2017 P18 GO_SHIP Repeat Hydrography Section
LADCP Post-Cruise QC Report

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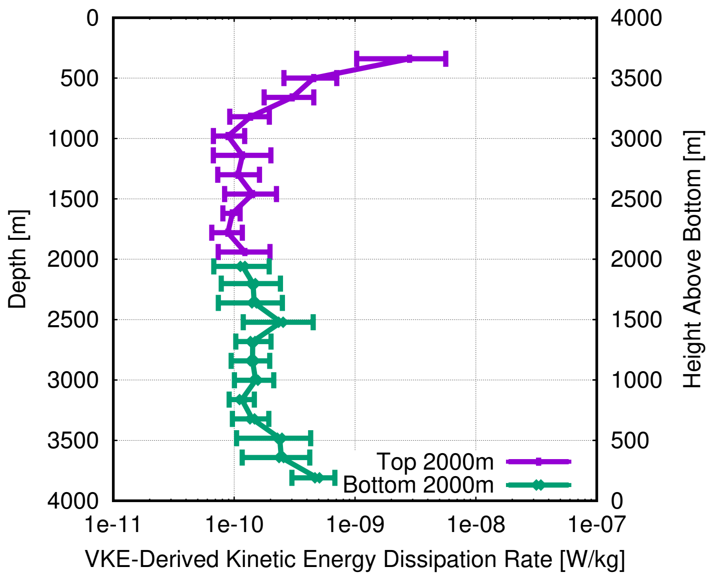

Figure 1: Section averaged profile of kinetic energy dissipation estimated from LADCP-derived vertical velocities using a finestructure parameterization method. Data from the top 2000 m are plotted against depth (left axis); data from the bottom 2000 m are plotted against height-above-bottom (right axis). Error bars are from bootstrapping.

1 Summary

This report describes the results from the post-cruise quality control of the LADCP data collected during the two legs of the 2016/17 P18 GO-SHIP (CLIVAR repeat hydrography) cruise on the NOAA Ship *Ronald H. Brown.* Using two ADCPs installed on the hydrographic rosette (Section 2), one looking downward (DL) and the other upward (UL), full-depth profiles of all three components of the oceanic velocity field were collected at most stations. Entirely different methods are used for processing LADCP/CTD data for horizontal and vertical velocity, requiring separate QC (Sections 3 and 4, respectively). As an important side-goal of the LADCP work, a new hardware upgrade for Teledyne/RDI 150 kHz Workhorse (WH150) instruments was tested on this cruise (Section 5).

Main Results: 1) There is good overall agreement ($\Delta u_{\rm rms} \approx 4\,{\rm cm{\cdot}s^{-1}}$) between the independent upper-ocean horizontal velocity measurements from the LADCP and SADCP systems, indicating that the LADCP-derived horizontal velocities from the 2017 re-occupation of the P18 repeat-hydrography line are of excellent quality. 2) Based on correlations between the independent vertical velocity measurements provided by the two ADCPs, most of the LADCP-derived $w_{\rm ocean}$ profiles are of high quality as well, although signal levels are generally low and some of the profiles are adversely affected by CTD data-transmission problems during the cruise. 3) There are two groups of profiles[1] with elevated LADCP errors: 115–140, collected in a region of reduced acoustic backscatter, and ≈190-210, collected in heavy seas.

2 Instruments and Data Acquisition

Due to delays of the cruise, the LDEO scientist in charge of LADCP data acquisition during leg 1 was unable to participate. Data collection was carried out by volunteers J. Hooper and A. Stefanick. In addition to the shipboard QC carried out by Hooper, the data were transmitted to shore at least once per day for processing and monitoring by Thurnherr. During leg 2, co-Chief Scientist S. Purkey was responsible for LADCP data collection, and carried out shipboard processing and QC.

