75

- very poor range compared to other OS75 installations

OS150

- range is slightly less than two other OS150 ADCPs
- broadband mode is severely biased ("bias towards zero" results in a bias in the ocean velocity in the along-track direction); Figure 8.

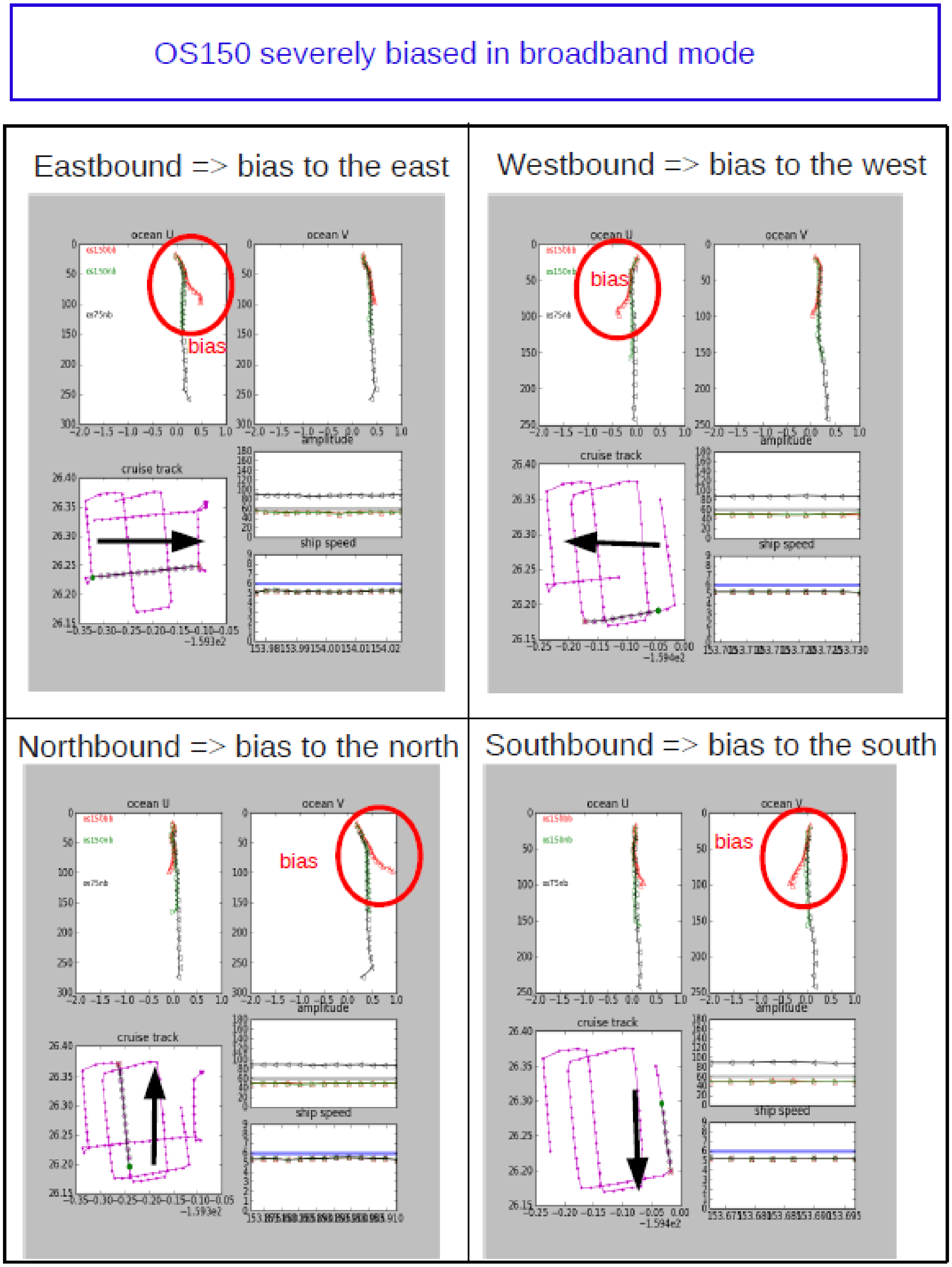

Figure 8: Illustration of OS150 broadband bias. Amplitude panel shows the noise floor as recorded by the instrument, in units of approximately 0.45 dB.

3.3.3 Results from Multibeam surveys south of Dutch Harbor

During the multibeam surveys, the OS75 was run in interleaved mode; bias was evident in the broadband mode of both the OS150 and the OS75 (Figure 9). This was not new; bias in the OS75 broadband mode has been reported in the RDI Grooms. In both instruments, the bias increases with distance from the transducer, and is about the same magnitude by the end of the range.

