2018 GO-SHIP S4P LADCP Post-Cruise QC Report

A.M. Thurnherr

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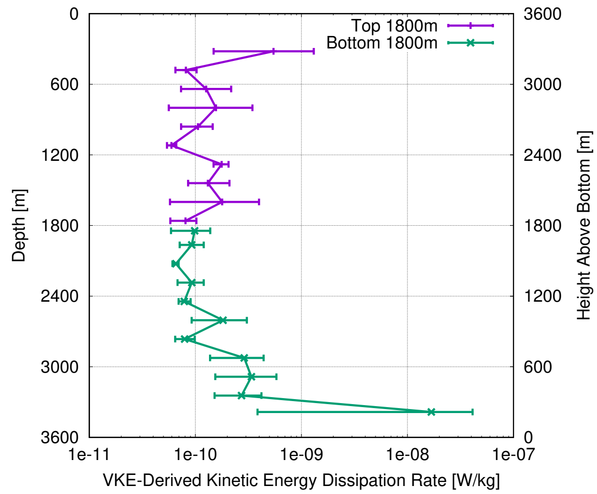

Figure 1: Section averaged profile of kinetic energy dissipation estimated from LADCP-derived vertical velocities using a finestructure parameterization method (Thurnherr et al., GRL 2015). Data from the top half of the water column are plotted against depth (left axis); data from the bottom half are plotted against height-above-bottom (right axis); error bars are from bootstrapping. Profile 001, a comparatively shallow profile with strong internal-wave signatures, was not used for this average.

1 Summary

This report describes the results from the post-cruise quality control of the LADCP data collected during the 2018 GO-SHIP re-occupation of the S4P repeat hydrography section with the UNOLS vessel R/V *Nathaniel B. Palmer.* Using two ADCPs installed on the CTD rosette, one looking downward (DL) and the other upward (UL), full-depth profiles of all three components of the oceanic velocity field were collected at all stations. The 150 kHz TRDI Workhorse ADCP that was used as the downlooker returned mostly bad attitude and water-track velocity data throughout the cruise. When merged with calibrated heading, pitch and roll from an external IMU the bad DL nevertheless provided valid bottom-tracking (BT) velocities. Without simultaneous data from two ADCPs several of the most useful quality checks for LADCP velocities are not possible. As a result, there is greater uncertainty associated with the LADCP velocities from this cruise than is typically the case. However, based on diagnostics produced during processing, the LADCP data from S4P are of good quality. This is especially true for the vertical velocities (Section 5), which show low levels of noise indicating

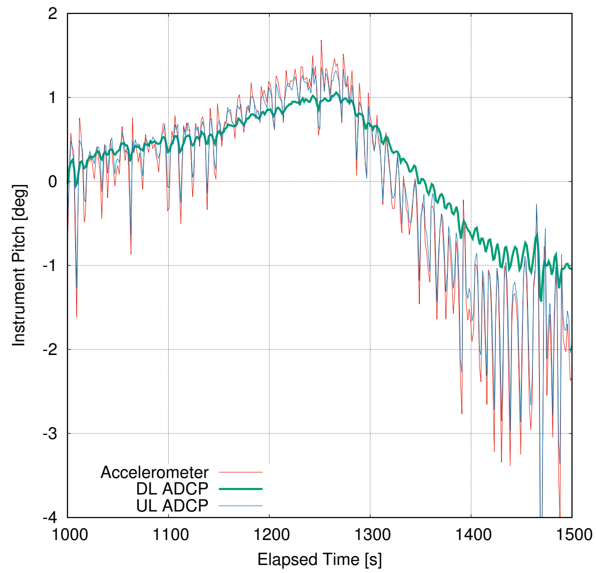

Figure 2: Arbitrary snippet of instrument pitch (rotated into the coordinate frame of the UL ADCP) as measured by the two ADCPs (blue and green), as well as by an external accelerometer (red).

excellent performance of the UL. Based on comparisons with SADCP velocities in the upper ocean the horizontal LADCP velocities are also of good quality (Section 4), although the uncertainties are higher than usual, especially near the seabed.

