2021 GO-SHIP A22 LADCP Post-Cruise QC Report

A.M. Thurnherr

January 10, 2022

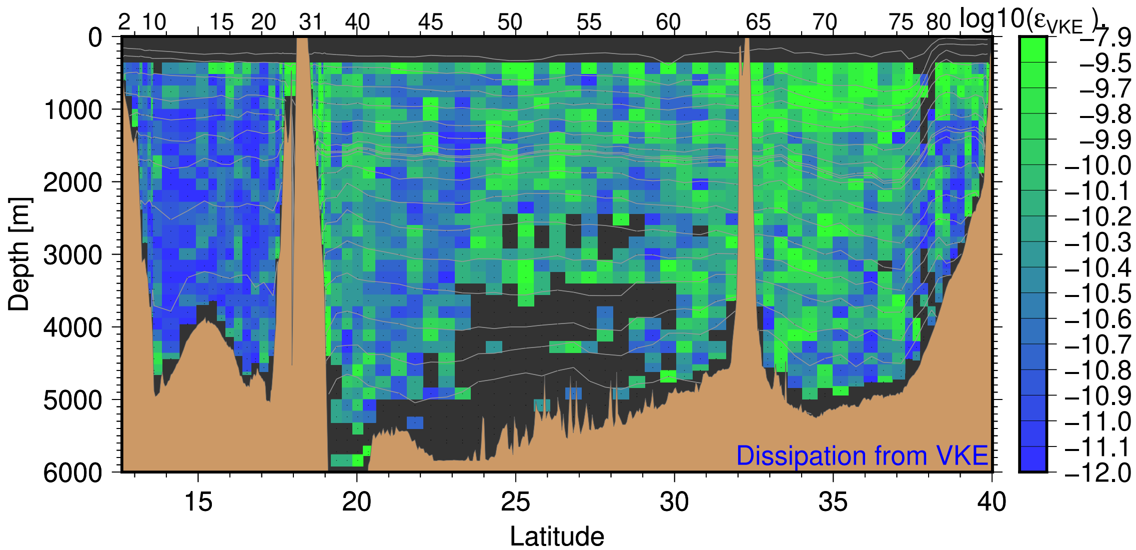

Figure 1: Kinetic energy dissipation in units of $\mathrm{W \cdot kg^{-1}}$ from a finescale parameterization based on vertical kinetic energy (ϵ_{VKE}) overlaid with σ_2 potential-density contours. VKE in the upper 300 m are contaminated, perhaps by moving organisms. Gaps below that depth, indicating fewer than 2 spectral estimates in a window, are mostly caused by insufficient instrument range. The figure was produced from the default output of the `LADCP_w` software, version 2.1, applied to the A22 LADCP data, without any manual filtering or modification of the default processing parameters. See Section 7 below for a discussion of the main spatial patterns apparent in this figure.

1 Summary

This report describes the results from the post-cruise quality control of the LADCP data collected during the 2021 GO-SHIP re-occupation of the A22 repeat hydrography section with the UNOLS vessel R/V *Thomas G. Thompson.* Using two ADCPs installed on the CTD rosette, one looking downward (DL) and the other upward (UL), as well as an independent IMU, full-depth profiles of all three components of the oceanic velocity field were collected at all stations. The cruise track