Three different ADCP instruments were used during this cruise. Initial configuration consisted of the WHM15O #19394 as downlooker and the WHM300 #12734 as uplooker. (WHM150 #19394 had not performed well during P16, but was upgraded by TRDI immediately prior to the cruise — see Section 5 for testing results.) During profile 215 one of the beams of the DL failed, and the spare WHM150 #24544, a brand new unit with upgraded power supply, was installed on the rosette as a replacement for profiles 219-227. The UL performed well throughout the entire cruise. All ADCPs were set up to record velocity data with 8 m pulses/bins and zero blanking. Staggered pinging was used to avoid previous ping interference, which is particularly important for 150 kHz instruments. See cruise report for additional information on the LADCP system and sampling logistics, including a list of missing profiles.

Figure 2 shows the maximum profile depths, as well as the number of net rotations experienced by the CTD package. Most profiles extended to ≈4000 m with deeper profiles toward the end of the 2nd leg (left figure panel). Package rotation was predominantly clockwise when viewed from above, with a clear break due to wire re-termination after LADCP profile 171 (right panel).

LADCP data quality is sensitively dependent on instrument range (Figure 3, left panel), which depends on the acoustic scattering environment. During most of the P18 cruise acoustic backscatter was comparatively strong, resulting in WH300 range exceeding 65 m (an empirical limit for good data) in most profiles, and WH150 range mostly above 150 m. Sea state is also known to affect LADCP data quality; in the right panel of Figure 3 sea state is quantified as the *rms* vertical package acceleration. There is a clear break around LADCP profile 150, with significantly rougher seas in the Southern Ocean.

3 Horizontal Velocity

The overall quality of the horizontal LADCP velocities is assessed by processing all profiles with the velocity-inversion method (LDEO_IX_13 software), using the bottom-track (BT) and ship-drift (GPS) constraints and comparing the resulting LADCP velocities near the sea surface to the corresponding

[1]LADCP profile numbers are used throughout in this report. The LADCP data distribution contains the file `STATIONNUMBERS.nc`, which associates LADCP profile numbers with CTD station and cast numbers. The CTD station and cast numbers are also printed in the titles of all diagnostic figures produced by the LDEO_IX software.

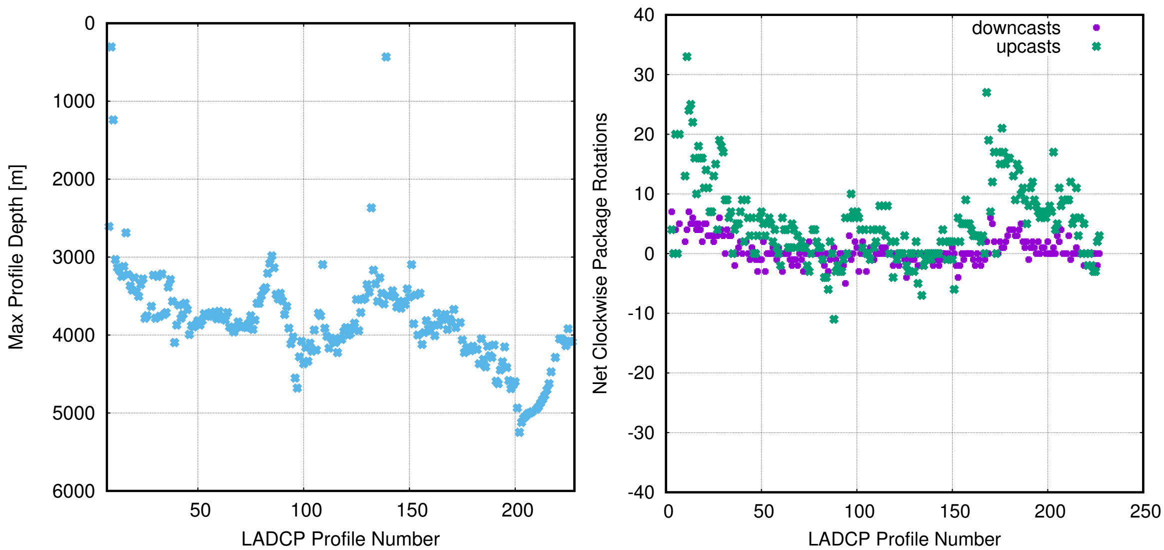

Figure 2: Profiling parameters. Left panel: Maximum depth. Right panel: Net package rotations.