2 Instrumentation

Two ADCPs were used during this cruise: WHM15O #19394 as the DL and WHM300 #12734 as the UL. The DL had last been used during the 2016/17 occupation of P18 section when it performed well but lost a beam toward the end of the cruise and was serviced by TRDI prior to S4P. During the first few profiles there were repeated cabling-related problems hampering fault detection, but it was soon determined that the DL had a stuck orientation switch (it thought it was installed as an uplooker), a fairly common problem that can usually easily be solved with software. The standard diagnostic for assessing the quality of raw LADCP data files — integrating the vertical velocities and comparing the resulting time-depth trajectory to the corresponding one from the CTD — indicated that this post-processing correction worked. As the instrument range was excellent throughout the cruise it was used as the DL for all profiles. The UL ADCP, WHM300 #12734, had also been used during P18 where it performed excellently. For P18 a self-recording magnetometer/accelerometer was installed inside its pressure case. Throughout the cruise the two ADCP compasses showed large differences, which were assumed to be caused by magnetic interference of the magnetometer/accelerometer in the UL.

After the cruise, the data from the external magnetometer and accelerometer were processed as described by Thurnherr et al. (J. Tech., 2017). Comparison of the ADCP pitch/roll time series to those from the accelerometer clearly indicates that the tilts (pitch and roll) from the DL are significantly damped (Figure 2). While both DL tilt sensors are similarly affected the damping

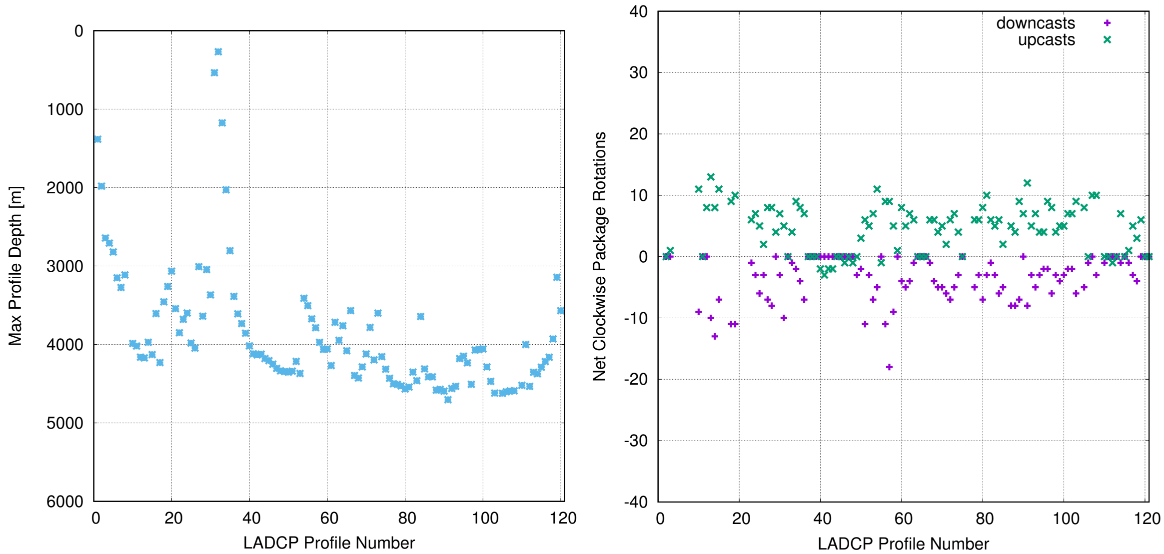

Figure 3: Profiling properties. Left panel: Maximum profile depth. Right panel: Net package rotations, positive indicating clockwise when viewed from above.

factors are not constant, i.e. the DL attitude cannot be corrected simply by scaling the pitch/roll measurements. Since pitch and roll are used to time-match the accelerometer/magnetometer data to the ADCP time series the automatic time-lagging algorithm failed for most profiles, requiring significant manual effort for processing. After processing the magnetometer/accelerometer data, the resulting replacement time series of pitch, roll and heading were merged with the raw ADCP data files, which were then processed with standard software.