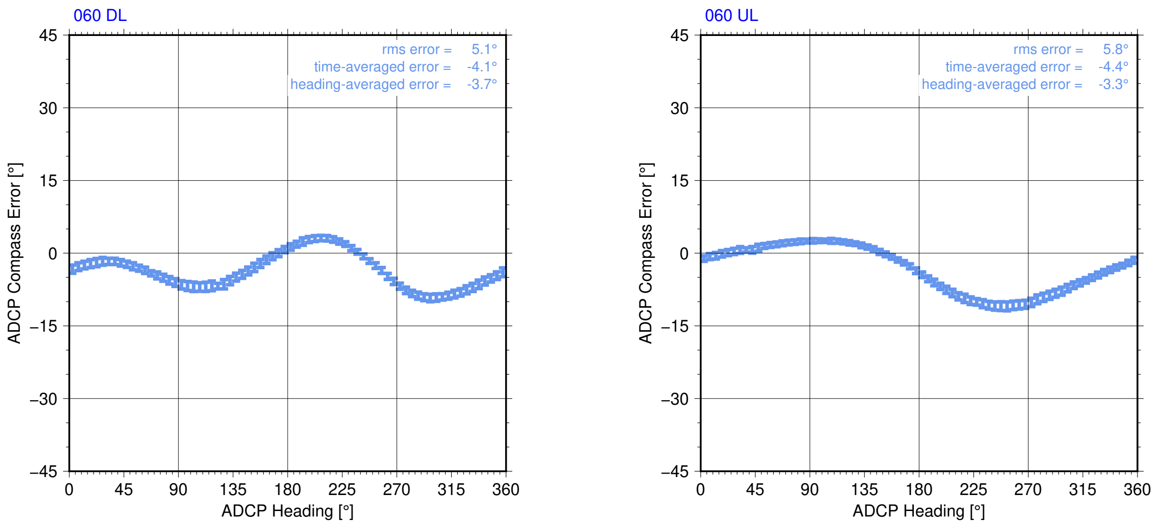

Figure 2: Heading dependent errors of the two ADCP compasses in an arbitrary profile; it is these errors that are corrected for by using external magnetometer data.

crosses a region with extremely low acoustic backscatter, causing gaps in the LADCP data coverage of vertical velocity below about 2500 m Figure 1. Except for these gaps the quality of both horizontal and vertical velocities is excellent, as indicated by the agreement with shipboard ADCP velocities for the former, and by high correlations between the measurements taken with the two instrument for the latter. Additional information about the LADCP data acquisition on this cruise can be found in the main cruise report.

2 ADCP Instruments

Two ADCPs were used during this cruise: A 300kHz TRDI Workhorse Monitor ADCP (WH300, s/n 12734), fitted with a custom self-recording accelerometer/magnetometer package (called IMP), was installed as the uplooker during all casts, and another WH300 (s/n 24477) was installed as the downlooker. Both instruments performed well. On three stations (9, 10 and 54) one of both of the ADCPs created additional small data files before and/or after the profile — these additional files can simply be ignored during processing and are not included in the archive.

3 Compass Calibration

After the cruise, the data from the IMP (magnetometer and accelerometer) were downloaded and processed as described by Thurnherr et al. (J. Tech., 2017), and the resulting replacement time series of pitch, roll and heading were merged with the raw ADCP data files, which are suitable for processing with standard software. Figure 2 shows the heading-dependent errors of the two ADCP compasses in a random profile. (Consistency of the heading errors from all profiles is used to QC the IMP data.)

