2018 GO-SHIP I7N LADCP Post-Cruise QC Report

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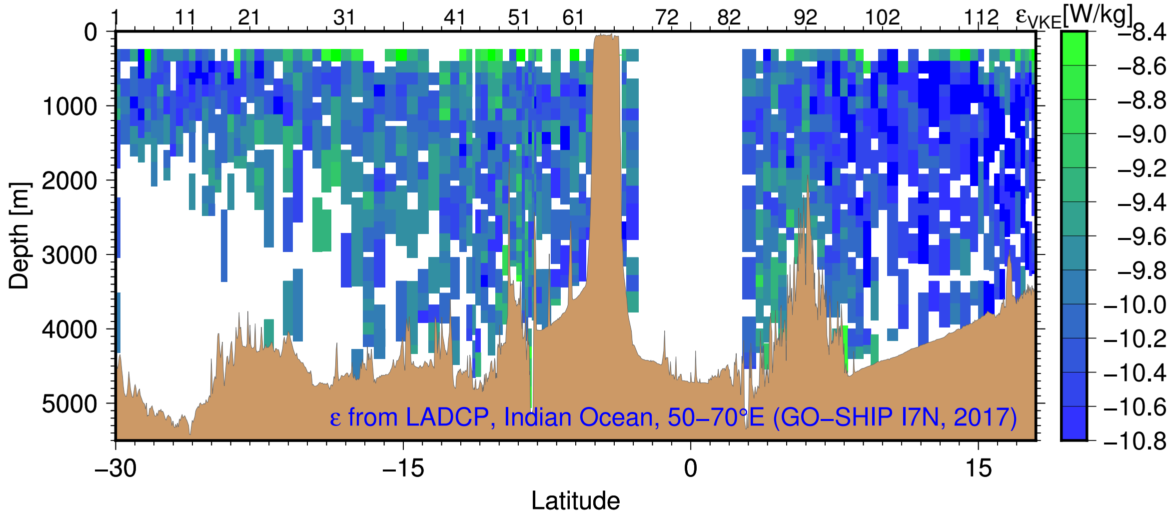

Figure 1: Kinetic energy dissipation along I7N estimated from LADCP-derived vertical velocities using a finestructure parameterization method (Thurnherr et al., GRL 2015). Since the relationship between internal waves and turbulence at low latitudes is not known, there are no parameterization estimates at latitudes below 3°. The remaining large gaps at depth are caused by insufficient instrument range.

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 I7N repeat hydrography section with the NOAA's *Ronald H. Brown.* 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 124 stations. A relative lack of acoustic scatters south of the Mascarene Plateau significantly reduced the instrument range during the first third of the section. The velocities of profiles 1–44 below 2000 m are therefore associated with higher-than-usual uncertainties and should be analyzed with particular care. The remaining profiles are of excellent quality.