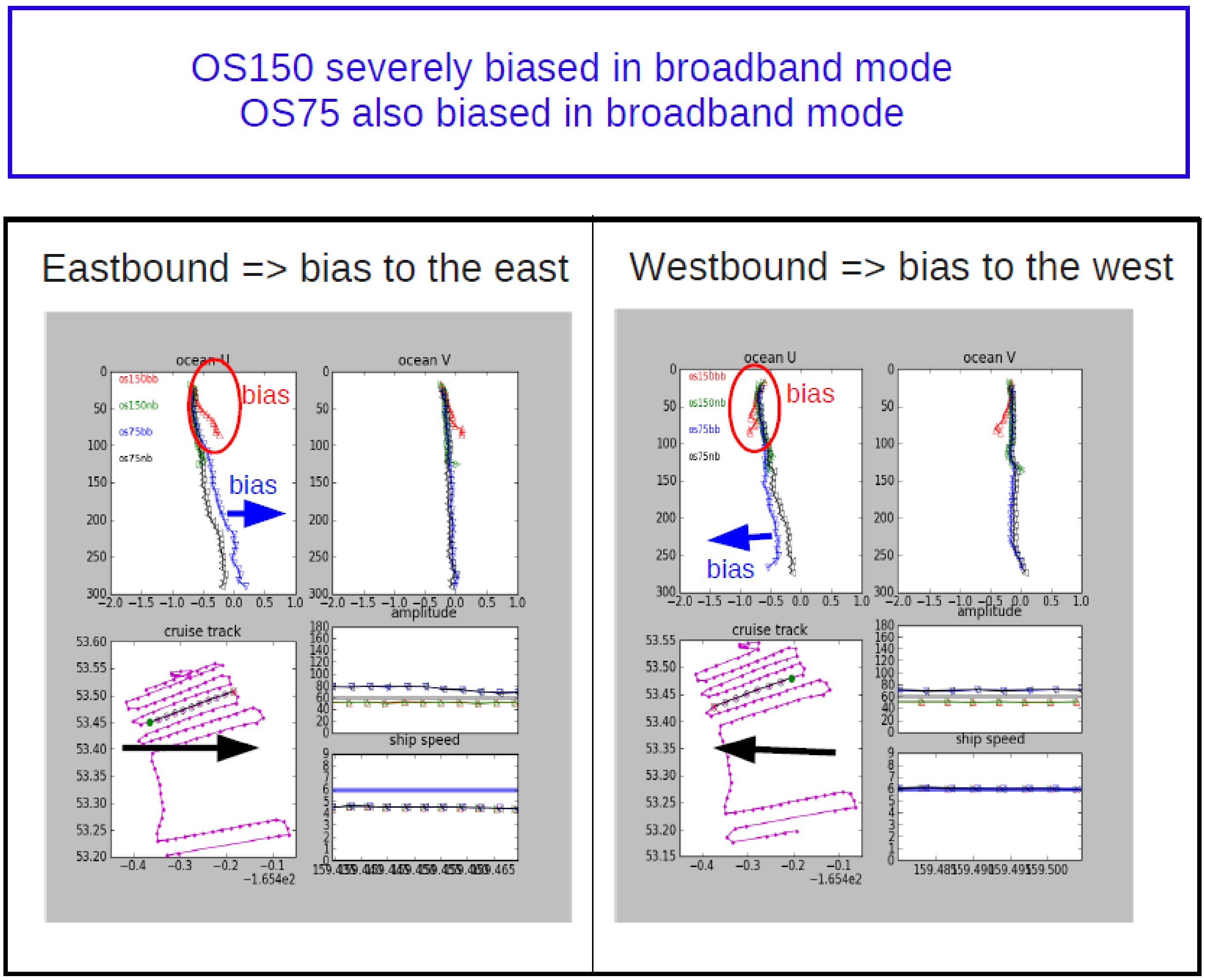

Figure 9: OS150 and OS75 bias in broadband mode

After the survey shown in Figure 9, the ship headed south for a deep water survey. ADCP data from 2010/06/10 15:10 to 2010/06/10 18:30, on the transit back to the north, show an uncharacteristically low (for the Healy) noise floor in both OS75 and OS150 (Figure 10). An Elog entry at 2010/06/10 15:49 says

> A cycloconverter tripped and engines went offline.
> `Engines are now back online but in an abnormal configuration. There are 12 pulses going to one engine and 6 pulses going to another.`

