A MANUAL FOR ACQUIRING LOWERED DOPPLER CURRENT PROFILER DATA

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1. INTRODUCTION

1.1 Scope of Document

This manual describes "best practices" for acquiring ocean-velocity data using Lowered Acoustic Doppler Current Profiler (LADCP) systems. Adherence to the recommendations in this manual should help ensure that the acquired data can be processed to derive full-depth absolute velocity profiles of high quality. Processing LADCP data, which is not covered in this manual, is not a trivial task and there are several publicly available software packages available for this purpose. Care has been taken to ensure that the guidelines in this manual are independent of the processing software. In principle, any ADCP instrument with sufficient depth rating can be lowered on a wire to obtain LADCP data. As the data quality depends significantly on the instrument setup, some of the recommendations in this guide are necessarily instrument dependent.

1.2 LADCP Profiling

In order to obtain full-depth ocean velocities one or two ADCPs are lowered on a wire to some distance above the seabed and raised back to the surface. (Non-standard casts, such as tow-yos and yo-yos are not covered in this manual.) While the ADCPs are in the water they use acoustic pings to collect short (order 100m) velocity profiles measured in the frame of reference of the moving instruments. In order to combine those short profiles into a record of full-depth absolute (i.e. in the Earth's frame of reference) velocities the effects of the instrument motion must be removed. Regardless of the method used to accomplish this (Fischer and Visbeck, 1993; Visbeck, 2002) additional constraints must be used to reference the velocities. The most widely used constraints are:

Ship Drift. The fact that every LADCP cast begins and ends at the ship's position can be used to constrain the mean horizontal velocities observed during a cast if the ship's drift is known. Ship drift can readily be inferred from navigational records, such as GPS measurements.

Shipboard ADCP Data. Many oceanographic vessels are equipped with hull-mounted ADCPs. These data can be used to constrain the LADCP profiles near the sea surface.

Bottom-Tracking Data. When a downward-looking ADCP used on an LADCP system is within acoustic range of the seabed, it can track the instrument velocity over ground, providing a constraint for the LADCP profiles near the seabed.

To maximize LADCP profile accuracy, all three velocity-referencing constraints should be used simultaneously (Thurnherr, 2009). Therefore, it is recommended that both shipboard ADCP and navigational data are collected for each LADCP cast. Additionally, high-quality LADCP profiles also require depth and sound-speed data, which are usually derived from pressure, temperature and salinity measurements. While some ADCPs are equipped with ancillary sensors for measuring pressure and temperature, LADCP systems more typically use data from high-quality CTDs for this purpose. For details, see Section 8 below.

Deep-ocean LADCP profiling is typically carried out near and sometimes even beyond the limits of the instruments' capabilities. In order to obtain high-quality full-depth velocity profiles, the range of the individual relative velocity profiles must not fall below an instrument-dependent threshold anywhere in the water column. The range of an ADCP is a function of acoustic power, sound frequency and scattering in the water column. In regions of the ocean where there are insufficient scatterers full-depth absolute velocity profiles cannot be obtained. However, even in those regions, useful velocity profiles can be obtained near the surface (using shipboard ADCP data to reference the velocities) and near the seabed (using bottom-tracking data).

1.3 LADCP System Overview

A full LADCP system consists of multiple hardware components:

Instrument Platform. The instruments used in an LADCP system are typically installed on an instrument platform that is lowered at the end of a hydrographic wire. The instrument platform is often a fully loaded CTD/bottle rosette. However, it can be as simple as a wire frame with attachments for a single ADCP instrument. The ADCPs used on LADCP systems are typically internally recording and do not require communications via a conducting cable.

Downward-Looking ADCP. The primary ADCP used on LADCP systems is usually installed pointing downward and is called a downlooker. It measures velocity profiles below the instrument platform.

Optional: Upward-Looking ADCP. Dual-headed LADCP systems use a secondary ADCP pointing upward (called uplooker), which measures velocity profiles above the instrument platform. The second ADCP provides redundancy and denser sampling; it allows filling gaps caused by interference from the bottom return in the lower part of the profile; and provides pings without wake contamination on the upcast. The up- and downlookers do not have to be instruments of the same type. Uplooker-only systems are not recommended, primarily because they cannot be used to collect bottom-tracking information.

Batteries. Most LADCP systems use separate battery packs installed on the instrument platform to power the ADCP(s). While it might be possible to draw power from the same cable supplying the CTD, this requires a dedicated voltage converter. Either rechargeable or disposable batteries can be used, but rechargeables are highly recommended. While it is possible to use self-contained ADCPs with built-in battery packs for LADCP work this is not recommended because of the need to periodically open the ADCP pressure cases in order to change batteries.

Cabling. On many LADCP systems there is a single cable connecting the ADCPs to the battery, to each other (in order to allow synchronized pinging), and to communications- and charging connectors. Because of the multiple connectors, this cable is often called an octopus cable. Typical self-contained LADCP systems must be connected to a battery charger and a communications computer before and after each cast. For convenience and safety the connectors should be easily accessible while minimizing whipping motion during a cast. This is commonly ensured by semi-permanently attaching the cables to the instrument platform a short distance (10 cm or so) from the plugs. The short free cable ends are called pigtails. Whenever the pigtail connectors are disconnected from the deck cables they (as well as the corresponding deck-cable connectors) must be mated with dummy plugs to protect the connectors from water. Failure to "dummy up" the pigtail connectors during an LADCP cast will destroy any connector with significant voltage (e.g. from the battery) on its pins.

Communications/Charging Cable(s). While on deck, LADCP systems are usually connected to a battery charger and a data-acquisition computer, both of which are typically located in a dry lab. Depending on the ship, this may require long cables.

Power Supply (Battery Charger). This piece of equipment is typically used both to power the ADCPs while on deck (i.e. during instrument programming and data downloading) and to charge the batteries. For safety, the power supply should be located in a dry area of the ship.

Data Acquisition Computer. Programming the ADCPs for a cast and downloading the data requires a computer, which can also be used for processing the LADCP data. Any system that provides required communications ports and software for communicating with the ADCPs can be used. For the Teledyne/RDI ADCPs presently in use (see Section 2 below), communication and data downloading can be done using open-source software on computers running Microsoft operating systems, Linux, FreeBSD and MacOSX, and probably other UN*X flavors as well.