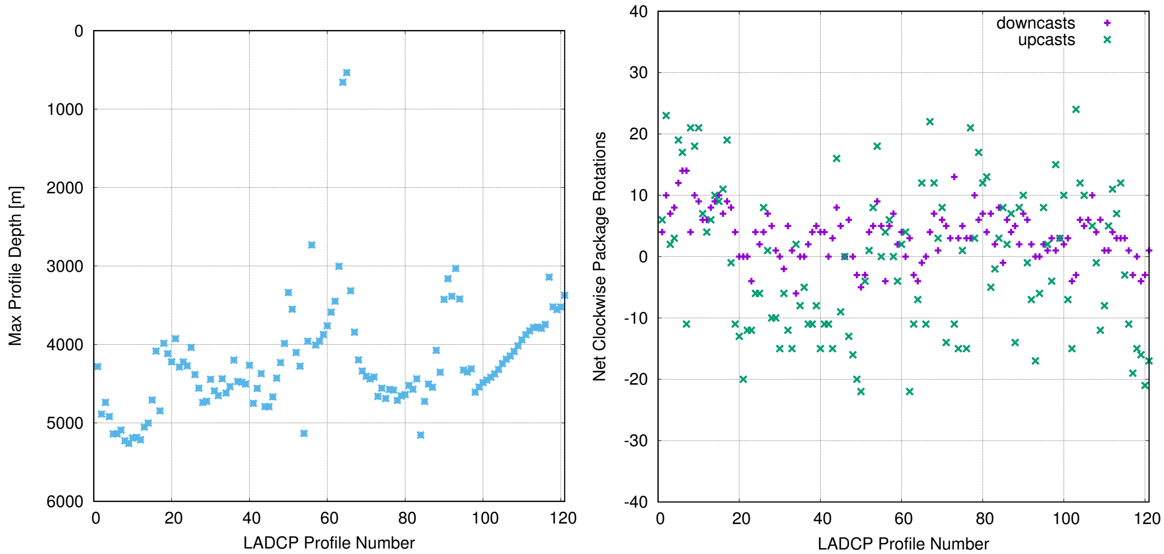

Figure 2: Left panel: Maximum profile depth. Right panel: Net package rotations, positive indicating clockwise when viewed from above.

2 Instrumentation

Three ADCPs were used during this cruise: A single WHM150 (serial #24544) was used as the DL and two different WHM300s, #150 (profiles 1–6 and 11–44) and #24497 (profiles 7–10 and 45–124), served as ULs. While beam 1 of the DL did not record any valid velocity data in the first few profiles, the instrument was not replaced because there were no apparent problems with the 3-beam solutions, and because all available backup instruments were 300 kHz Workhorse ADCPs with insufficient range in the low-scattering waters encountered at the beginning of the cruise (Figure 3, left panel). By station 25 the scattering environment had improved to the point of the beam being reported as "weak" rather than "broken" by the LDEO_IX processing software, and after station 40 performance of beam 1 was adequate. This overall behavior indicates that while this instrument is not broken, it is not particularly suitable for use in low-backscatter environments. After the first 6 profiles were collected with WHM300 #150 the UL was swapped with a spare for three profiles in an attempt to see whether a better range could be achieved, but as the resulting horizontal velocity profiles looked distinctly worse, the instruments were swapped back and #150 was left on the rosette until profile 44 in spite of also developing a bad beam on profile 11. On profile 44 a second beam of the UL started going bad and the spare #24497 was swapped in again and used as the UL for the remainder of the cruise.

3 Sampling Conditions

Figure 2 shows the maximum profile depths as well as the number of net rotations experienced by the CTD package during each cast. Most profiles extend below 4000 m with the deepest profiles near the beginning of the cruise (left figure panel). Package rotation was rather unusual, with almost exclusively clockwise rotation during the downcasts and consistently more net rotations *of either sign* during the upcasts. During the entire cruise the rosette performed a net total of 393 clockwise