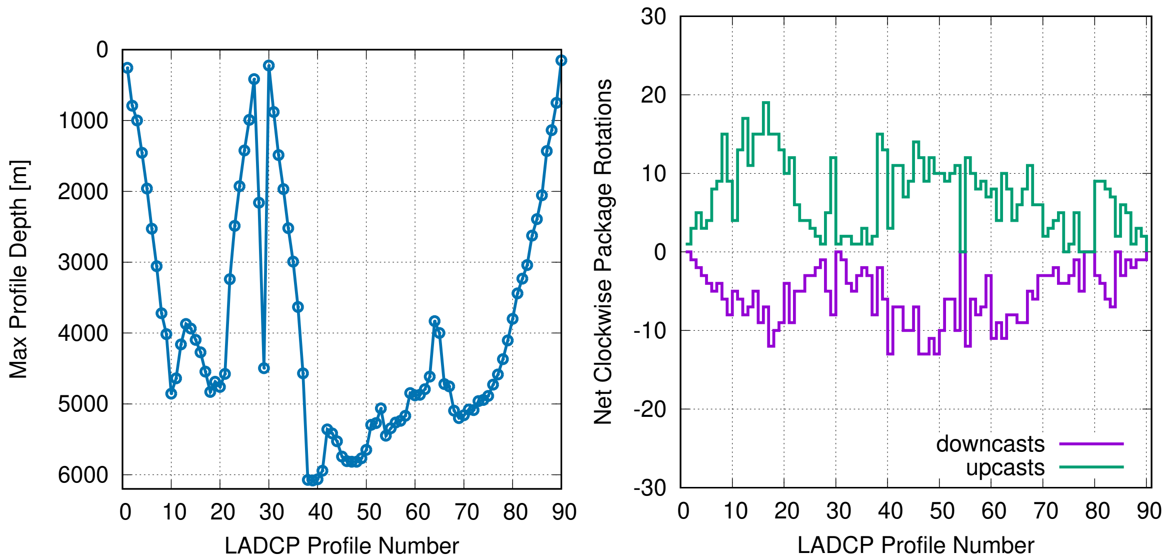

Figure 3: Profiling properties. Left panel: Maximum ADCP profile depth (which is greater than the max. CTD depth). Right panel: Net package rotations, positive indicating clockwise when viewed from above.

4 Sampling Conditions

Figure 3 shows the maximum depths as well as the number of net rotations experienced by the CTD package during each profile. The cruise track, starting near the South American shelf break first crosses the Caribbean Sea, with profile 27 close to the Southern Coast of Puerto Rico. Two deep profiles (28 and 29) were occupied in the Anegada Passage east of Puerto Rico before the meridional section was continued northward starting near the northern coast of the island and crossing the subtropical North Atlantic toward Bermuda (profiles 30–64) and then continuing along line W from Bermuda to Cape Cod (profiles 65–90). CTD package rotations were approximately balanced, with similar numbers of downcast counterclockwise and upcast clockwise rotations (right panel), indicating that the wire was fully adjusted to the load.

The most important parameter affecting the quality of horizontal LADCP velocities is the measurement range of the instrument which, for a given instrument, depends primarily on the acoustic backscatter environment. Along the track of A22 the backscatter environment below about 1000 m is extremely variable with backscatter approaching zero at depth between 23° and 29°N (Figure 4). Note the sharp transition in backscatter between stations 46 and 48 and the layered vertical structure in the upper 1000 m. There are indications of eddy-related full-water-column elevation of backscatter both in the Caribbean and along line W.

The weak acoustic backscatter below 1000 m in the middle third of the section causes the measurement range of the two ADCPs to drop below 65 m (Figure 5, left panel), which is an empirical limit for processing of single-head LADCP profiles for horizontal velocity. While there are only two profiles (49 and 50) where the combined range is below 65 m, based on the results from the preceding A20 cruise we expect reduced quality of the horizontal velocity data in profiles 45–60.

Sea state can also affect LADCP data quality with some LADCP installations; in the right panel of Figure 5 sea state is quantified as the *rms* vertical package acceleration. Conditions during the cruise were mostly calm (heave acceleration below $0.2\,\mathrm{m{\cdot}s^{-2}}$) with elevated package motioni in profiles

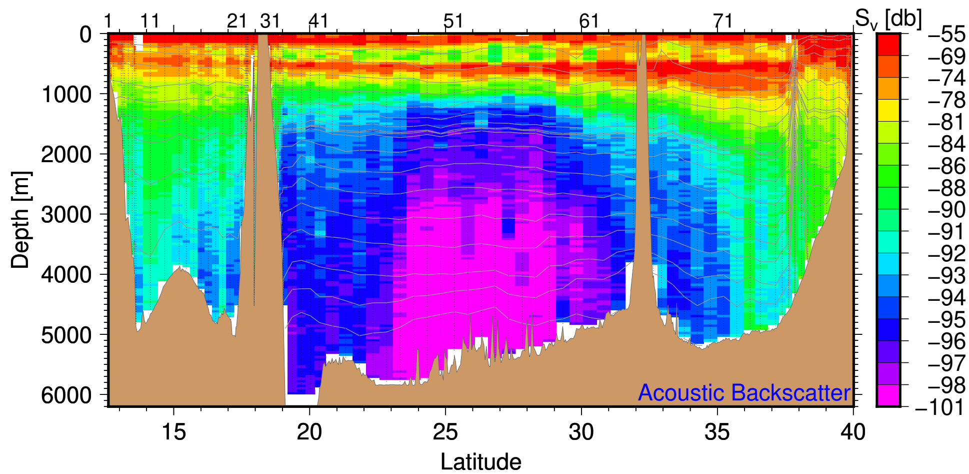

Figure 4: Downcast acoustic backscatter coefficient S_v from the UL data, calculated using the vertical-velocity processing software. Based on the data from the previous A20 cruise, the lower limit for collecting LADCP profiles with a dual Workhorse LADCP system is ≈−97 dB.