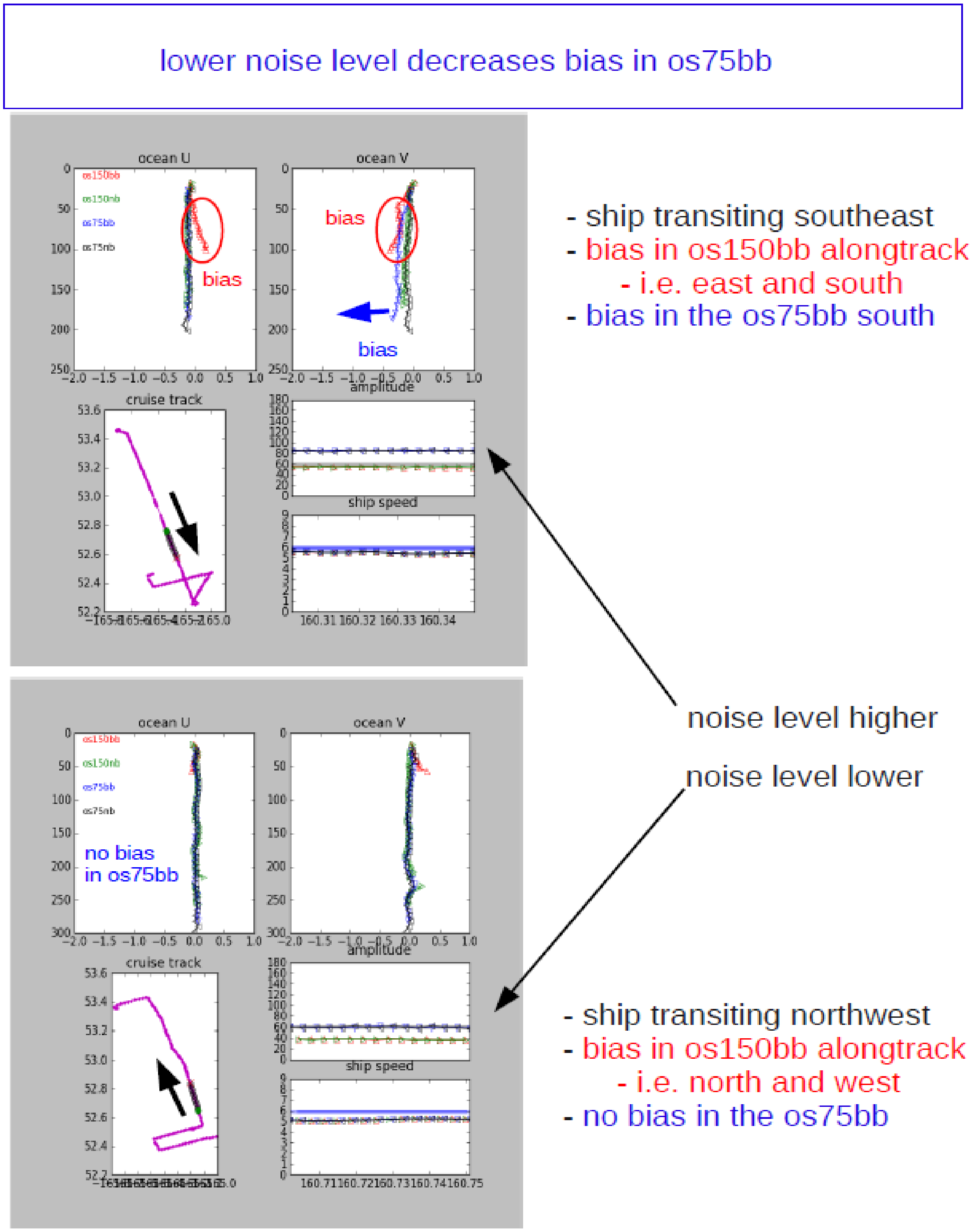

Figure 10: OS75 broadband mode not biased during lower-noise event

Comparing the southbound transit (high noise floor) to the northbound transit (lower noise floor), we see OS75 broadband bias only in the former. The OS150 broadband pings were still strongly biased on the lower-noise northbound transit, though, and their range is surprisingly reduced while the OS75 range is increased. We have no explanation for this inconsistency.

Another period of reduced noise occurred during the last night of the cruise, while both instruments were in narrowband-only mode. The OS75 noise floor was consistently near 60 for much of that night. (All amplitudes are given in the units in which they are recorded by the instrument, approximately 0.45 dB per count.) Although this is lower than the 70-80 level typical of the Healy, it is still much higher than the range of 10-40 found on other installations, and expected based on the manufacturer's specifications. Ranges during this lower-noise survey were:

OS150 4m narrowband : range 160m
OS75 8m narrowband: range 320m

Healy is unlikely to see these values in general. More typical maximum values will be

OS150 4m narrowband : range 80-100m
OS75 8m narrowband: range 150-200m.

These ranges decrease with the presence of bad weather (increased sea state), ice, or electrical noise.

3.3.4 Ocean Data

The Healy and Thompson crossed the Alaska Stream, a narrow jet that flows west along the Alaska panhandle, within 3 days of each other (Figure 11). The weather was similar for each transit. Weather and scattering conditions limited the Thompson OS75 depth penetration to the low end of its typical 600-800 m range. The Healy OS75 achieved only 180-280 m (Figure 12). Although the Healy OS75 is inevitably handicapped by a thick window and by the tendency of icebreakers to entrain a bubble layer, it should be capable of more closely approaching the range of other installations than it does at present.