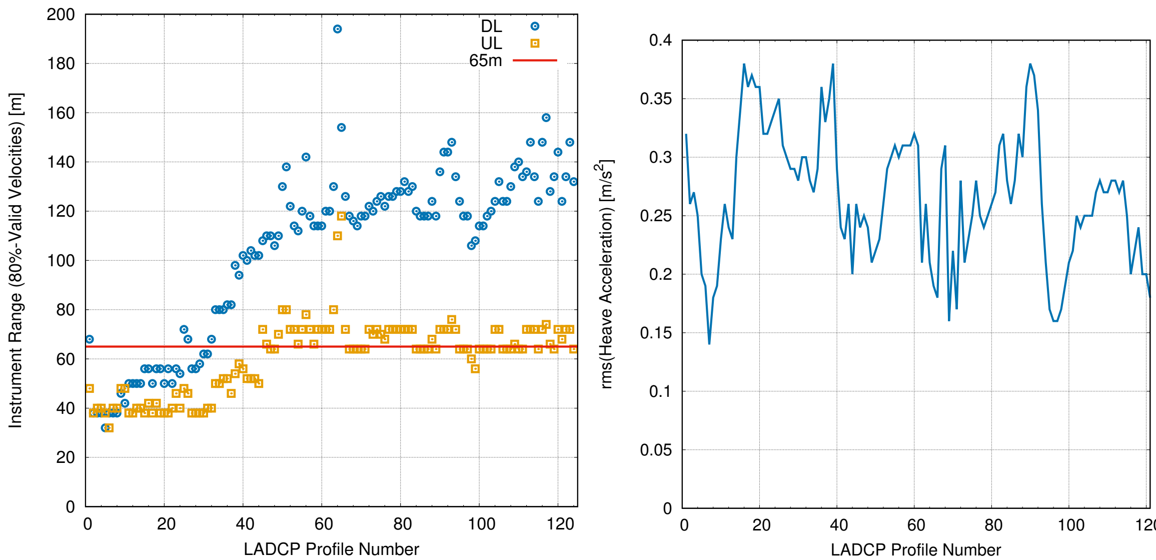

Figure 3: Left panel: Instrument range, with the red line indicating the minimum range (65 m) typically required for successful processing of full-depth LADCP profiles from a single 300 kHz TRDI Workhorse ADCP. Right panel: *rms* vertical acceleration due to vessel heave (sea state).

rotations.

LADCP data quality is sensitively dependent on instrument range (Figure 3, left panel), which depends on the acoustic scattering environment. During the first third of I7N the acoustic backscatter was extremely weak with a WH300 range consistently below 65 m (an empirical limit for good data). From profile 40 onward acoustic backscatter was more reasonable although the WH300 range never rose significantly above the 65 m range threshold. Sea state is also known to affect LADCP data quality in some cases; in the right panel of Figure 3 sea state is quantified as the *rms* vertical package acceleration. Conditions during the cruise ranged from calm (around $0.15\,\mathrm{m{\cdot}s^{-2}}$) to stormy (around $0.3\,\mathrm{m{\cdot}s^{-2}}$ or greater).

4 Horizontal Velocity

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–$6\,\mathrm{cm{\cdot}s^{-1}}$ when averaged over a few profiles. In case of the I7N profiles, this criterion is clearly satisfied for the profiles after 45, without indications for sea-state dependent errors (Figure 4). The *rms* velocity discrepancy of $4.5\,\mathrm{cm{\cdot}s^{-1}}$ for these stations indicates that the corresponding horizontal LADCP velocities are of excellent quality, with larger uncertainties for profiles 1–45. Visual inspection of the diagnostic plots produced during processing indicates no glaring problems with the early velocity profiles either however, suggesting that the apparent problems due to low backscatter are likely restricted to low-wavenumber shear, which is at least partially corrected in the final velocity profiles for which all available referencing constraints are used, including the SADCP velocities. As a result, the final velocity uncertainties are