2. ADCP HARDWARE

In principle, any ADCP rated for a sufficiently high pressure can be used in LADCP systems. However, not every available ADCP may be equally suitable to the task. In particular, ADCP transducers are not typically designed to withstand the repeated pressure cycling associated with LADCP work. Furthermore, it is important that ADCPs return unbiased velocities, even near and beyond the range of valid measurements. Therefore, not every instrument type that works well, for example, when deployed on moorings, is suitable for LADCP profiling. The primary experience of the authors of this guide is with the following instruments:

Teledyne/RDI 300 kHz Workhorse (WH300). This is the most widely used ADCP in LADCP systems. While all Workhorse variants are suitable for LADCP work, "Sentinels" are recommended because they are designed for use with external battery packs. Workhorse ADCPs can be upgraded with a firmware option specifically designed for LADCP work. Installation of the LADCP firmware is not required for LADCP work, however. When the LADCP firmware option is installed, the ADCPs calculate bottom-tracking information from regular (water-tracking) pings. Without this firmware upgrade, bottom-tracking data has to be calculated during processing (Visbeck, 2002). In principle, the bottom-tracking information calculated by the ADCP firmware can be better than the post-processed bottom-tracking data, because the former can detect the distance from the seabed with higher vertical resolution but at present there is no evidence for a significant difference in bottom-tracking data quality.

RDI 150 kHz Broadband ADCP (BB150). This older instrument type performs significantly better than WH300s, in particular in regions of low acoustic scattering. However, its production has been discontinued and the remaining instruments have been deteriorating markedly.

Although at the time of writing these are the only instruments commonly used in LADCP systems, other options may become available in the future. In particular, there is a 150 kHz ADCP under development by Teledyne/RDI that will hopefully perform at least as well as the obsolete BB150. (It appears that there is no substitute for the improved range that a lower frequency can provide.) Other manufacturers may also be able to supply suitable instruments.

3. INSTRUMENT MOUNTING CONSIDERATIONS

Before installing the LADCP hardware on the instrument platform it is recommended that the fully connected system is thoroughly tested as detailed in Section 5.3 below. An LADCP system typically consists of several separate components (Section 1.3) that must be attached securely to the instrument platform. Additionally, it is recommended that each component is attached to the frame with a lanyard to prevent loss in case the primary mounting hardware fails. If the LADCP components are attached to the frame using nuts and bolts, as is usually the case, these should be checked periodically (e.g., daily) and tightened when necessary.

Usually, there is hardware that is not part of the LADCP system installed on the platform as well. Typical examples include CTDs, sampling bottles, optical instruments, altimeters, etc. Care has to be taken that the different instruments do not interfere with each other. For example, no LADCP component should be placed in close proximity to CTD sensors in order to avoid hydrographic measurement errors due to flow distortion. Conversely, a bottom switch triggered by a weight suspended some distance below the instrument platform should generally not be used in conjunction with a downward-looking ADCP, as the acoustic echo from the suspended weight can seriously degrade LADCP data quality.[1] Acoustic altimeters, an alternative to bottom switches, can also be problematic: While they do not seem to degrade LADCP data quality, they often cease to work reliably when used in combination with an LADCP system. Overall, with suitable data editing algorithms, there does not appear to be any evidence for degraded LADCP data quality caused by typical acoustic instrumentation used for oceanography (multi-beam, shipboard ADCP, bottom pingers, navigation transponders, other ADCPs, etc.)

An important consideration when mounting the instruments on the platform is the overall weight distribution: The fully loaded instrument platform should be balanced so as to minimize tilts during deployment and recovery, as well as while the instruments are in the water.

The ADCPs are the most important components of LADCP systems. ADCPs should be installed as close to horizontally as possible — a few degrees off the horizontal does not significantly affect the data quality, however. Since ADCPs contain compasses, they should be mounted as far away as possible from hardware associated with significant magnetic fields, which includes some battery packs. This is particularly important because it is usually not feasible to calibrate the ADCP

[1] Under some circumstances (short suspension line, long blanking distance, sufficient instrument range) it is possible to use bottom switches without adversely affecting the LADCP data quality. In this case it is very important to discard data from bins that may be influenced by either along-beam or side-lobe echoes from the weight or suspension line.

compasses on a fully loaded instrument platform (see also Appendix B). If only a single ADCP is used it should be installed as a downlooker. The ADCP beam paths must not be obstructed. In case of the downlooker this can usually be ensured by installing the ADCP near the lower frame of the platform (Figures 1 and 2) and avoiding any equipment extending below the platform, such as bottom switches.

Uplookers can be installed to extend above the platform frame (Figure 3), but care has to be taken to rotate them so that the hydrographic wire passes between two beams. While the relative orientation of the ADCPs in a dual-headed setup does not affect data quality, aligning the up- and downlookers allows compass, pitch and roll measurements to be compared directly, which can be useful for diagnosing problems. When installing ADCPs care must be taken to protect the sensitive transducer faces. In particular, no ADCP should ever be placed transducer-down on a hard surface.

LADCP battery packs also require special mounting considerations. In addition to their effect on the overall platform balance due to their weight, some batteries must be mounted in a specific orientation (Figure 4). Some rechargeable battery types furthermore have venting ports that must be opened during charging and closed when submerged. Since those venting ports are closed and opened before and after each cast, they should be easily accessible and visible. To further complicate matters, some battery packs are associated with sizeable magnetic fields that can induce compass errors in nearby instruments. Therefore, battery packs associated with magnetic fields should be installed as far as possible from instruments containing compasses, including the ADCPs used in an LADCP system.

Once the main LADCP hardware has been installed on the instrument platform, a full suite of power and communications tests should be carried out before running the cables within the frame of the instrument platform. The cables should be routed so that they can be replaced as easily as possible (cable failures are a common hardware problem of LADCP systems). Care must be taken not to bend the cables in tight loops. Furthermore, the cables should not be run along the outer parts of the frame, where they can easily be damaged during deployment and recovery, or on any other part of the frame that is likely to be grabbed or stepped-on. Particular attention should be paid to the charging and communications pigtails to allow easy access to the plugs while at the same time preventing whipping motion when submerged. One recommended option consists in using bungee cords to fasten the pigtails to a radial frame strut or to a sampling bottle (Figure 5). Alternatively, Velcro or releasable cable ties can be used for the same purpose. The pigtails should be installed high on the frame in order to avoid the connectors to be dripped on. Furthermore, the pigtail connectors should point downward to avoid kinking under the weight of the deck cables. Before the cables are tie-wrapped to the instrument platform another full suite of power and communications tests should be carried out.