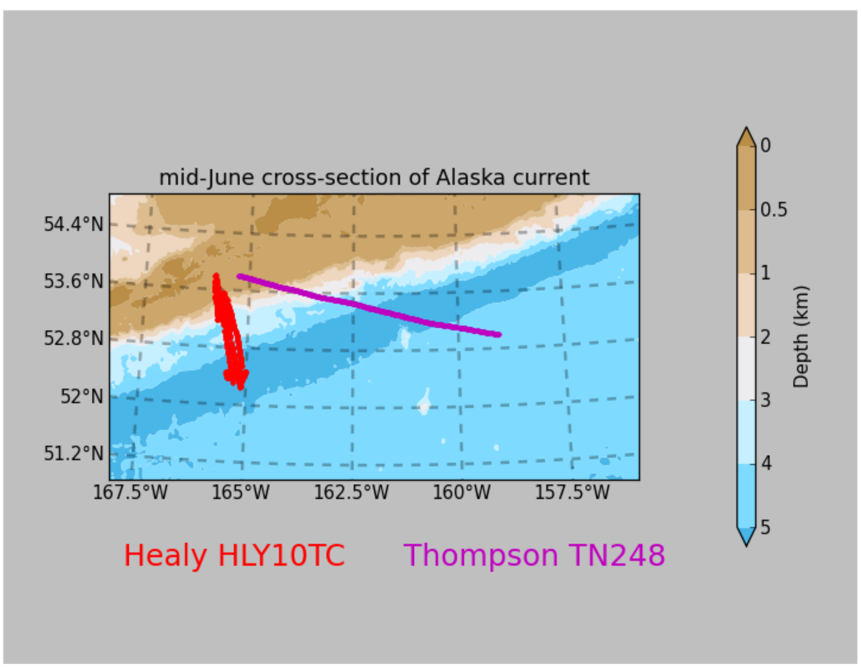

Figure 11: Healy and Thompson Alaska Stream crossing track

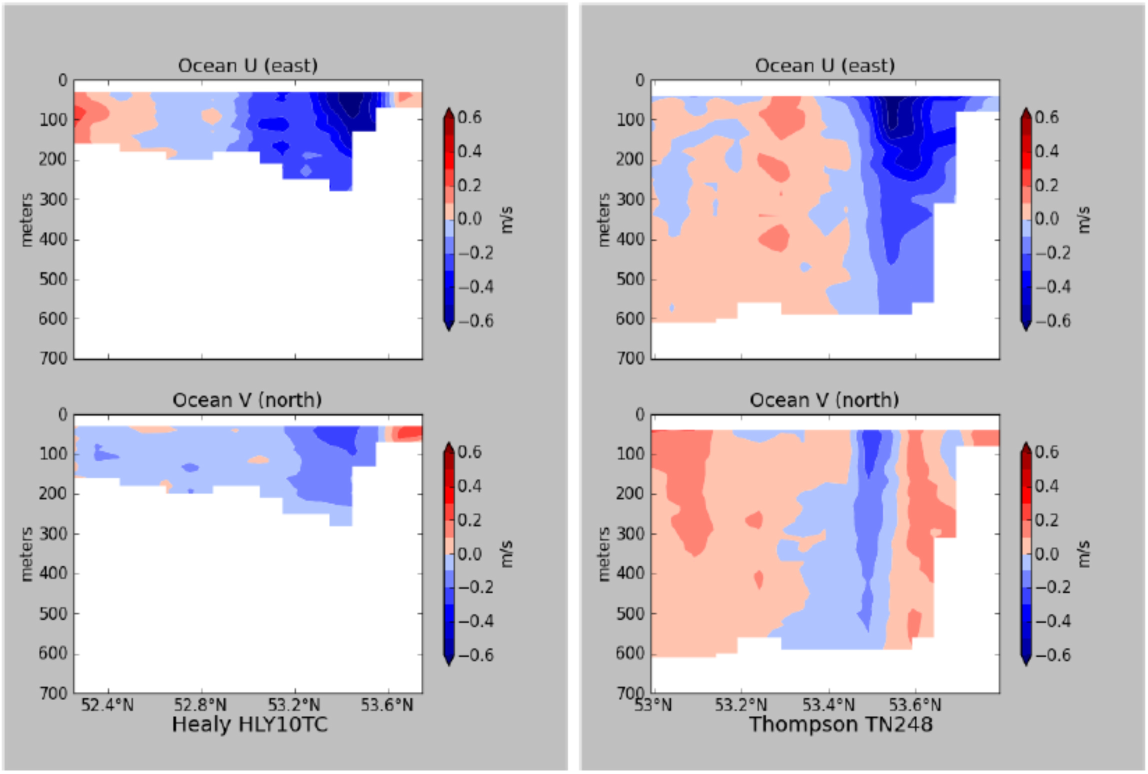

Figure 12: Two nearby crossings of the westward-flowing Alaska Stream by OS75 ADCPs. The 600-m depth range of the Thompson system (right panel) contrasts with the 180-280-m range of the Healy (left panel).

4 Evaluation

The data samples discussed above show that the Healy ADCP installations suffer from high noise, poor range, and bias in broadband mode. Although not the only factor, noise is clearly a major contributor to the range and bias problems.

The noise floor (the signal strength indicator from deep depth cells, where signal strength is roughly constant with depth and where no valid velocities are measured) varies from one installation to another, and for any given installation, it varies with ship speed, sea conditions, and potentially with other factors such as the configuration of the ship's electrical system. The latter may change abruptly during a cruise, as illustrated in the discussion of Figure 10, above. (We have also recently seen such major abrupt changes in the noise level on the Kilo Moana OS38, so the Healy is not unique in this regard. Elevated noise on the Kilo Moana is sometimes, but not always, connected with biased broadband velocity estimates.)

Comparing the Healy to several other ships, we see its extraordinarily high noise level in the OS75, and its moderately high level in the OS150 (Figure 13). Both instruments show large scatter in their noise levels, but, in these samples, little systematic variation with ship's speed. The Melville OS75 and the Knorr NB150 show the most systematic variation in noise floor with ship's speed, again with the caveat that Figure 13 is based on somewhat arbitrary data samples.