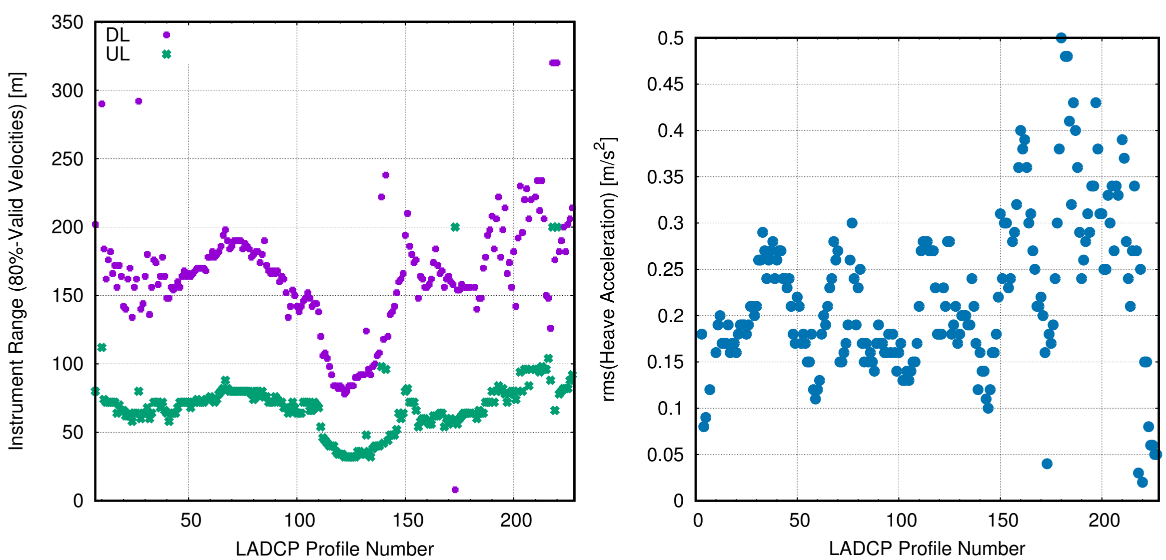

Figure 3: Left panel: Instrument range. Right panel: *rms* acceleration due to vessel heave (sea state).

SADCP velocities. Based on data from other cruises, high-quality LADCP and SADCP velocities typically agree within 3–6 $\mathrm{cm\cdot s^{-1}}$ when averaged over a few profiles. The data from the 2017 P18 occupation clearly fit this criterion (Figure 4). Two sequences of profiles with velocity discrepancies exceeding 6 $\mathrm{cm\cdot s^{-1}}$ were observed: 1) profiles 115–140 from the southern half of the subtropical gyre where acoustic backscatter is comparatively weak (Figure 3, left panel), and 2) profiles 190–210 from the Southern Ocean where the sea state was rough (Figure 3, right panel).

For final horizontal-velocity processing, the LADCP data were re-processed with all available

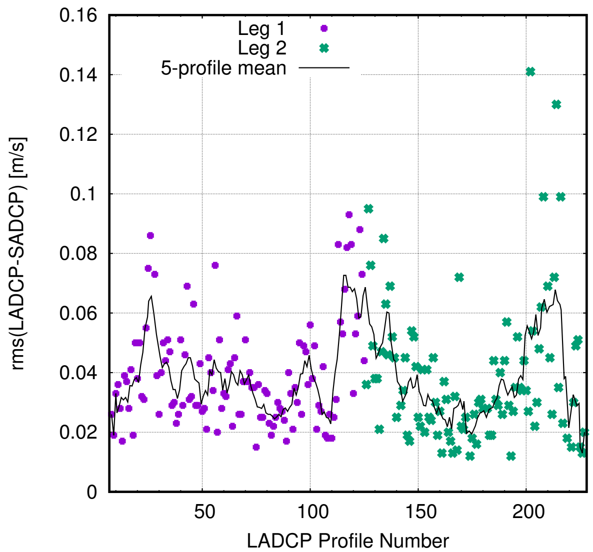

Figure 4: *rms* LADCP-SADCP horizontal velocity differences; low values indicate good agreement.

referencing constraints, including the SADCP velocities. As a result, the final velocity uncertainties are smaller than those shown in Figure 4, indicating that the quality of the 2017 P18 LADCP data is excellent.