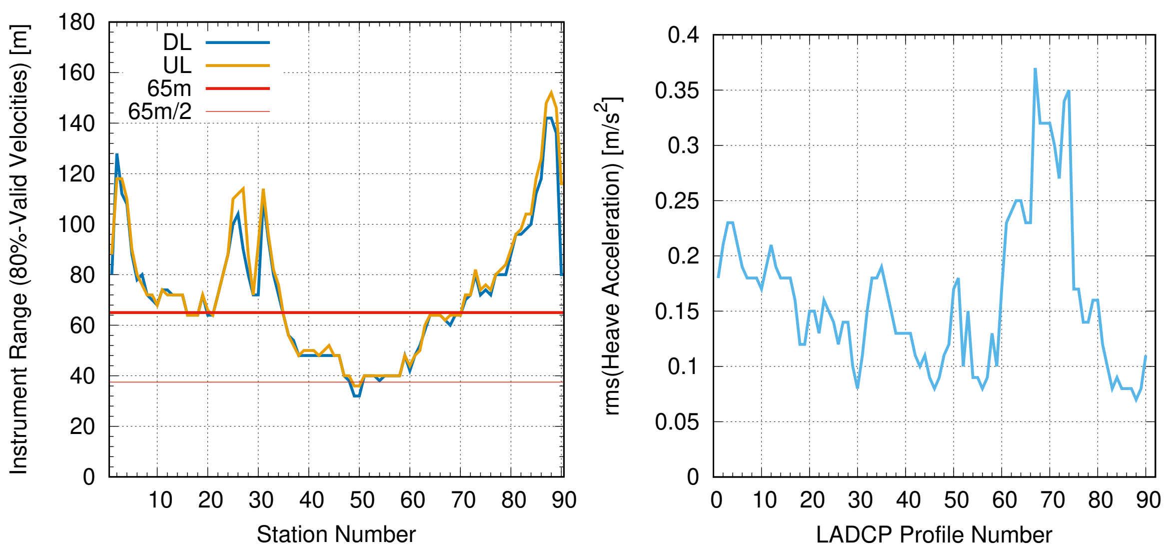

Figure 5: Left panel: Instrument ranges, with the horizontal lines indicating the minimum ranges typically required for successful processing of full-depth LADCP profiles from a dual/single 300 kHz TRDI Workhorse ADCP systems. Right panel: *rms* vertical acceleration due to vessel heave (sea state).

60–75.

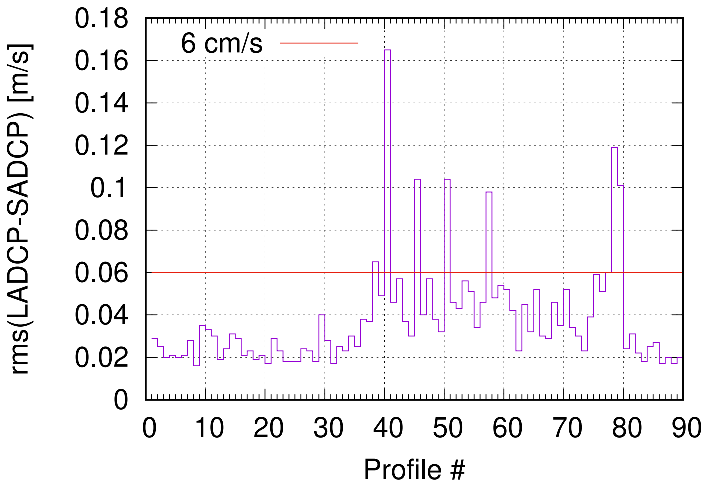

Figure 6: *rms* LADCP-SADCP horizontal velocity differences; low values indicate good agreement; overall *rms* is $4.5\,\mathrm{cm\cdot s^{-1}}$, $\approx 5\,\mathrm{mm\cdot s^{-1}}$ lower than the corresponding value from processing without the external magnetometer/accelerometer. The horizontal line indicates an empirical limit for high-quality profiles collected in regions of not-very-strong near-surface currents.