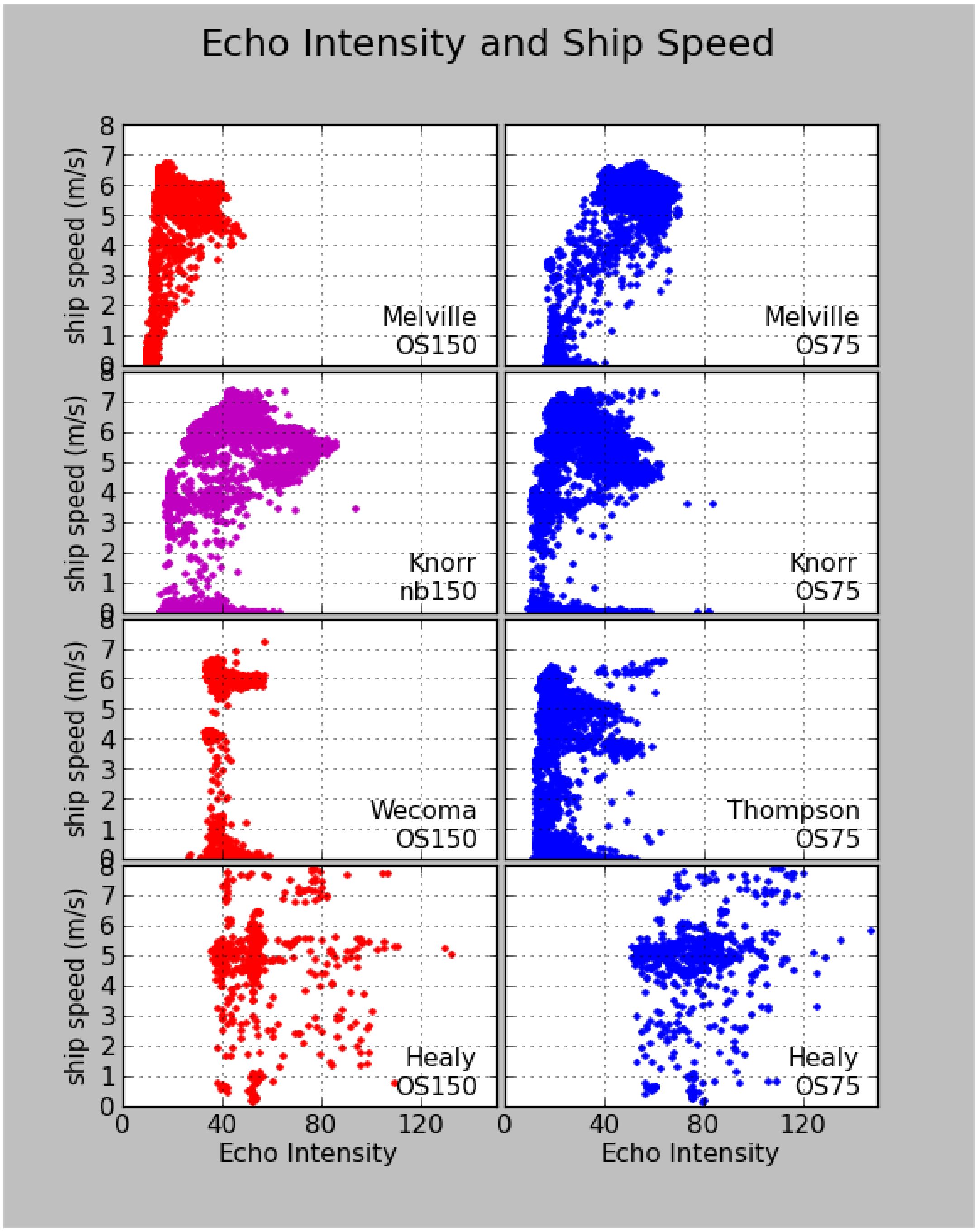

Figure 13: Noise floor and ship speed for a variety of ships. (Although the NB150 on the Knorr is a different instrument than the OS150 on the other ships, its signal strength measure is roughly similar to that of the OS instruments.)

How much of the noise in the Healy installations is acoustic and how much is electrical? We believe electrical noise is by far the dominant problem at present. Evidence includes the lack of systematic variation of noise with ship's speed, the abrupt changes in noise correlated with changes in electrical configuration, and the dependence of the noise level on the physical location of the instrument electronics chassis and transducer cable.

The best illustration of the role of chassis and cable location may be a brief test in 2006 of the OS75 on the Healy, with the chassis located in the potable water room (Figure 14). The noise floor in that instance dropped to a more normal level. The range was markedly better, but still poor; it is not clear whether this is because of sea conditions (bubbles), the acoustic window, or lack of scatterers.

Another crude test of varying the transducer cable route can be obtained by comparing the noise floor from the BB150 that was originally installed on the Healy to that of the present OS150. The deck box of the BB150 was in the same location as the present OS150 and OS75, and the transducer cable route was identical to that of the present OS75. The OS150 transducer cable, however, runs roughly parallel to, but mostly about a meter away from, the OS75 cable. It enters and leaves the potable water room through different penetrators than the OS75 cable; the latter is bunched with a large group of other cables. The noise floor of the BB150 is similar to that of the OS75, and above that of the OS150 (Figure 14). This is consistent with the idea that the OS75 cable run is leading to strong noise induction, but by no means proves it.

A high noise floor inevitably reduces the range of an ADCP, but, bad as it is, the noise floor alone does not appear to account entirely for the poor range of the OS75. The next candidate is the acoustic window, thought to be 2-inch Seabeam Orange, and expected to cause roughly a 6-dB round-trip loss at 75 kHz (Bockstege, 1991: Insertion loss measurements for a composite urethane acoustic window. Report for ASA.) Comparison with other ships is difficult because the signal amplitude, as opposed to the noise floor, depends on the availability of scatterers, and this is highly variable from place to place and even with time of day. It appears that the signal level of the OS75 on the Healy is reduced by more than the expected 6 dB (Figure 15, middle panels); if so, it is still not clear whether the problem is the window, some other aspect of the installation (e.g. separation between transducer face and window, or foreign material between transducer and window), or perhaps a weak transducer. If the window thickness is the same for the OS75 as for the OS150, the latter should have about twice the loss (12 dB round-trip) because of the higher frequency, based on the same test report. This is consistent with the crude comparison between the Healy and other OS150 installations (Figure 15).