4 Vertical Velocity

In order to process the LADCP data for vertical ocean velocity the `LADCP_w` software, version 1.3, was used. In addition to high-quality velocity data from the ADCPs, vertical-velocity processing also requires 24 Hz CTD time series with very few or no missing scans. Missing CTD scans appear to make the CTD clock run fast, resulting in time-lag offsets that "slip" during a profile (Figure 5). Such apparent CTD-clock drifts require manual intervention for processing and result in artifacts and gaps in the resulting w_{ocean} profiles. CTD data transmission problems during P18 were frequent, resulting in significant numbers of dropped scans in 47 out of the 213 profiles, which resulted in gaps in 21 of the processed w_{ocean} profiles.

In contrast to LADCP-derived horizontal velocity, the two w measurements at a given depth (from the DL and UL ADCP) are largely[2] independent. Diagnostics based on linear regressions between UL vs. DL-derived w are therefore useful measures of profile quality. Figure 6 shows two such statistics, calculated from w_{ocean} profiles processed at 40 m vertical resolution[3]: Correlation coefficients in the left panel and regression residuals scaled by $1/\sqrt{2}$ in the right panel. The scaled regression residuals can be taken as a quantitative estimate of the accuracy of the individual w_{ocean} samples in a profile. Based on experience with other data sets, high-quality LADCP profiles typically have DL-UL correlation coefficients above 0.3 and scaled regression residuals below $\approx 0.006\,\mathrm{m{\cdot}s^{-1}}$.

While the LADCP-derived vertical velocity profiles from the first leg of P18 (LADCP profiles up

[2]Only low-frequency errors in the CTD package-velocity time series give rise to ADCP-measurement errors that are correlated between the two ADCPs.

[3]Processing at the default 20 m vertical resolution yields similar, but somewhat inferior, results (not shown).