5 Horizontal Velocity QC

The overall quality of the horizontal LADCP velocities is assessed by processing all profiles with the LDEO_IX implementation of the velocity-inversion method without using the SADCP velocities to constrain the solutions, and then comparing the two independent velocity profiles in the upper ocean; Figure 6 shows the profile-averaged *rms* velocity differences from this cruise. Based on data from many other cruises, high-quality LADCP profiles constrained with GPS and BT data typically agree with the corresponding SADCP velocities within 3–6 $\mathrm{cm\cdot s^{-1}}$ when averaged over a few profiles. In case of the A22 data there are 7 profiles exceeding this limit:

38 & 40: There are no BT data in these profiles collected over the Puerto Rico trench, implying that greater velocity discrepancies are expected.

45, 50 & 57: These profiles are from the region of particularly low backscatter, where LADCP velocity errors are expected to be comparatively large.

78 & 79: These two profiles were collected in the Gulf Stream where upper-ocean velocity exceeds $1.5\,\mathrm{m\cdot s^{-1}}$. With such large signals, $6\,\mathrm{cm\cdot s^{-1}}$ is a small relative error.

The diagnostic figures from all these profiles were carefully inspected but no indications for significant problems were found in either. This indicates that all final processed profiles (constrained with GPS, BT and SADCP data) of horizontal velocity are likely of high quality in spite of the low backscatter environment in the middle of the section. Fair weather (low sea state) during this section of the cruise likely contributed to this fact. Since the fully processed profiles additionally use the SADCP data in the upper ocean to constrain the LADCP velocities, the errors in the archived data set are smaller than the values shown in Figure 6.

Figure 7 shows sections of zonal and meridional final processed velocity from the LADCP system. All strong currents are associated with qualitatively consistent horizontal density gradients (sloping