Other things being equal, ADCP range scales inversely with operating frequency. In addition to solving the noise problem, ADCP range on the Healy could be improved by installing an OS38. RVIBs N.B. Palmer and L.M. Gould, both operating OS38 instruments behind 2-inch Zelux windows, have ranges that can exceed 1000m. It is worth noting that the Gould attains better range than the Palmer, particularly in ice and in bad sea conditions, because it uses an “ice knife” to keep the transducer below the ice and below the layer of bubbles flowing under the hull.

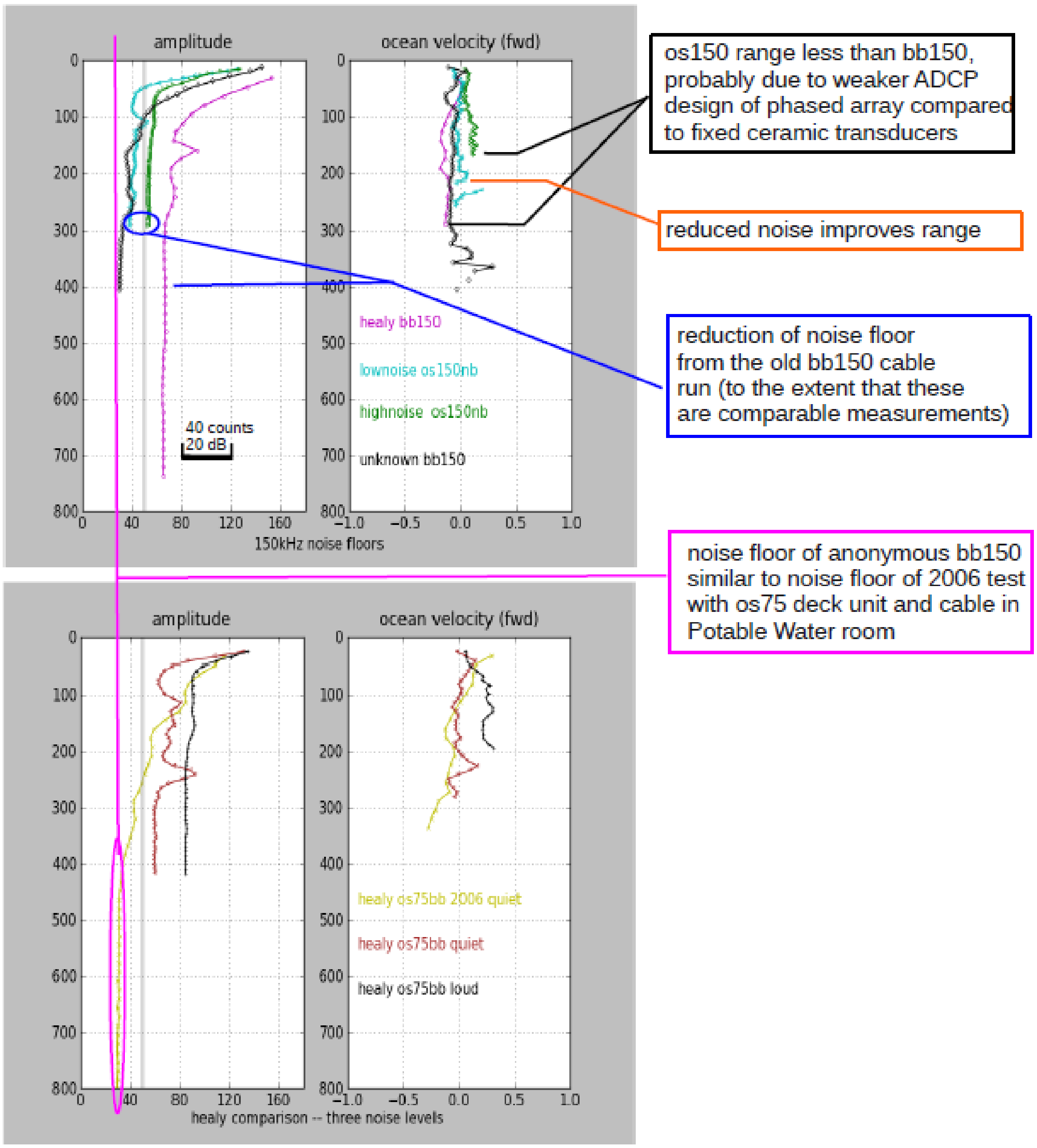

Figure 14: Examples of the noise floor on Healy. The "anonymous bb150" is an old data sample of unknown origin, included here merely to illustrate that a BB150 can have the expected noise floor, reinforcing the conclusion that the BB150 on the Healy had an unusually high noise floor.