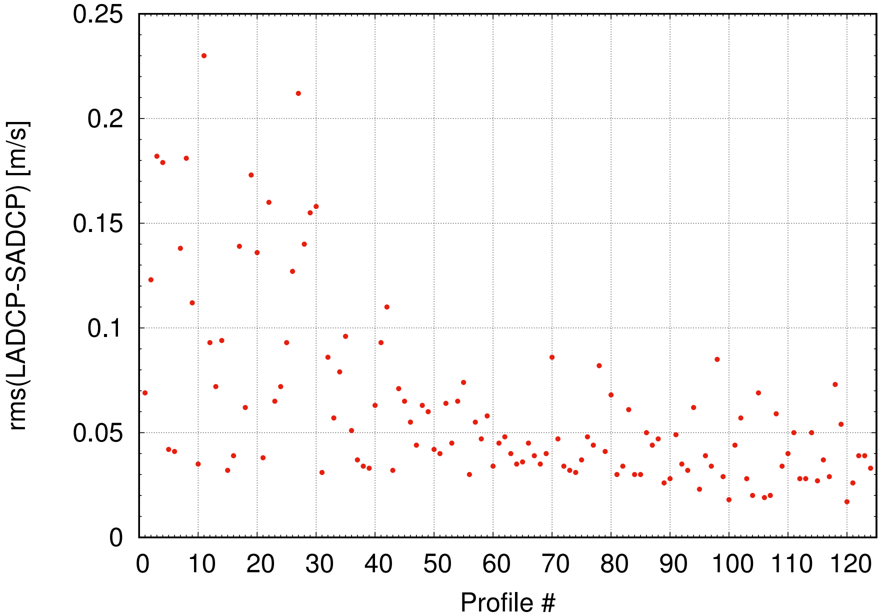

Figure 4: *rms* LADCP-SADCP horizontal velocity differences; low values indicate good agreement .

smaller than those shown in Figure 4, especially for profiles 1–45.

5 Vertical Velocity and VKE

In order to process the I7N LADCP data for vertical ocean velocity version 1.4 of the `LADCP_w` software is used. Across this section, depth-averaged VKE varies regionally by about factor 5, with generally good agreement between down- and up-cast data (Figure 5). In the early profiles where instrument range was low (Figure 3), higher apparent VKE is observed consistently in the downcast profiles. While this uncertainty obscures the spatial pattern south of profile 40 or so, depth-averaged VKE is clearly elevated over both the Mascarene Plateau (Figure 2, profiles 45–70) and Carlsberg Ridge (85–95). These patterns are consistent with elevated internal-wave energy, which dominates w in the ocean, over rough topography. More quantitatively, comparing the dc/uc averages to the corresponding magnitude differences indicates that many of the profile-averaged VKE values agree within factor 2 or better (Figure 5, right panel).

In order to evaluate vertical-velocity and VKE data from some previous cruises, correlations between the two almost completely independent w profiles collected by the DL and UL ADCPs were used as indicators of data quality. The I7N data indicate, however, that these correlations depend sensitively on the magnitude of the signal (Figure 6), implying that these correlation coefficients are not very useful absolute data-quality indicators. The UL-DL correlations may be useful, however, to compare the relative quality of two data sets. In case of I7N, the data for example suggest that the upcast w are significantly superior to the corresponding downcast data. This is not unreasonable, as the mean slower winch speed during the (bottle stops) increases oversampling of the velocity field. (In contrast to horizontal LADCP velocity, where instrument range is the most important parameter affecting data quality, vertical velocity can be improved by oversampling.) However, it is also possible