4. POWER SYSTEM

The LADCP power system consists of battery, power supply (battery charger), cables and connectors. Due to the high power requirements of ADCPs when pinging rapidly, the use of disposable batteries is not recommended. Rechargeable batteries in a pressure case typically require a vent port that must be open during charging to prevent buildup of hydrogen, but closed while submerged. Furthermore, water must be prevented from entering the pressure case while the venting port is open. This can be accomplished, for example, by replacing the venting plug with a short piece of silicone tube pointing downward during battery charging. If the tube is marked with a red flag, for example, it will be harder to forget to close the venting port for deployment. While rechargeable batteries in pressure housings with venting ports have been used safely for many years, more recently batteries in oil-filled plastic cases have become common in LADCP systems (Figure 4). Because of their ready availability, safety and ease-of-use this type of battery is highly recommended.[2]

The bench power supply of LADCP systems serves two separate purposes: 1) It provides power to the ADCPs during instrument setup and data downloading. 2) It is used to charge the batteries between casts. Chargers recommended by the battery manufacturers can be used, but programmable power supplies provide better monitoring and more control over current and voltage. In addition, dedicated "smart" chargers may not work correctly with very long cables, or with cables that include diodes to prevent the battery voltage from appearing on the charging cable.

The connector gender on the power pigtail of the octopus cable is usually female. Since the connector of the cable connecting the pigtail to the power supply is therefore male, great care has to be taken not to (dis-)connect the power cable while the power supply is turned on, and also to dummy up any disconnected deck-cable connector. The voltage required by many ADCPs (approximately 50V) is high enough to be dangerous, in particular on a wet deck, and an LADCP battery charger can deliver a substantial current. An unprotected male plug with power applied is easily short-circuited by contact with a metal object, typically destroying the connector and rendering the cable useless.

For all components of the LADCP power system, a full set of spares (including fuses) should be available. A multimeter is a minimum prerequisite for trouble shooting. For additional information on cables and connectors, see Section 6 below.

5. COMMUNICATIONS SYSTEM

5.1 Hardware

The communications hardware of an LADCP system consists of a data-acquisition computer with 1 or 2 serial ports, as well as a variety of cables, adapters and converters. All the ADCPs the authors are familiar with use either the RS-232 or the RS-422 serial-communications standards.[3] Both options are slow and neither of them is natively supported by many modern computers. The maximum cable length allowed by the more widely used RS-232 standard is 50 feet (<20m); longer cables often work, but sometimes at the price of reduced communications speed. Cable length is not an issue for RS-422, but because RS-422 interfaces are uncommon and connectors are not standardized, assembling the necessary converters, cables, and connectors can be troublesome.

Today's data-acquisition computers usually have no built-in RS-232 or -422 serial ports. The problem can be solved with plug-in interface cards (e.g., CardBus or ExpressCard for laptops) or with suitable USB-to-RS232[4] converters but the converters should be tested with the actual data acquisition

[2] Most of the potential safety problems associated with rechargeable batteries in pressure cases can also be avoided if the pressure cases are equipped with safety valves instead of venting ports.

[3] RS-232 is a 3-wire system in which the transmit and receive circuits share a ground return, while RS-422 uses separate twisted pairs with differential signals. Hence RS-422 can tolerate much greater cable lengths and higher electromagnetic noise environments than RS-232.

[4] A variety of Keyspan converters have been used successfully by the Lamont group.

computer and the ADCPs before buying because many of them do not correctly handle the BREAK condition, which is used to wake up sleeping or interrupt pinging ADCPs. While most USB-to-RS232 converters deliver only a 5V signal level (RS-232 allows up to 15V), some special converters use higher signal levels allowing the use of longer cables. Since the maximum USB cable length is only 5m, USB cannot be used to overcome RS-232 cable-length restriction. There are different possibilities for increasing the length of LADCP communications cables. One consists in using the RS-422 standard. Another is based on USB-to-RS232 converters and USB cable extenders that use CAT-5 patch cables. (Even the slow USB 1.1 can easily handle parallel downloading from 2 ADCPs at full speed.)

Since communications with ADCPs is slow, the data from both heads of a dual-headed LADCP system should be downloaded in parallel, which requires separate communications ports and lines for the two instruments. Some octopus cables provide separate communications pigtails for each instrument and there are others which use only a single cable/connector, in which case a "Y-cable" is used to split the lines back out for serial communication. In the case of long or improperly shielded cables providing two communications lines, "cross-talk" can occur. (For example, a BREAK sent to one instrument can be received by both.)

For additional information on cables and connectors see Section 6 below.

5.2 Communications Software

ADCP manufacturers provide Microsoft-Windows-based software for programming the instruments and downloading the data. For Teledyne/RDI ADCPs, at least two groups have developed open-source communications-software packages that allow parallel data downloading from dual-headed LADCP systems. The UH communications software[5] runs on Linux and MacOSX systems; the LDEO communications software[6] runs on Linux, FreeBSD and MacOSX systems. General-purpose terminal emulation programs can also be used. Teledyne/RDI ADCPs use the ymodem protocol for data downloading.

5.3 Installation and Testing

The communications part of a fully installed LADCP system is often quite complex, involving several different cables, and often also protocol converters. Diagnosing and fixing problems can be tricky, especially once the LADCP hardware has been installed on the instrument platform. It is, therefore, highly recommended that the system is tested, both before shipping but also, repeatedly, during the installation process. A typical LADCP installation with frequent incremental testing of all components can proceed as follows:

1. Verify the operation of the ADCP(s) by connecting each of them in turn to the acquisition computer using a short communications/power cable and bench power supply. Use each serial port at least once for this test.
2. Carry out the same tests with the octopus cable instead of the short communications/power cable. In case of a dual-headed system, connect both ADCP heads and test, in particular, parallel data downloading.

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[5] Available from http://currents.soest.hawaii.edu/ladcp
[6] Available from ftp://ftp.ldeo.columbia.edu/pub/LADCP/acquire

3. Connect the battery pack to the octopus cable, disconnect the bench power supply and carry out the same tests.
4. Connect the power supply and verify that the battery is charging.
5. One-by-one add the required extension cables, testing the system after each addition.
6. Lay out the ADCP(s) and battery on deck near the instrument platform, run the communications and power cables from the acquisition computer and test the system once more.
7. Mount the ADCP(s) and battery on the instrument platform and test the system before installing the cables.
8. Install the cables on the platform and test once more.
9. Tie-wrap the cables and perform a final thorough test of all aspects of the system.