3 Sampling Conditions

Figure 3 shows the maximum depths as well as the number of net rotations experienced by the CTD package during each profile. Average profile depth is ≈3600 m with the deepest profiles toward the end of the cruise (left figure panel). Per-profile package rotations were largely balanced, with similar numbers of downcast counterclockwise and upcast clockwise rotations (right panel), indicating that the wire was fully adjusted to the load. LADCP data quality is sensitively dependent on instrument range (Figure 4, left panel), which depends on the acoustic scattering environment. During S4P, the acoustic backscatter was comparatively strong, resulting in WH300 range exceeding 65 m (an empirical limit for good data) in all profiles, although a dozen or so profiles approach this limit. Sea state is also known to affect LADCP data quality; in the right panel of Figure 4 sea state is quantified as the *rms* vertical package acceleration. Conditions during the cruise ranged from stormy (around $0.3\,\mathrm{m\cdot s^{-2}}$ or greater) to calm (around $0.15\,\mathrm{m\cdot s^{-2}}$) with a number of profiles collected close to the ice with minimal vessel motion. It is interesting to note that the rosette barely rotated during those profiles taken close to the ice (Figure 3, right panel), suggesting that package rotation was affected by “wave pumping.”

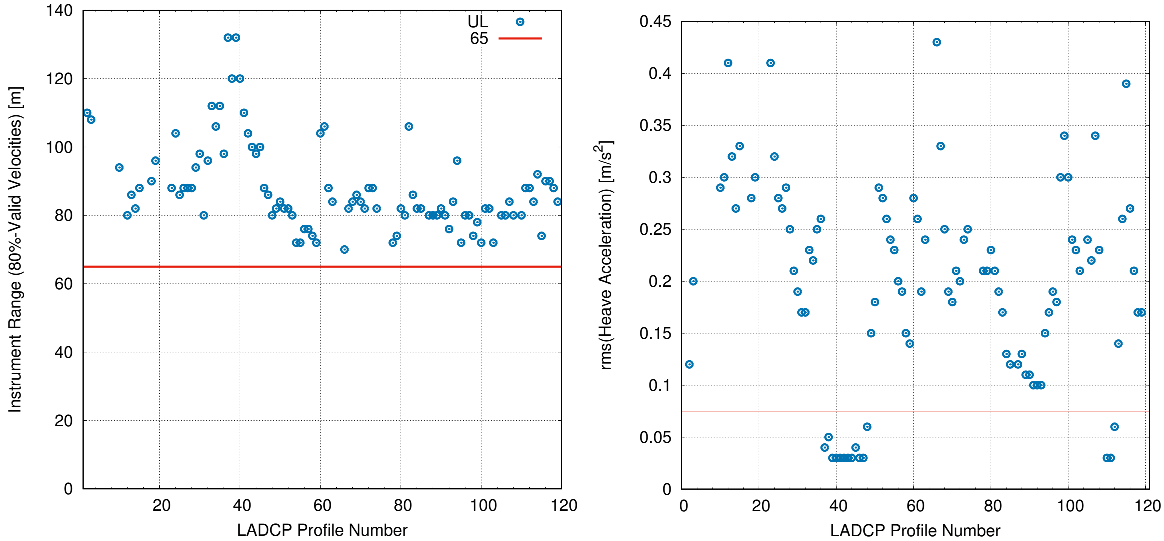

Figure 4: Left panel: Instrument range, with the red line indicating the minimum range (65 m) typically required for successful processing of full-depth LADCP profiles from a single 300 kHz TRDI Workhorse ADCP. Right panel: *rms* vertical acceleration due to vessel heave (sea state); the red line indicates the lower limit for open ocean conditions; profiles with accelerations below this limit were taken in close proximity to the ice edge, with minimal vessel motion.