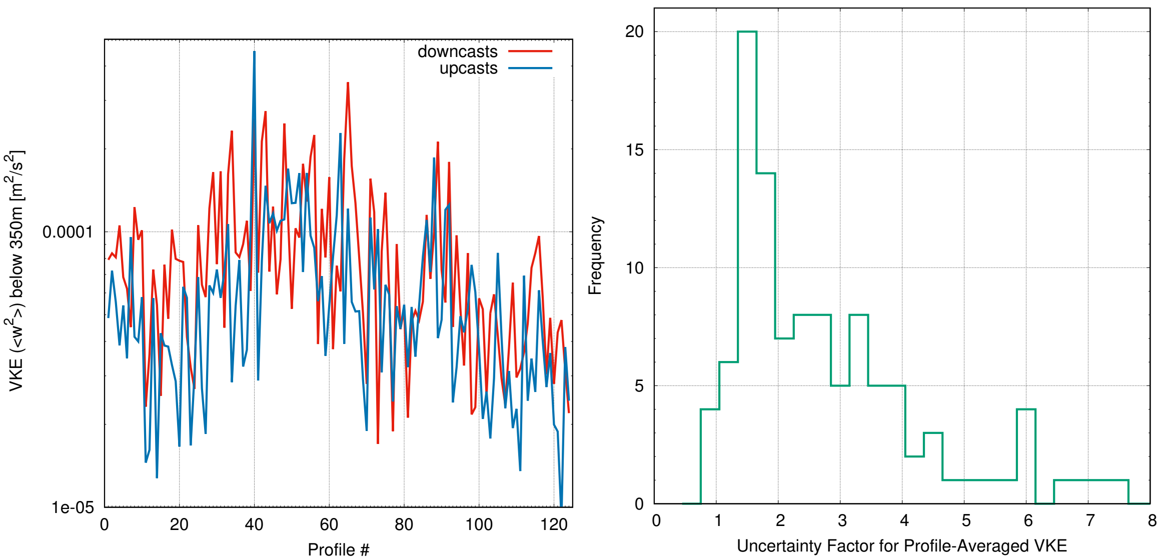

Figure 5: Station-averaged vertical kinetic energy (VKE). Left panel: Mean-square vertical velocity below 350 m. Right panel: Histogram of the ratios of spread-to-mean profile averaged VKE from the dc and uc data.

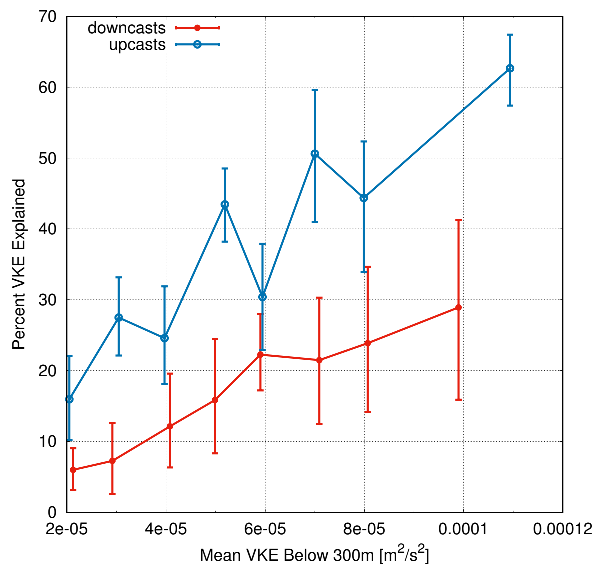

Figure 6: Correlation between UL and DL vertical velocities binned with respect to VKE; error bars indicate 95% confidence from bootstrapping.

that at least some of the apparently better upcast correlations are related to w artifacts associated with the bottle stops.

Another quantity that has been used to assess the quality of LADCP vertical velocities consist in

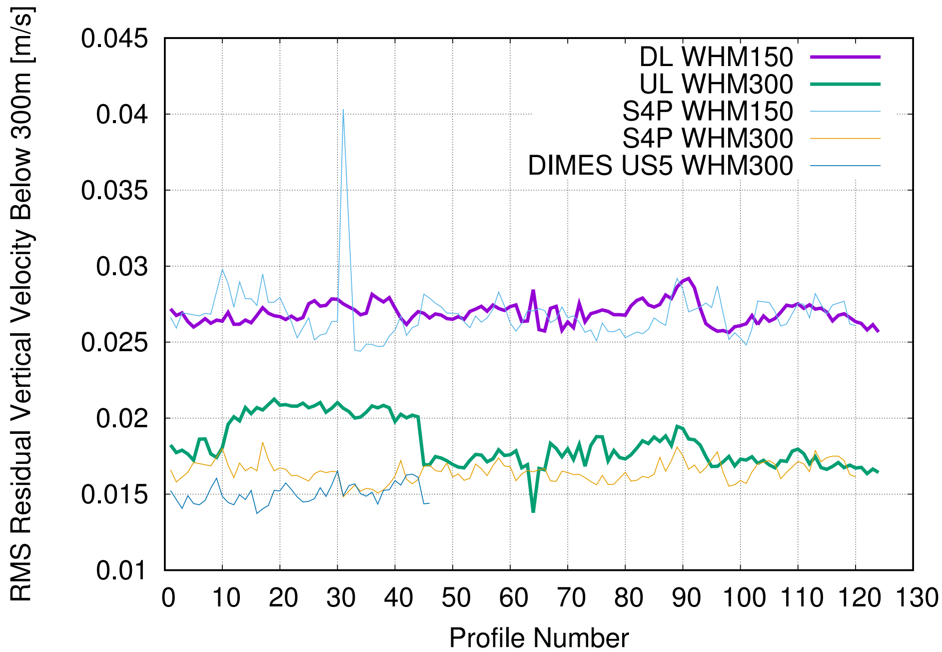

Figure 7: Profile-averaged (*rms*) residual vertical velocities below 300 m from the I7N DL and UL ADCPs (heavy lines), with corresponding values from other instruments and cruises for comparison (thin lines); see text for details.