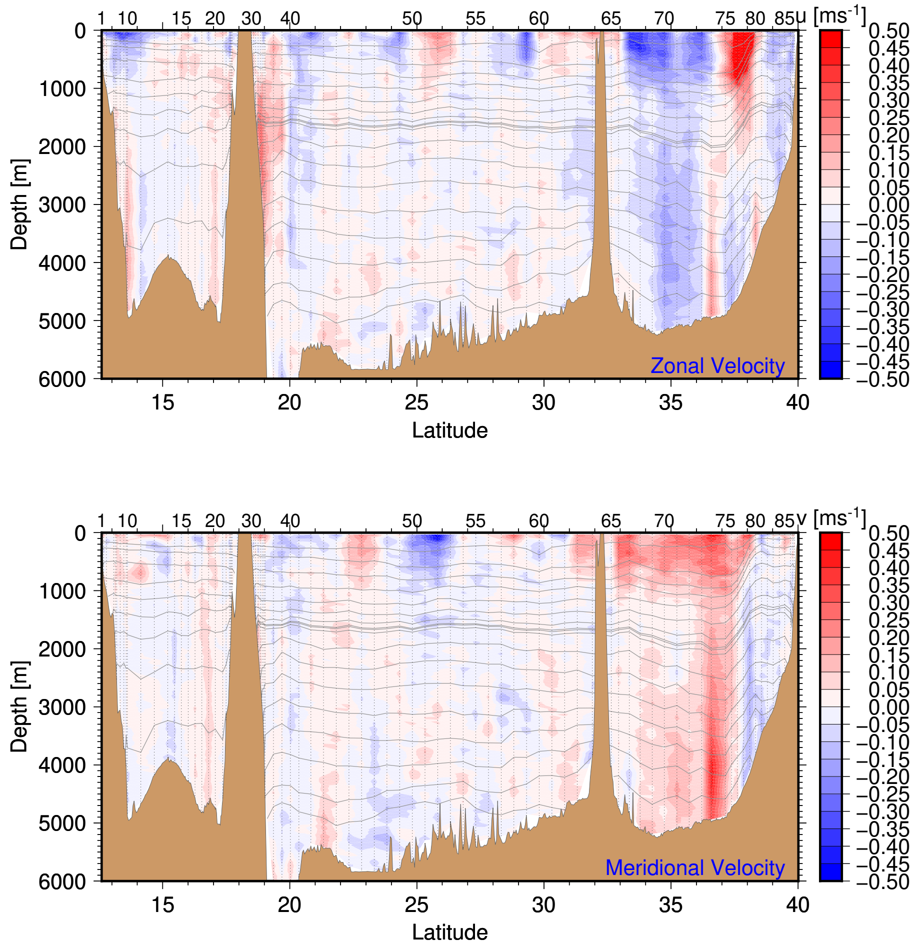

Figure 7: Zonal (upper panel) and meridional (lower panel) velocities from the LADCP; with superimposed histogram-equalized σ_2 contours, which emphasizes the narrow density range (weak density stratification) of the abyssal Caribbean compared to the western North Atlantic.

σ_2 contours), increasing our confidence in the LADCP measurements.

6 Vertical Velocity QC

In order to process the LADCP data for vertical ocean velocity the `LADCP_w` software, version 2.1, was used. With two ADCPs measuring the vertical velocity field QC is based primarily on comparisons between the two largely independent[1] w measurements. In contrast to horizontal velocity, which can only be derived from full profile data, the effects of measurement errors due to insufficient

[1]The same portion of the water column is sampled at different times by the two ADCPs. Only biases related to the CTD pressure measurements are common to the vertical velocity measurements from both instruments.

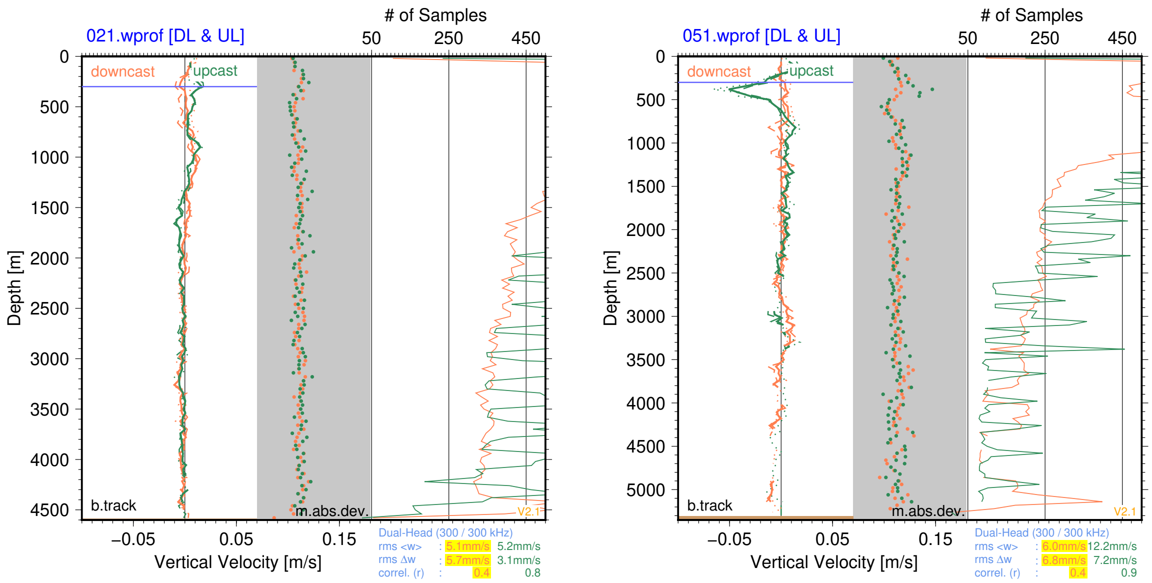

Figure 8: Example diagnostic figures from two vertical velocity profiles. Left panel: Profile 021, collected in the Caribbean sea where backscatter is sufficient throughout the water column. Right panel: Profile 051, collected in the core of the subtropical gyre where backscatter in the abyssal ocean is insufficient causing profile gaps. Each panel shows (from left to right) vertical ocean velocity (dashed: DL, dotted: UL, combined: heavy), mean-absolute-deviation in each w bin (bullets) and number of samples in each bin (lines), as well as instrument type and profile-averaged w statistics (blue text in the bottom right corner).

backscatter, excessive instrument motion, etc., on vertical velocity are localized and can be removed during processing, causing gaps in the resulting profiles. The example profile shown in the right panel of Figure 8 was collected in the region with weak backscatter, resulting in a partial-depth profile with full coverage extending down to about 2500 m. In contrast, in the profile shown in the left figure panel there was sufficient acoustic backscatter for both instruments to produce complete down- and upcast profiles. In both profiles there is good agreement between the data from the two ADCPs, especially during the upcasts, as indicated by the w correlation statistics printed in the figure panels.