6. CABLES AND CONNECTORS

Cable/connector problems are a likely cause of hardware failure of LADCP systems. Because of the inherent complexity, involving different cables and often also communications protocol converters (Section 5.1), cable/connector problems can be hard to diagnose. The fact that cables/connectors sometimes deteriorate slowly over time adds to the trouble-shooting difficulties. It is therefore recommended that LADCP operators keep careful logs of glitches, even if they are minor and appear to be easily correctable. Additionally, it is recommended that the LADCP toolbox contain a variety of special purpose cables that are useful for trouble-shooting purposes. In contrast to the octopus cable, these special-purpose cables typically have only a single function, which helps in isolating problems. Typical special-purpose cables include power-only (also for battery charging), communications-only and communications-with-power.

Once diagnosed, the easiest way of dealing with a cable/connector problem consists in replacing the faulty cable with a spare. There should therefore be spares for all components of the LADCP cabling system, including at least one complete spare for each cable, bulkhead connector, as well as short cables with connectors on one end and unterminated ends at the other.

If no spares are available it may be possible to assemble a replacement on the ship, provided that the required cable, connectors and tools are available. A basic cable-repair tool kit includes at least some basic tools, testing equipment (e.g. multimeter, serial breakout box, etc.) spare cables/connectors, electrical tape, as well as connector-specific tools.

It is worth noting that LADCP operations with WH300 ADCPs is possible without octopus cables, because the instruments automatically restart pinging after power failures. In order to program such an ADCP, it is connected to the benchtop power supply and to the data acquisition computer with a communications /power cable. After the ADCP has been programmed and is pinging it can safely be disconnected from the power supply & acquisition computer, as it will automatically re-start pinging once it is connected to the battery with a short power cable. After the cast has been carried out, the ADCP can be disconnected from the battery and connected to the acquisition computer and benchtop power supply for data downloading. Of course, battery charging has to be done with a separate cable under those circumstances.

Preventive maintenance and handling care can significantly prolong the life of cables and connectors. During installation of the cabling on the instrument platform it should be ensured that the cables are not bent in tight loops or crimped. The connectors, in particular those on the power and communications pigtails, should be kept lubricated in accordance with the manufacturer's instructions. It is furthermore recommended that even wet-mateable connectors are rinsed with freshwater before (un-)plugging. Many connector types should not be unplugged by pulling on the cables. The most likely connectors to fail are the communications and power pigtails on the octopus cable. Since this is typically the most expensive cable of an LADCP system, it is recommended that short extension cables are used as pigtails. The only off-the-shelf octopus cables for dual-headed LADCP configurations are for WH300 systems. Cables may also be custom-ordered from connector and cable manufacturers, providing more freedom of design. Note, however, that superficially identical connectors from different manufacturers sometimes turn out to be incompatible in practice; the safest procedure is to ensure that both connectors in any pair to be used under water are from the same manufacturer. In particular, this includes the bulkhead connector on the ADCP itself.

For improved safety, power- and octopus cables can be designed with a diode between the charger and the battery to keep the battery from discharging (e.g. due to a short circuit) through the charger pigtail. While this design improves safety it has the disadvantages that the battery voltage cannot be checked on the charging cable and that "smart" battery chargers cannot be used with this type of cable. Programmable power supplies impose no such limitation.

7. INSTRUMENT CONFIGURATION

Before each cast, the ADCP(s) have to be configured by sending a set of commands. The available commands vary with instrument type and, as in the case of the WH300 series, with the firmware version and installed options. The following settings are common to Teledyne/RDI broadband ADCPs; instruments from other manufacturers will differ in some aspects:

Factory Defaults. In order to ensure that a command file always has the same effects, it is advisable that the ADCPs are first returned to their factory defaults.

Depth-Cell (Bin) Size and Pulse Length. The data-processing cell size is typically equal to the transmitted pulse length, but need not be. Either or both may be decreased in order to increase vertical resolution, but reducing the pulse length reduces the range and accuracy, both of which are crucial for LADCP work. For open-ocean full-depth profiling with WH300 ADCPs, 8–10m works well for both the bin- and pulse lengths; for the older BB150 instrument, 16m bins are commonly used. In regions characterized by low scattering, increasing the cell size and pulse length can sometimes improve the LADCP data quality.

Number of Depth Cells. This parameter should be set to correspond approximately with the maximum range of valid data. Setting it too small artificially restricts the range, potentially reducing the accuracy of the full LADCP profile; setting it too large increases data-file size and download time — which can be a problem with closely-spaced deep stations — and in extreme cases would also reduce the ping rate.

Ensemble Size (Number of Pings to Average). It is recommended to record single-ping data, as this provides the maximum flexibility in editing.

Blank After Transmit. This parameter defines the distance between the ADCP and the bin closest to the instrument. If the first bin is too close (i.e. if the velocity is measured too soon after the transducer has transmitted the acoustic pulse) the resulting velocity data are contaminated by "ringing". The default blanking interval recommended by Teledyne/RDI, half the pulse length, is typically too short for LADCP work. For WH300 ADCPs it appears that the velocity data in the first bin are always of inferior quality. Therefore, it is recommended to set the blanking distance to zero for these instruments and to discard the data from the first bin.

Velocity Coordinate System. Two coordinate systems are widely used for recording ADCP velocities: 1) Instrument or beam coordinates, i.e. the raw along-beam velocities are stored in the data files. 2) Earth coordinates, i.e. zonal, meridional and vertical velocities are stored. For LADCP work either coordinate system can be used, but beam coordinates are recommended; they have no disadvantages and provide maximum accuracy and flexibility in editing and in calculating the velocity. Earth coordinates must be used, on the other hand, in extraordinary circumstances that require multiple pings to be averaged in the instrument.

Sampling Rate. In principle, the ADCP(s) should ping as quickly as possible to maximize the number of samples and thereby minimize the standard errors of the velocities. In practice, however, it has been found that the overall LADCP velocity quality is not a strong function of pinging rate (Thurnherr, 2009), consistent with theoretical arguments (Visbeck, 2002). Additional considerations include the advantages of using "staggered pinging" to deal with previous-ping interference, which is particularly important for low-frequency instruments (Firing, 1998), and the assumption made in some processing software packages of a regular pinging rate. For dual headed WH300 LADCP systems, staggered pinging with alternating sampling intervals of 1.5 and 2.0 s works well. These should also work for the BB150, although to date the UH group has typically used 1.0 s and 1.6 s.