4 Horizontal Velocity QC

The overall quality of the horizontal LADCP velocities is assessed by processing all profiles with the velocity-inversion method without using the SADCP velocities to constrain the solutions, and comparing the resulting LADCP velocities in the upper ocean to the corresponding SADCP velocities. Based on data from other cruises, high-quality LADCP profiles constrained with GPS and BT data typically agree with the corresponding SADCP velocities within 3–6 $cm \cdot s^{-1}$ when averaged over a few profiles. In case of the S4P profiles, LADCP solutions with data from the UL alone are mostly satisfactory with regards to this criterion even when processed without BT data (red line in Figure 5). Processing with the addition of the unmodified DL data greatly degrades the solutions (not shown). Even the DL data patched with heading, pitch and roll from the external magnetometer/accelerometer do not consistently improve the UL-only solutions (blue line), either, indicating that the problems with the DL were not restricted to the attitude measurements. Prompted by problems with this instrument type encountered on earlier GO-SHIP cruises, some of the profiles were re-processed with different subsets of the available DL bins (e.g. only the near bins), but neither of these experiments yielded promising results. While the water-track velocities from the DL where therefore not used for final processing, adding the BT constraint from the DL, on the other hand, significantly improves the UL LADCP velocities (green line). The overall *rms* velocity discrepancy of 4.8 $cm \cdot s^{-1}$ from these solutions indicates that the horizontal LADCP velocities from the profiles from this cruise are of good quality, as long as the large vertical scales are constrained by BT and SADCP velocities. Profiles without BT data (004, 005, 117) are therefore missing from the final processed data set, as are the profiles without UL data (006, 007), two profiles that were aborted at shallow depth (009, 104), as well as one that was cancelled before deployment (109). With these exceptions, there are valid horizontal LADCP profiles from all stations. For archiving the LADCP data were re-processed with

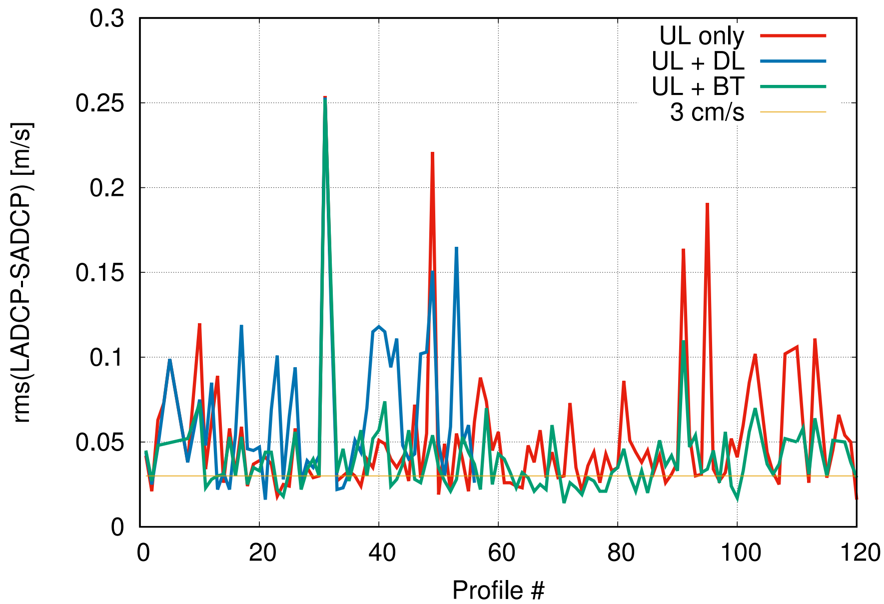

Figure 5: *rms* LADCP-SADCP horizontal velocity differences; low values indicate good agreement. Red: Using only UL data, constrained by GPS. Blue: Using combined UL and DL data, constrained by GPS; not all profiles were processed with these options. Green: Using only UL data, constrained by GPS and BT (from the DL).

all available referencing constraints, including the SADCP velocities. As a result, the final velocity uncertainties are smaller than those shown in Figure 5.