the vertical velocity residuals w_{residual}, defined as

$$w_{\mathrm{residual}}[ens, bin] = w_{\mathrm{ADCP}}[ens, bin] - w_{\mathrm{CTD}}[ens] - w_{\mathrm{ocean}}[ens, bin], \tag{1}$$

where w_{ADCP} is a velocity measurement from a particular ensemble and bin, w_{CTD} is the vertical package velocity at the time of the ensemble, and w_{ocean} is the vertical ocean velocity (the median of all valid measurements at a given depth) at the time of the ADCP ensemble and at the depth of the measurement bin. Diagnostic plots of velocity residuals produced during processing are useful for detecting problems with particular instruments and/or individual beams. In order to evaluate whether w_{residual} is also useful for assessing the quality of individual vertical velocity profiles, per-profile *rms* values of w_{residual} below 300 m are compared to the corresponding values from two other cruises (Figure 7). It is clear that transducer frequency has a major influence on w_{residual}, consistent with the larger single-ping standard deviations of lower-frequency ADCPs. Based on this figure, WH150 instruments require approximately $3\times$ as many samples for the same level of vertical-velocity accuracy as WH300 ADCPs. For a given instrument, the velocity residuals in a profile with sufficient range are highly correlated with the corresponding *rms* vertical package acceleration due to vessel heave (Figure 3), which indicates that errors in w_{CTD}, rather than in w_{ADCP}, dominate the variability of w_{residual}. However, instrument range also plays a role, as clearly apparent in the I7N UL data from the early profiles. We conclude that while w_{residual} contains information about the profile quality, the close correlation with vessel motion makes this quantity a less than ideal diagnostic. However, the data in Figure 7 suggest that high-quality WH300 profiles collected with 8 m bins have residual vertical velocities around $1.5\,\mathrm{cm\cdot s^{-1}}$, whereas profile-average residuals exceeding $2\,\mathrm{cm\cdot s^{-1}}$ indicate potential

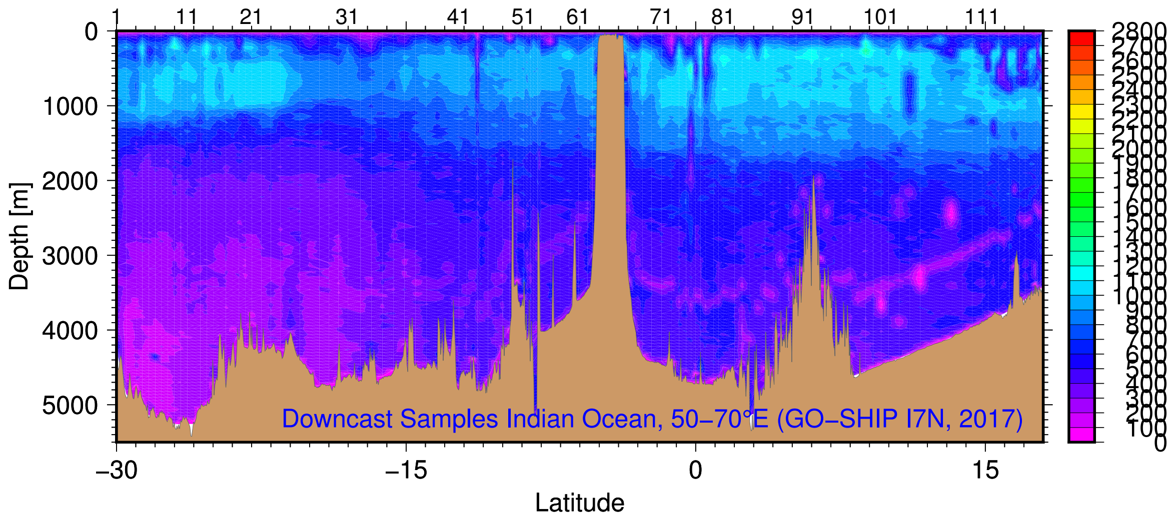

Figure 8: Number of vertical-velocity samples in each 40 m downcast bin.

problems. The corresponding limits for WH150 data are less clear because the two instruments used on I7N and S4P both had hardware problems.