In addition to those common parameters there are other, instrument-specific, settings that usually have to be configured for LADCP work. Example command files for WH300 ADCPs, which are widely used for LADCP work, are part of the LDEO data acquisition software (Section 5.2). The following recommendations are based primarily on experience with Teledyne/RDI ADCPs but they may also be applicable to other instruments:

Bottom Tracking. Bottom-tracking data provide important constraints for LADCP velocities near the seabed (Section 1.2). In the case of RDI ADCPs, dedicated bottom-tracking pings can be interspersed with regular (water-tracking) pings to obtain bottom-tracking data of very high quality. Dedicated bottom tracking pings are sometimes used in LADCP work (e.g. Cunningham et al., 1997), although it is not clear whether this improves the overall data quality because of the reduced water-track pinging rate. Furthermore, bottom-tracking information can also be extracted by post-processing regular water-track data (Visbeck, 2002), although at a reduced range. In the case of WH300 ADCPs with the LADCP firmware upgrade installed, post-processing of water-track data is carried out by the instrument.

Synchronized Pinging. When using dual-headed LADCP systems, sampling of the two ADCPs should either be synchronized (if supported by the ADCPs) or slightly different sampling rates should be used for the up- and downlookers to ensure precession of the acoustic interference. When synchronized pinging is used, either instrument may be the master, although it is more conventional to use the downlooker in that role.

Instrument Range. The instrument range is the primary factor affecting the quality of LADCP velocity profiles (Visbeck, 2002). If there are tunable parameters that affect the instrument range, they should generally be set for maximum range. In particular, the user-selectable bandwidth setting of Teledyne/RDI broadband ADCPs should be set to the narrowest bandwidth, sacrificing some single-ping accuracy for improved range.

Ambiguity Velocity. This parameter should be set to a value somewhat greater than the maximum along-beam velocity the ADCP is likely to encounter. The maximum along-beam velocity is typically slightly less than the sum of the maximum winch speed and the maximum vertical speed associated with wave-induced ship motion. Increasing the value of this parameter slightly degrades the accuracy of single-ping velocity data.

8. ANCILLARY DATA

8.1 Hydrographic Time-Series Data

In order to apply sound-speed and depth corrections, time series of temperature, salinity and pressure should be recorded with a temporal resolution that is approximately equal to (or better than) the ADCP sampling rate. (Either sub-sampled or averaged 1Hz data usually work well.) In most cases hydrographic time series are easily obtained because LADCP systems are usually installed on instrument platforms that also house a CTD. Note, however, that CTD time series are not commonly used outside LADCP processing and that pressure- or depth-binned CTD profiles *cannot* be used instead of time-series data. A simple ASCII file format is recommended for recording the time-series data. Data gaps are difficult to deal with and should, therefore, be avoided at all cost.

Depending on the processing software used, the hydrographic time series are matched to the ADCP data based on time or on vertical velocity (or depth, vertical acceleration, etc.). For software that only implements matching based on time, clock offsets can be determined manually from time series of depth (integrated vertical velocities in the case of the LADCP data) or vertical velocity (time-derivative of depth for the CTD data). When using absolute times characterized by large number (e.g. Julian dates) for the timestamps of the hydrographic time series, care must be taken that the time field has enough digits to resolve the sampling interval.

8.2 Navigational Data

Precision navigation from a shipboard GPS receiver is essential for estimating the ship's drift during the LADCP cast. Although this requires only the positions at the beginning and end of the cast, the effective cast start and end times may be adjusted during processing, so it is desirable to have GPS time series available.

Ship drift provides an important velocity-referencing constraint, implying that deployment/recovery positions are known as accurately as possible — uncertainties of ~30m or better are achievable with modern GPS systems with antennas installed close to the hydrographic wire or when the ship's heading is held approximately constant during a cast. In contrast to the hydrographic time-series data, offsets between the LADCP and the GPS clocks cannot be determined from a property measured by both instruments. The following methods can be used to deal with LADCP/GPS clock offsets:

Prevent clock offsets. This can be accomplished by synchronizing all instrument clocks to a common (UTC) time source at the beginning of each cast. If significant clock drift during LADCP casts is suspected, it is useful to log clock offsets after each cast.

Co-record navigational with CTD data. Any navigational/CTD clock offset can then be determined as indicated above. This option may not be available for all CTD systems.

8.3 Shipboard ADCP Data

Shipboard ADCP data can be used to constrain the LADCP velocities near the sea surface. Present processing-software packages that use shipboard ADCP data calculate cast-averaged velocity profiles before use, i.e. the temporal resolution of the shipboard ADCP data does not have to be very high. (The 3- or 5-minute averages that are available in near-real-time on many oceanographic vessels are suitable for LADCP processing.) Furthermore, small offsets between the LADCP and the shipboard ADCP clocks are not usually a problem, either.

The complexities associated with processing underway shipboard ADCP data are largely absent for on-station data. Therefore, it is usually sufficient to use minimally processed shipboard ADCP data for LADCP processing.

8.4 Bottom-Tracking Data

Any downlooking ADCP recording data while in acoustic range of the seabed collects data from which bottom-tracking velocities can be extracted. In the case ofWH300 ADCPs, bottom-tracking velocities are calculated internally by the instrument if the LADCP firmware upgrade has been installed. Many ADCPs allow collection of high-quality bottom-tracking velocities using dedicated bottom-tracking pings — this requires special set-up in the command file (Section 7).

9. LADCP CAST LOGISTICS

Below, all steps that are taken during a typical LADCP cast are listed. It is assumed that the battery is charged, and that all data from previous casts have been downloaded, checked and backed up. Since LADCP systems are often considered somewhat peripheral to the CTD effort, the following procedure is designed not to interfere with standard CTD acquisition logistics.