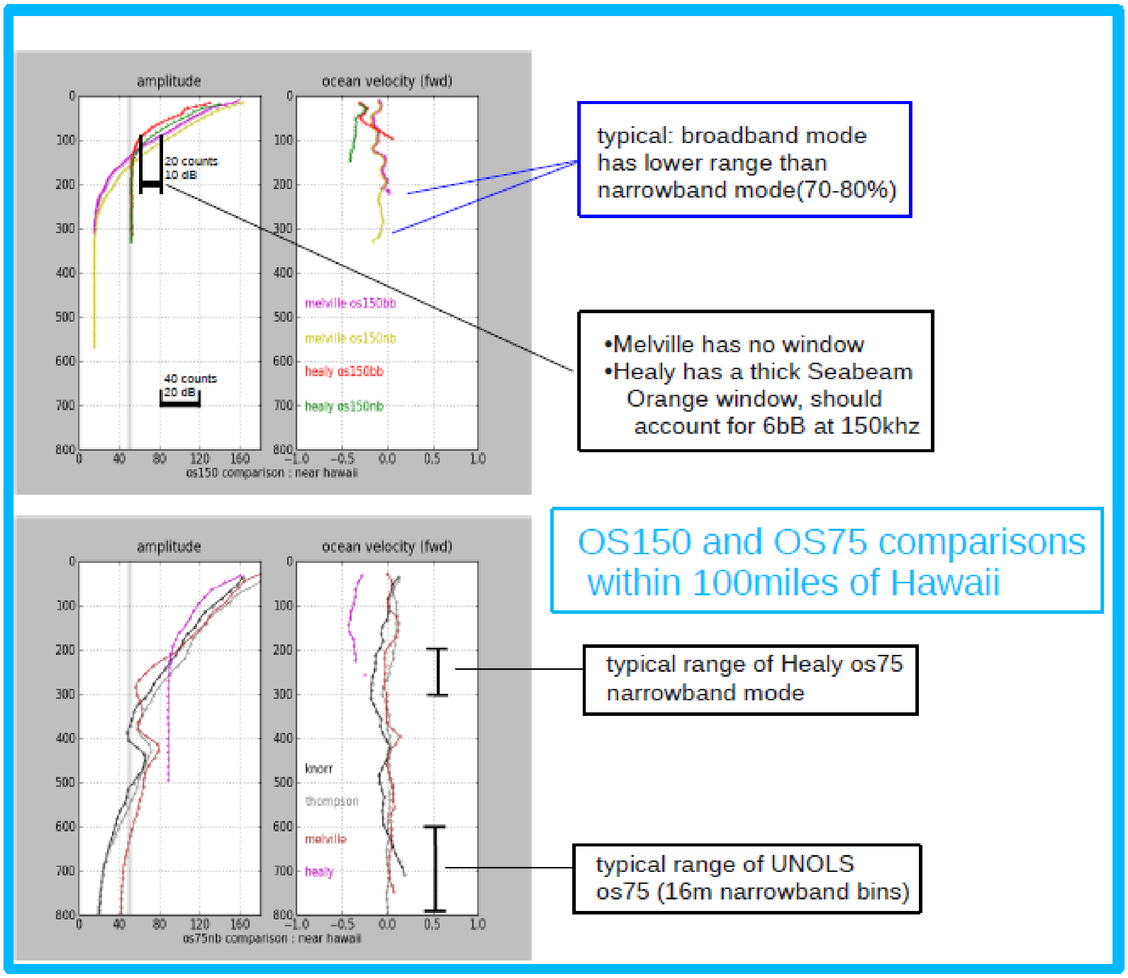

Figure 15: Comparison of OS150 and OS75 for different ships.

The two striking problems with the Healy's ADCPs are the poor range of the OS75, and the bias in the broadband mode of both the OS75 and the OS150. A common factor is electrical noise. In the OS150, the noise, and the noise-induced bias differs greatly between the forward-pointing beams (lower noise), and the aft-pointing beams (Figure 16). The broadband velocity bias increases with noise floor, both in the comparison between aft and forward beams and in the comparison between high-noise and lower-noise periods. In some cases the biased velocity estimates are variable; in others, they are zero.