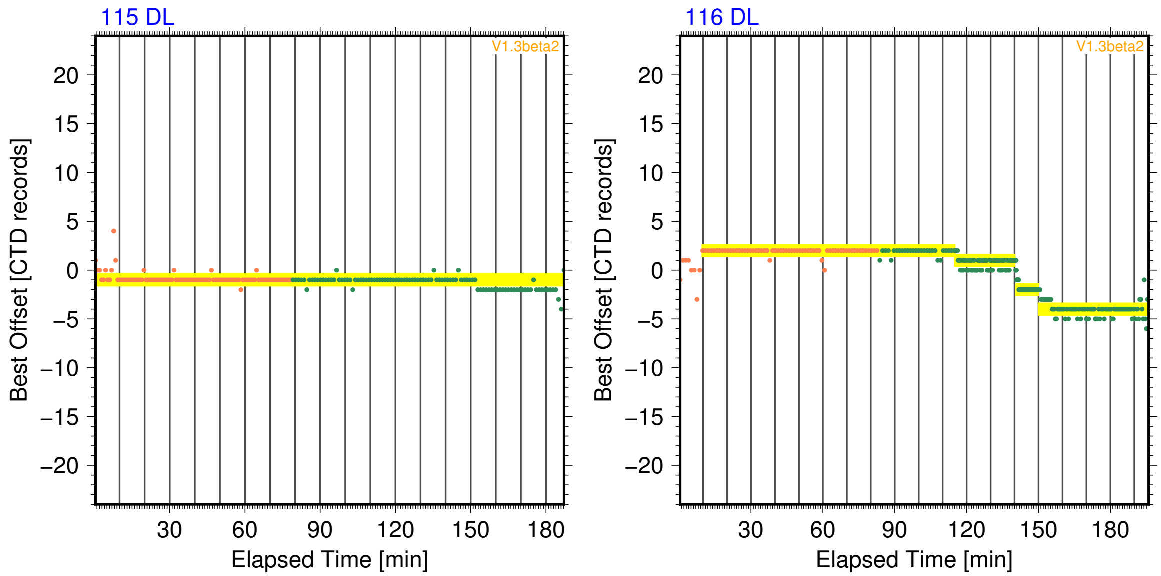

Figure 5: LADCP_w time-lagging offsets from two example profiles. Left panel: Profile 115 without any dropped scans, resulting in a constant offset for the entire profile. Right panel: Profile 116 with several dropped scans, causing discrete steps in the offsets.

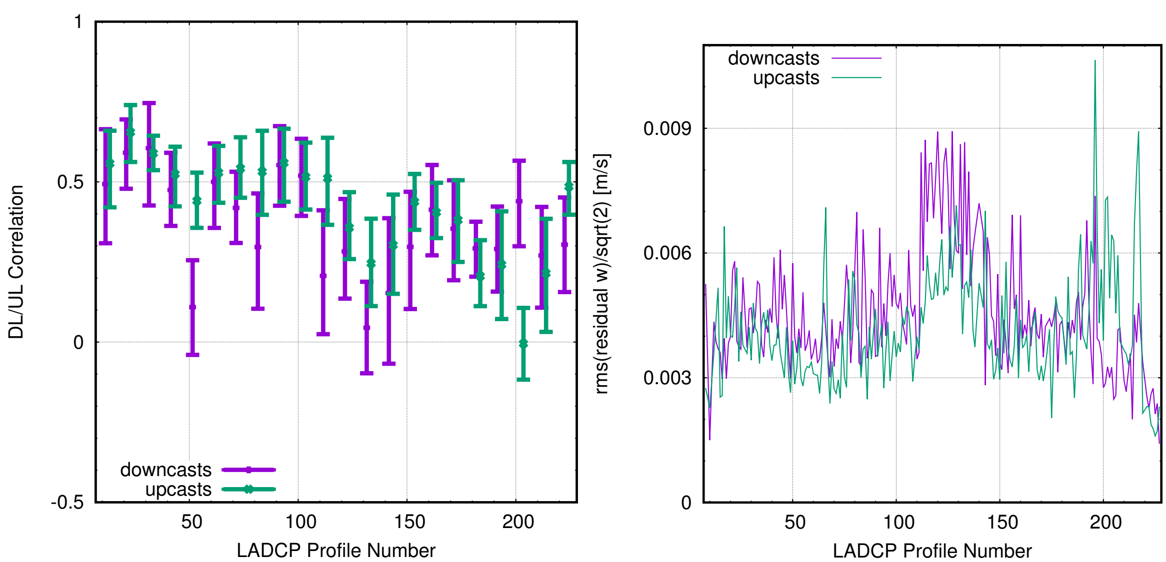

Figure 6: Vertical-velocity DL/UL correlations. Left panel: Correlation coefficient vs. profile number averaged in groups of 10 profiles, with error bars from bootstrapping; high values indicate good agreement. Right Panel: Corresponding regression residuals scaled by $1/\sqrt{2}$; low values indicate good agreement.

to 125) mostly pass those two criteria, many of the profiles from the second leg do not. Comparing Figures 3 and 6 suggests, in particular, 1) that the low acoustic backscatter during profiles 115–135 caused increased w noise, in particular in the downcast data, and 2) that the rough seas around profile 200 adversely affected the upcast vertical velocities. Increased sampling (because of CTD bottle stops) during the upcasts provides a possible explanation why they are comparatively less affected by reduced acoustic backscatter, compared to the downcasts. The apparently greater effect of the sea state on the upcast- than downcast profiles in the latter group suggests an effect related to bottle stops.