1. Some time (not too much; 10–20 minutes recommended) before a cast, wake the ADCP(s) and clear the memory.[7] It may also be useful to carry out ADCP systems tests at this stage. Log information on the battery charge level, if available. Inspect LADCP system for lose bolts, unmated connectors, open battery venting port, etc.
2. Just before (5–10 min) the ship comes on station, begin data acquisition of the ADCPs of the LADCP system. Unless the ADCP clocks are automatically synchronized with a master clock at this stage, record any ADCP clock offsets. If possible, verify that the instruments are pinging. Once on station, log relevant metadata (station numbers, time, location, water depth,[8] file names, etc.).
3. Turn off power supply (charger), if it is still on.
4. Ensure that battery vent port is closed.
5. Disconnect and dummy-up charging and communications cables. (Dummy-up both the pigtail and the deck-cable connectors!) Secure pigtails to instrument platform to prevent whipping while deployed.
6. Inform CTD watch leader that the LADCP system is ready for deployment.

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[7] The memory must only be cleared once the data from the previous cast have been successfully downloaded, backed up and verified; see step 12. LADCP data acquisition does not require the memory to be empty.

[8] Note, however, that water depths recorded at this stage can be inaccurate, especially for stations carried out on slopes.

7. A normal CTD cast should now be carried out, with the following LADCP-specific considerations:
    - CTD should acquire data before it enters the water and continue doing so until it leaves the water;[9] standard CTD "sensor soaking protocols" do not affect LADCP data quality;
    - log time the instrument enters the water;
    - many acoustic altimeters used to monitor the seabed approach of CTD systems do not work reliably when used in conjunction with an LADCP system; bottom switches should not be used as an alternative (Section 3);
    - winch speed during descent should be slow enough to keep instrument tilt <10°;
    - in order to minimize the data gap near the seabed of downlooker-only LADCP systems, either minimize bottom-stop durations or carry out bottom stops >30m above the seabed;
    - a 2-minute stop somewhere between 30m and 100m above seabed can be used to increase the amount of bottom-tracking data;
    - bottle stops do not affect LADCP data quality and they can help in matching the LADCP and CTD time series (Section 8).
8. Immediately after the CTD has been secured to the deck after a cast (i.e., before any water sampling starts) rinse, dry and connect the communications and power pigtails.
9. Open battery venting port (if using a vented battery), ensuring that no water enters the battery housing.
10. Log battery charge (if available) and other relevant information; turn on battery charger.
11. Stop LADCP data acquisition and begin data downloading; record time.
12. Once the ADCP data have been downloaded, they should be checked and backed-up to external storage as soon as possible. Full processing can be carried out or, for a quick and useful test, the depth-vs-time instrument trajectory estimated by integrating the measured vertical velocities can be inspected.
13. Once the battery has been fully re-charged, turn off the charger and close the battery vent port (if available).

10. REFERENCES

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[9] Some groups like to switch their CTDs off shortly before they leave the water in order to avoid contamination by surface slicks.

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ANNEX 1. COMMON PROBLEMS AND SUGGESTED SOLUTIONS

LADCP systems are complex and there are many things that can go wrong. Some of the more common problems include:

Insufficient Range. In regions where there are insufficient acoustic scatterers in the water column for the type of ADCPs used, no full-depth absolute velocity profiles can be constructed from the LADCP data. Usually, the problem is worst at mid-depth, leading to gaps in the data. Using specialized processing, it is often still possible to infer absolute velocities near the seabed (constrained by bottom tracking) and near the sea surface (constrained by shipboard ADCP data), however. Since the attenuation of sound increases with increasing acoustic frequency the severity of this problem is instrument dependent, with lower frequency instruments typically performing significantly better. Increasing the cell size and pulse length can sometimes improve the LADCP data quality (Section 7).

In regions of marginal range it is often very difficult to determine whether the range in a particular cast was sufficient. In those situations there is a danger that bad LADCP profiles may not easily be recognized as such.

Discharged Batteries. A dropping battery voltage causes reduced instrument range with the associated problems described above. Once the battery voltage drops below an instrument-dependent threshold, the ADCPs turn off. While this does not typically lead to a loss of the recorded data with modern instruments, incomplete casts cannot be processed with standard techniques. Lead-acid batteries should not be fully discharged as they can be difficult or impossible to be re-charged afterward.

Compass Errors. A common source of compass errors are magnetic fields associated with equipment installed close to the ADCPs. Since these errors are difficult or impossible to detect from the data, care must be taken to minimize this problem when installing the instruments on the platform (Section 3). A second type of compass errors occurs when LADCP work is carried out at high latitudes near the magnetic poles where the field lines of the Earth's magnetic field are aligned close to vertical. In extreme cases ADCP compasses do not yield any meaningful data in those regions. It might be possible to avoid both types of compass errors by using an external gyrocompass installed on the instrument platform.

Instrument Tilt. In order to minimize tilt (pitch/roll) errors care must be taken that the mean instrument tilt remains small and that the instrument acceleration due to wave-induced ship motion is minimized. In particular, it appears that sustained tilt angles >10° can seriously degrade LADCP data quality. In order to reduce instrument tilt, the center of mass of the instrument platform should be as low as possible and the weight should be horizontally uniformly distributed (Section 3). Instrument tilts are usually largest during downcasts — if sustained instrument tilts >10° occur during downcasts the winch speed should be reduced, or additional weights should be added to the lower part of the instrument platform.

Bad Cables/Connectors. This is one of the most frequent hardware failures of LADCP systems. Cable problems can be surprisingly difficult to detect because the failures can be "creeping" beginning with apparently innocuous symptoms. Cable/connector life can be increased by following the manufacturer's guidelines regarding handling, lubrication, etc. For more recommendations, see Section 6.

Weak/Bad Beams. Some variability in performance between the individual ADCP beams is normal. If one beam has a significantly worse range than the others and/or it is markedly deteriorating from cast to cast, it will probably fail soon. Failure of a single beam is not usually catastrophic, as high-quality LADCP data can be calculated from three-beam solutions (Thurnherr, 2009). Once a beam has become suspicious, it is recommended that the affected casts are processed both with and without the data from the affected beam and the resulting solutions compared.

Switched Beams. When re-assembling some ADCPs (notably WH300 instruments) it is quite easy to misconnect transducers. This problem can be difficult to diagnose from the data, in particular which beams have been switched. Once the affected beams have been identified, the problem can easily be corrected during processing.

Sometimes it is necessary to replace an ADCP with a spare. In the simplest case, the main and spare instruments are of the same type. Even apparently identical instruments can, however, behave differently depending on the installed firmware version and options. Of particular importance for WH300 ADCPs is whether the LADCP firmware option is installed as this will have to be reflected in the instrument-configuration files (Section 7). If an instrument has to be replaced by one of a different type, the entire configuration (e.g. bin length, number of bins, etc.) should be verified and, furthermore, there may be significant differences in communications hardware and parameters (serial and file-transfer protocols, etc.).