In order to further quantify and visualize the quality of the vertical-velocity data, UL-DL correlation coefficients were calculated in 320 m-thick windows (Figure 9). Where there is data from both instruments, the correlations are mostly positive, indicating that the vertical velocities are dominated by the signal, rather than by measurement errors and noise. Inspection of individual profiles indicates that many of the negative correlations are from windows with approximately uniform w, i.e. where the signal is small, without indications for measurement problems. The comparatively low correlation in the Caribbean, compared to the remainder of the North Atlantic, therefore reflects the low VKE in that region, rather than a problem with the data. [While the correlation coefficients can easily be increased by increasing the window size, 320 m was chosen because it is a popular choice for quantifying internal-wave properties from LADCP data (e.g. Figure 1).]

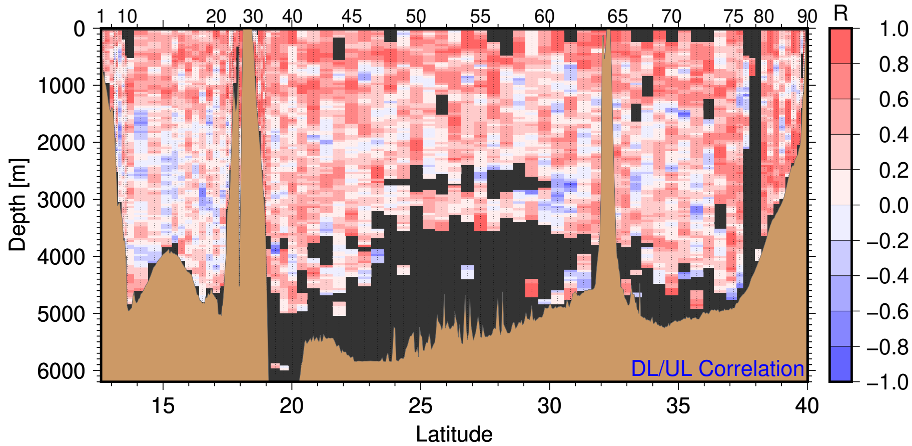

Figure 9: Downcast/upcast average correlation coefficients between the vertical-velocity measurements from the two ADCPs in 320 m-thick windows; a minimum of 6 samples are required for each correlation. Regions without data from both instruments are shaded dark. As discussed in the text, many of the low/negative correlation coefficients are related to low signal, rather than to measurement problems. The section averaged correlation coefficient is 0.33.

7 Vertical Kinetic Energy and Parameterized Dissipation

The LADCP_w software includes the LADCP_VKE tool, which is used to estimate vertical kinetic energy (VKE) and, implementing a finescale parameterization based on high-frequency internal waves, kinetic energy dissipation ϵ_{VKE} (for details, see Thurnherr et al., GRL 2015). When applied to the A22 data this parameterization results in physically reasonable patterns (Figure 1), especially when compared with the horizontal currents (Figure 7). In particular, parameterized turbulence levels are regionally different, with particularly low levels in the Caribbean sea. Noting that ϵ_{VKE} in the Caribbean is low both in the weakly stratified abyss and in the main pycnocline indicates that this pattern is not an artifact related to stratification. North of Puerto Rico there is elevated turbulence in the boundary current flowing along the island chain, then the turbulence levels are fairly low up to about 24°N where they increase again over the topographically rough MAR flank, and they remain fairly high over the remainder of the section, except for the water below about 1000 m flowing along the US continental slope. North of Bermuda the turbulence levels are elevated above 1000 m where the Gulf-stream related currents are strong