Applying a finescale parameterization based on Vertical Kinetic Energy, estimates of kinetic energy dissipation ϵ_{VKE} were derived from the vertical-velocity profiles. Excluding the profiles near the Equator (within 3° of latitude) where the parameterization is not expected to work, there are 4267 half-overlapping 320 m-wide spectral windows from which ϵ_{VKE} estimates can be derived. Out of these, only 517 (≈12%) yield valid estimates, while the remainder does not pass the consistency checks built into the processing software. The low return rate in this data set is due to a combination of low w_{ocean} signal (weak internal waves and turbulence levels) and comparatively large errors affecting some of the profiles as discussed above. Nevertheless, the available VKE samples are sufficient to describe a section-averaged turbulence profile characterized by background dissipation levels around $10^{-10}\,\mathrm{W\cdot kg^{-1}}$ sandwiched between well defined boundary layers in the top 1000 m and bottom 700 m of the water column (Figure 1).

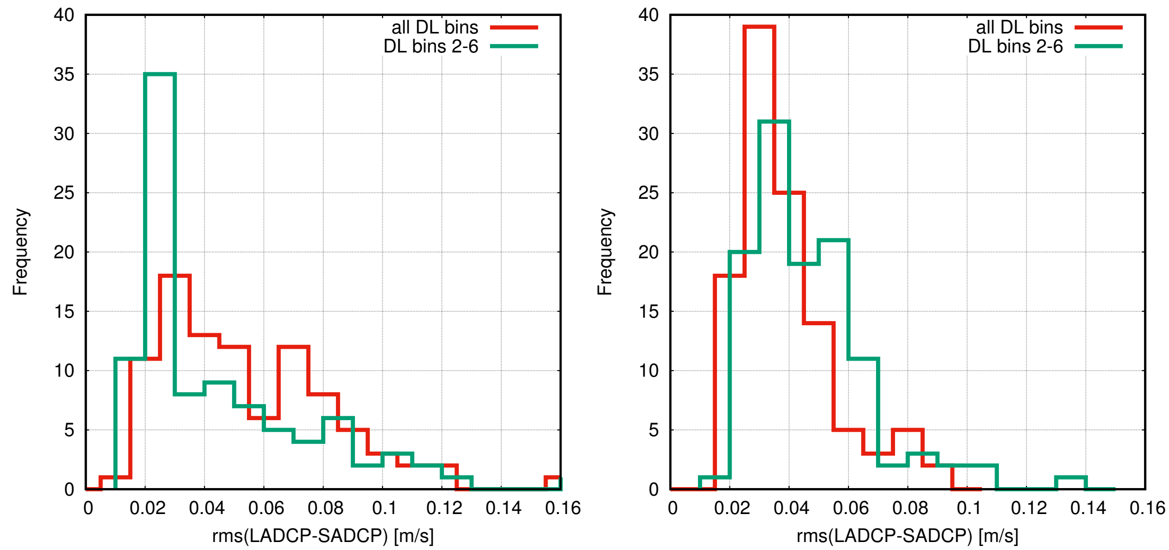

Figure 7: Histogram of *rms* LADCP-SADCP horizontal velocity differences from two cruises using the same WH150 ADCP. Left panel: 2015 P16 occupation before TRDI hardware upgrade. Right panel: 2016/17 P18 cruise, leg-1 data, after TRDI hardware upgrade.

5 ADCP Testing

The WH150 #19394 ADCP used as a downlooker during most of the cruise is the "Frankenhead" that had performed badly during the 2015 occupation of P16 (see corresponding cruise report). Immediately prior to the P18 cruise, this instrument was fitted with a hardware upgrade (a re-designed power-supply board) by the manufacturer. Before the hardware upgrade the "Frankenhead" returned biased velocity data in the far beams in regions of weak acoustic backscatter (see P16 LADCP QC report for extensive documentation), which, based on community reports, is a problem that has affected a sizable proportion of TRDI WH150 instruments. As a result, the errors of the P16 LADCP velocities are smallest when only data from bins 1–6 are used (Figure 7, left panel). The P18 data, collected with the same instrument after the hardware upgrade, no longer shows this problematic behavior (right figure panel). Similarly, the errors in profiles 219–227, which were acquired with the spare WH150 instrument, increase when the data from the far bins are excluded from processing (not shown).