ANNEX II: CRUISE PREPARATIONS

Cruise preparations should begin early, allowing for acquisition of all required materials, thorough bench testing of the complete system, training of support personnel, shipping to the port of departure, as well as contingencies.

For most autonomous operations, ADCP compasses should be calibrated before a deployment. In order to calibrate the compasses of an LADCP system, the fully loaded instrument platform would have to be moved away from the ship's immediate proximity, which is not usually feasible. However, it is recommended that the ADCP compasses be checked and nominally calibrated if necessary before an LADCP survey.

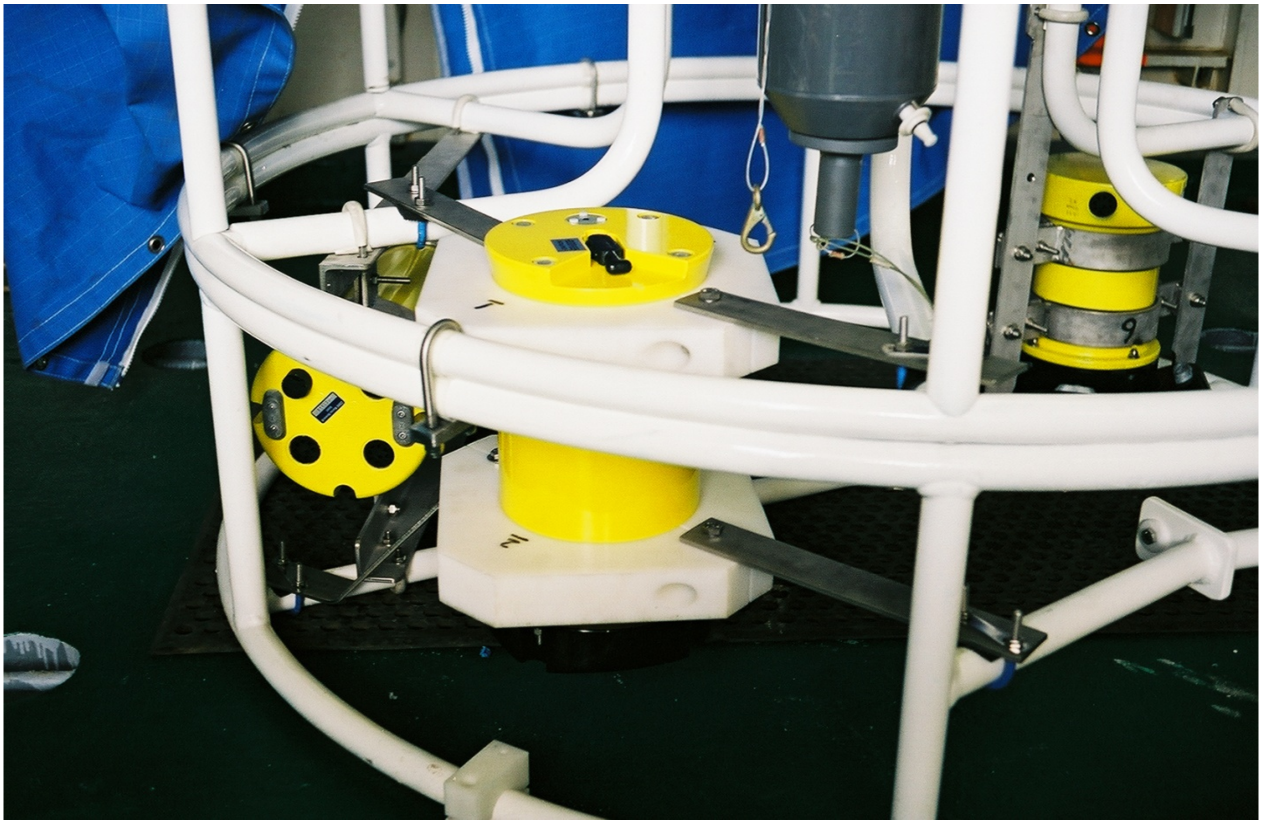

Figure 1. Teledyne/RDI Workhorse Monitor installed as a downlooker using custom-made brackets on an empty CTD rosette.

Figure 2. Teledyne/RDI Workhorse Sentinel installed as a downlooker using a plastic grate and safety lanyard on a fully loaded CTD rosette.