The anomalously high downcast VKE and velocity residuals in the early profiles suggest insufficient sampling in the region of short instrument range. Inspection of individual w profiles from this region indicates elevated noise/errors below about 2000 m (not shown). Figure 8 shows that the region of increased errors corresponds closely with the region where fewer than 300 downcast samples are available in each 40 m bin. Therefore, vertical velocities derived from fewer than 300 samples were discarded before applying the VKE finestructure parameterization.

Estimates of kinetic energy dissipation ϵ_{VKE} were derived with a VKE-based finestructure parameterization method (Figure 1). Valid estimates are available from all profiles, except for #64 which is too shallow for the standard depth bins, as well as in the equatorial band (latitudes below 3°; profiles 68–84). Based on a recent comparison between VKE and chiPod data in the P6N section (Lele et al., in prep) in contrast to previous cruises the low-ϵ cutoff at $5 \times 10^{-11}\,\mathrm{W{\cdot}kg^{-1}}$ was disabled. In the I7N vertical-velocity profiles there are 3055 half-overlapping 320 m-wide spectral windows, including bottom windows, for which ϵ_{VKE} estimates can potentially be derived. Out of these, 1194 (≈39%) yield valid ϵ_{VKE} estimates, while the remainder either does not have sufficient velocity data or the spectra do not pass the consistency checks built into the processing software. Over the entire section, the valid ϵ estimates follow an approximately log-normal distribution centered at $8 \times 10^{-11}\,\mathrm{W{\cdot}kg^{-1}}$ with a standard deviation of about factor 3 (Figure 9). The spatial patterns in Figure 1 make physical sense, with higher abyssal turbulence levels over rough than over smooth topography.

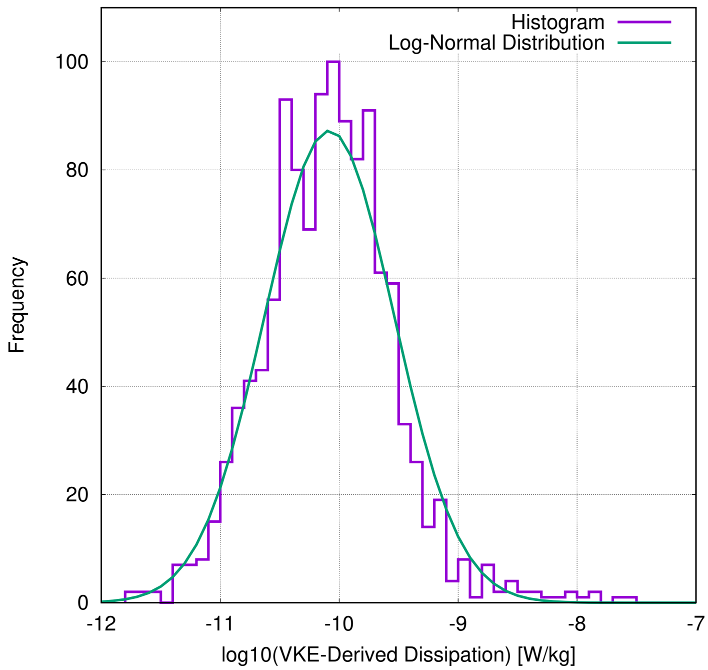

Figure 9: Distribution of all I7N VKE-derived dissipation estimates in log space (purple) and corresponding log-normal distribution with the same area, mean and standard deviation.