5 Vertical Velocity QC

For processing the LADCP data for vertical ocean velocity the `LADCP_w` software, version 1.4, was used. With two functioning ADCPs QC of vertical velocity is based primarily on correlations between the two largely independent w measurements. Unfortunately, the DL did not perform well during this cruise, resulting in many profiles with clear anomalies. In the example profile shown in Figure 6 these anomalies include downcast/upcast biases below 1500 m (divergent orange and green profiles), inconsistent beam-pair w measurements below the same depth (split of profiles into dotted and dashed lines), as well as atypically high (nearly $15\,\mathrm{cm \cdot s^{-1}}$) w scatter in the deep bins, in particular. The clearest indication that there are significant problems with the DL data from this profile is provided by the velocity residuals[1] averaged for each ADCP bin (Figure 7) — any value significantly different from zero indicates biased measurements in a particular bin. The corresponding velocity residuals from the UL (right figure panel) are small throughout the range of the well-sampled bins (connected by lines) and show no discernible structure with respect to bin number. The *rms* velocity residuals of the well-sampled bins (printed inside the figure panels) are below $1\,\mathrm{mm \cdot s^{-1}}$ indicating that the UL data are of excellent quality. On the other hand, many of the DL profiles, including the one shown in

[1] Since there are many measurements going into each bin of ocean w each ADCP ensemble is associated with a "velocity residual," which is the difference between the averaged (in a depth bin) and the instantaneous measurement.

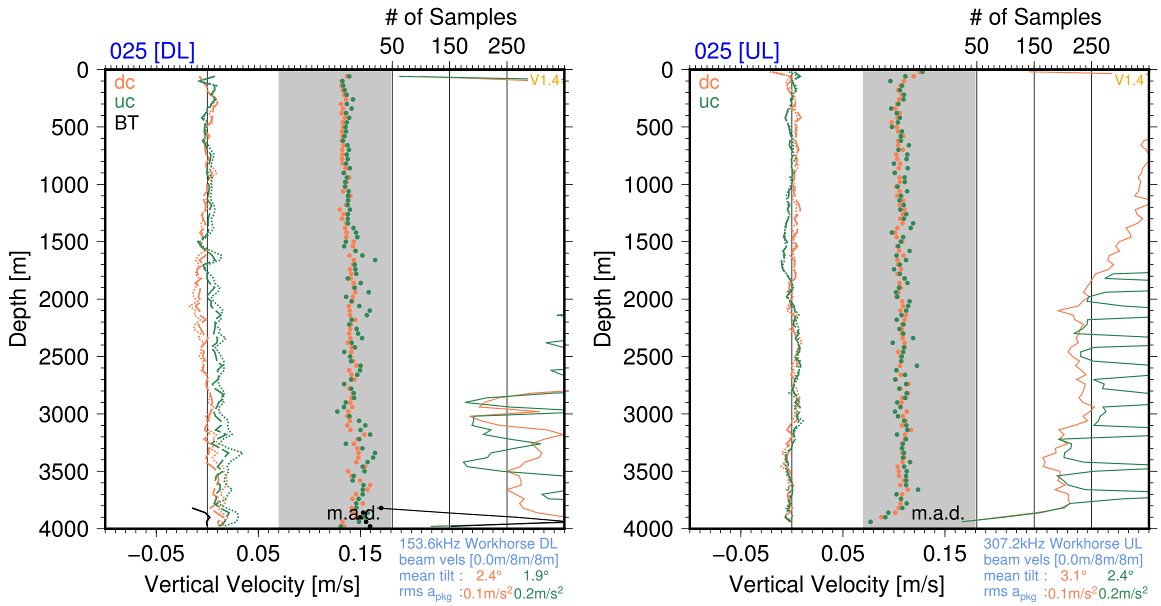

Figure 6: Example vertical-velocity profiles from the DL (left panel) and UL (right panel). Each panel shows (from left to right) vertical ocean velocity, mean-absolute-deviation in each w bin, as well as number of samples in each bin.