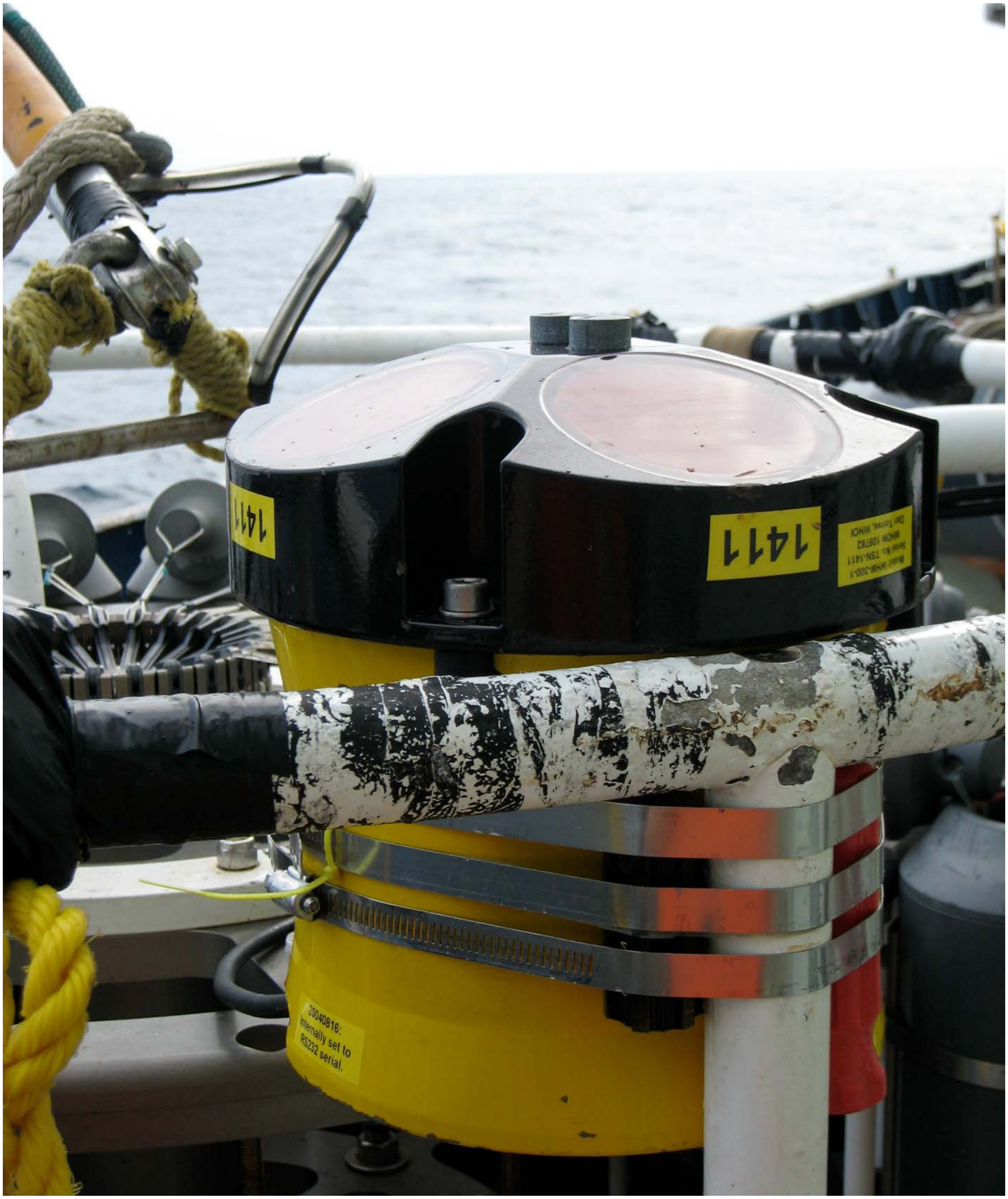

Figure 3. Teledyne/RDI Workhorse Sentinel installed as an uplooker using hoseclamps and screw-driver handles on a fully loaded CTD rosette.

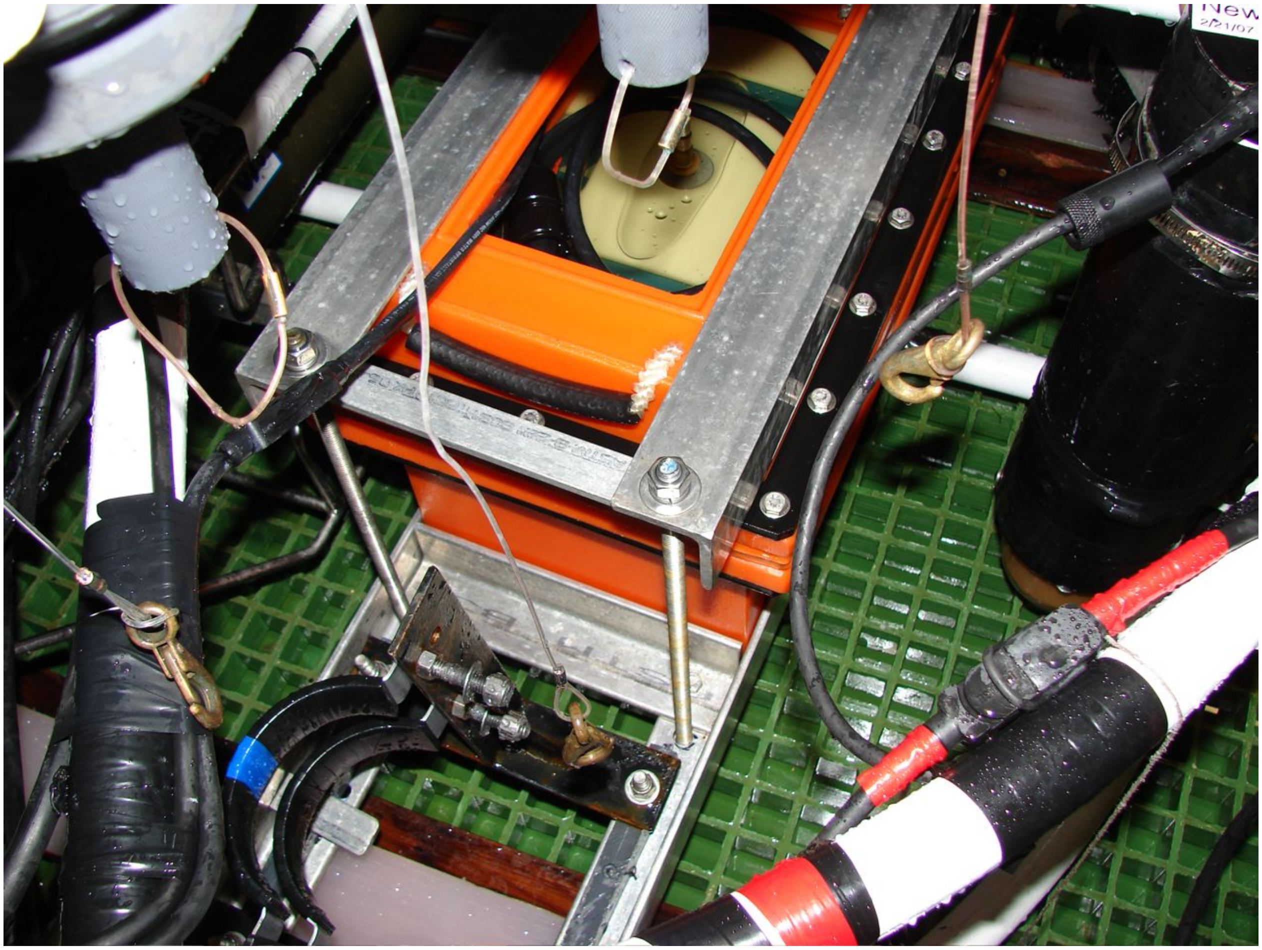

Figure 4. DeepSea Power & Light battery in oil-filled orange plastic case installed on a CTD rosette using custom-made brackets. This type of battery has a venting port that must point upward.

Figure 5. Octopus pigtail attached to a CTD sampling bottle with bungee cord. In this image, the pigtail is connected to the deck cable. When disconnected, the dummied-up lose end is tucked under the lower loop of bungee cord.