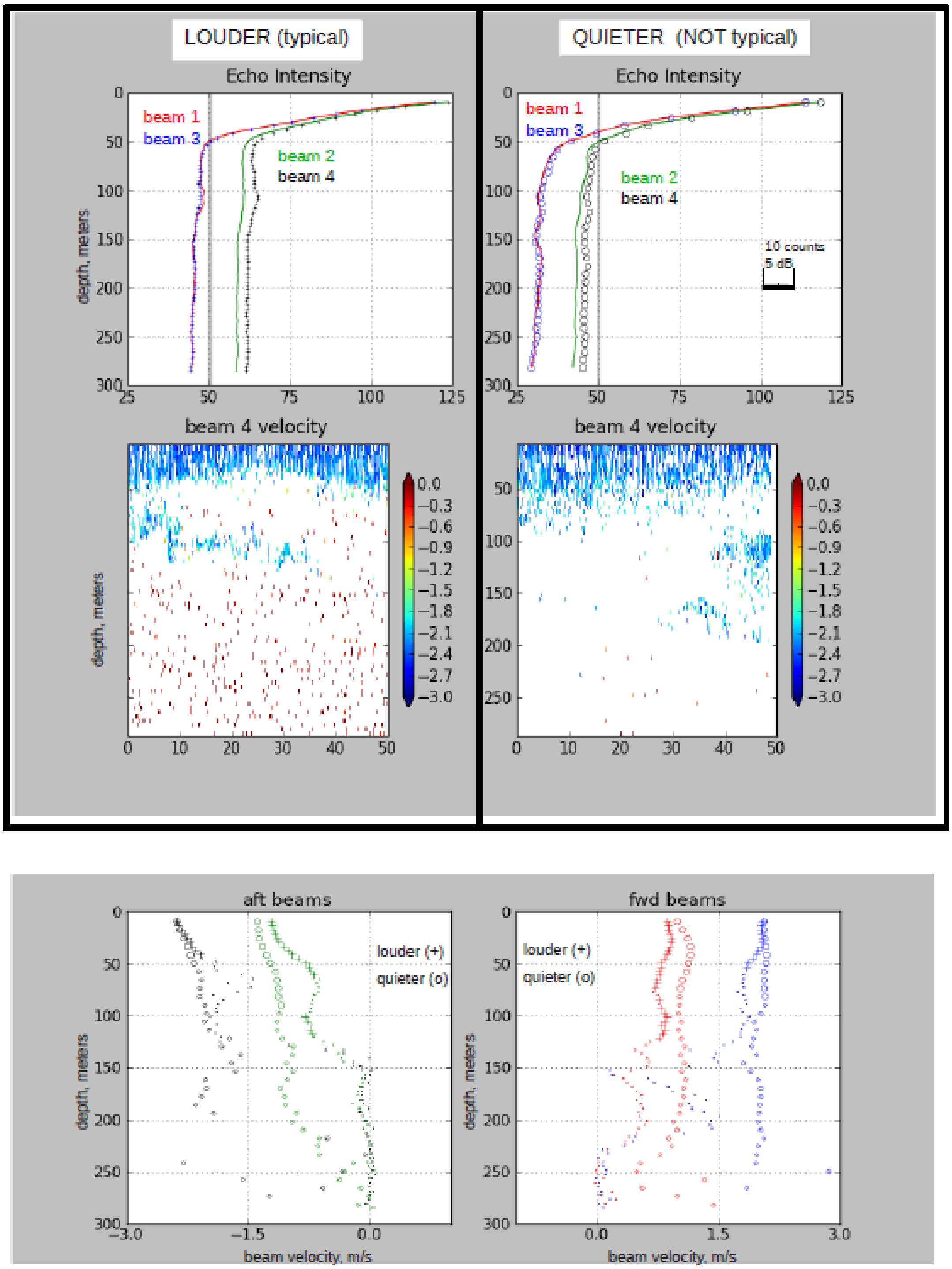

Figure 16: OS150 broadband mode bias, in more detail. Data are from the same periods as in Figure 10; the lower noise period corresponds to a change in the ship's electrical system.

5 Summary

characteristic	OS75	OS150
noise floor:	• usually 70-80 counts • "lower noise" events 55-65 counts	• usually 50-55 counts • "lower noise" events: under 40 counts • beams (1,3) have a significantly lower noise floor than beams (2,4) • the difference is 15 counts (8dB) • noise floor of the bb150 with the old cable run was around 70
acoustic interference:	• interference from other sonars is removed with CODAS processing	• OS150 is more subject to interference from OS75 than the reverse, but interference is effectively removed with CODAS processing
range:	• best conditions: 250-300m • more typical: 150-250m • changing from default (16m) narrowband to 8m did not have an obvious effect on range • Groom reports may present an optimistic interpretation of instrument range.	• best conditions 150m • more typical: 80-100m • changing from default (8m) narrowband to 4m did not have an obvious effect on range
bias:	• os75 broadband mode is biased, with possible exception of lower-noise period	• broadband mode was biased at all times, including lower noise period • beams 1,3 (quieter) - had better range than beams (2,4) - were slightly less biased than beams (2,4) • decreasing noise decreased the bias in all beams

6 Recommendations

The most important recommendation for improvement of ADCP performance on all time scales is to continue trying to understand and solve the problem of electrical noise. This may require changes in cable location, electronics chassis location, grounding configuration, power source, and possibly other factors not yet identified.

A second long-term recommendation is to ensure that there are instruments operating at two or more frequencies. The present OS150 is loaned; but an instrument operating at 150 or 300 kHz is essential for shallow-water work. Although the Workhorse 300 kHz instrument can fulfill this role on most ships, it almost certainly would not work on the Healy because of the strong sound absorption by the thick acoustic window required for ice protection. Even without a window, shipboard WH300 instruments typically have disappointing range, rarely over 100 m. Therefore an instrument operating at 150 kHz is likely to be the best choice for the Healy. If the noise problem can be solved, then the Healy's capabilities in deep water could be improved by adding an OS38 to the suite.

The third recommendation is for the immediate future. Because the Healy often operates in shallow water, and because the broadband mode is not usable at present, the only way to get measurements with high vertical resolution, and close to the hull, is by operating the ADCPs in narrowband mode but with shorter depth bins than we would ordinarily choose. This reduces the horizontal and temporal resolution; for a given accuracy, more pings must be averaged. The tradeoff seems worthwhile, however, so the recommended settings for Healy (2010 season) adcp data acquisition are:

ADCP	broadband mode	narrowband mode	bottom track
os150	biased: do not use	bin size = 4m 70 bins blank = 5m	use sparingly; not necessary with CODAS processing
os75	biased: do not use	bin size = 8m 50 bins blank = 10m	use sparingly; not necessary with CODAS processing