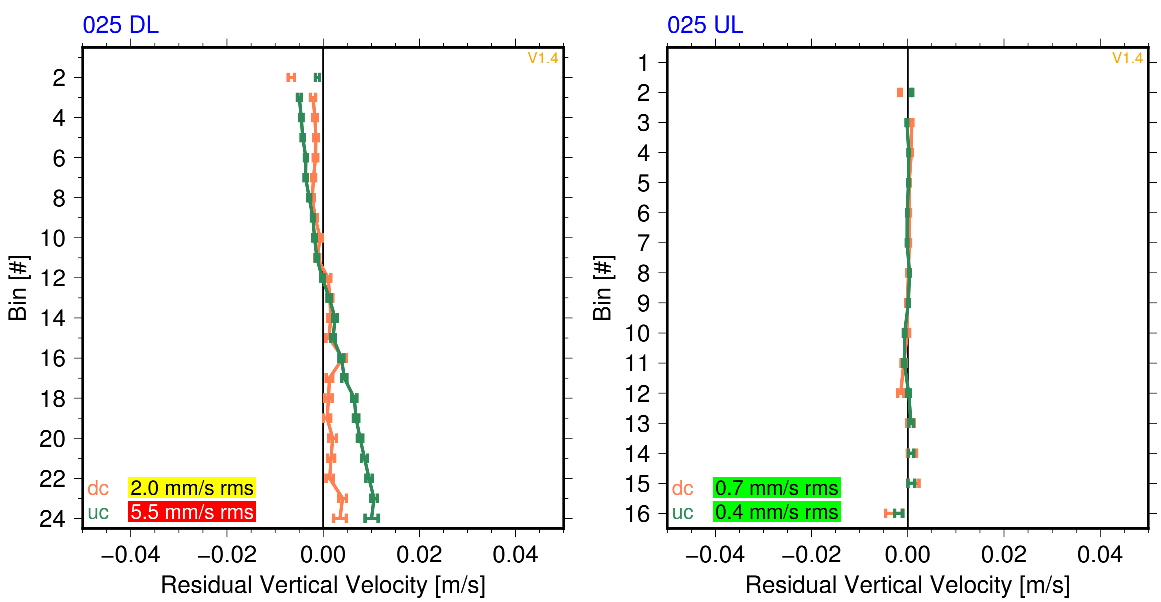

Figure 7: Bin-averaged residuals (measurement errors) for the example profile shown in Figure 6, with values significantly different from zero indicating biased measurements in a particular bin.

Figures 6 and 7, are not of useable quality. Profiles without UL data (006, 007) are therefore missing from the final processed data set of vertical velocity, as is profile 024 with a gap in the ADCP downcast data preventing processing, two aborted profiles (009, 104), as well as one that was cancelled before deployment (109). With these exceptions, there are valid vertical LADCP profiles from all stations.

Estimates of kinetic energy dissipation ϵ_{VKE} were derived with a VKE-based finestructure parameterization method from the UL vertical-velocity profiles. In addition to the profiles missing from the w data set (see above), profile 032 is missing from the VKE profiles because it is not deep enough for the spectral method to be applied. In the available S4P vertical-velocity profiles there are 2522 half-overlapping 320 m-wide spectral windows, including bottom windows, from which ϵ_{VKE} estimates can potentially be derived. Out of these, only 206 (8%) yield valid estimates, while the remainder does not pass the consistency checks built into the processing software. This low return rate is primarily due to the weak w_{ocean} signal (weak internal waves implying low levels of turbulence) in this data set — nearly 90% of the samples have VKE levels below the lower detectabiliy limit of the VKE method ($\approx 5 \times 10^{-11}\,\mathrm{W \cdot kg^{-1}}$). While the VKE method does not provide quantitative dissipation estimates for these samples, it does provide a strong constraint for the maximum magnitude of the corresponding turbulence levels (oceanic background). The mean dissipation profile from the samples with sufficient VKE is characterized by "open ocean type" dissipation levels over most of the water column, with a bottom boundary layer of downward-increasing turbulence levels in the bottom 700 m or so (Figure 1). The shallowest value in the mean profile at 320 m suggests the presence of an upper-ocean boundary layer, but biology is known to contaminate some LADCP vertical velocity measurements near the surface.