Title: Underwater Vision Profiler (UVP) Particle Size Distribution (PSD) Intercalibration for EXPORTSNA

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Summary:

Underwater Vision Profiler (UVP) Particle Size Distribution (PSD) observations from the RRS Discovery (DY131), RRS James Cook (JC214) and the R/V Sarmiento de Gamboa (SdG) during EXPORTSNA are intercompared using nearby in time and space casts. Four match-up casts were identified between DY131 and JC214 and two between the DY131 and SdG. PSD data from the DY131 and SdG UVPs were very similar; while the JC214 PSD data were considerably lower, particularly for the smaller size bins. Hence, it was decided to map the JC214 PSD observations to a consistent standard while the SdG observations were not corrected given the consistency between the DY131 and SdG matchups. DY131 PSD data were used as the "standard" as they were available throughout the entire cruise and were broadly consistent with SdG PSD results. The JC214 UVP data also had known issues due to the discovery of a zip tie in the field of view. Linear regression models were used to correct the JC214 PSD data to match best the DY131 for those bands where the linear correlation (r^2) value was greater than 0.8. Data were finally vertically binned to 25 m bins to enable better statistics for the largest size bins (without significantly altering the values of the smaller bin corrections). The resulting remapped data show consistency among the three UVP PSD data sources and provide a data set to explore the relationships among particle distributions and export fluxes.

UVP Data Sources:

Binned UVP-5 particle size distributions were provided from internal processing from the EcoTaxa particle module following processing procedures outlined in Picheral et al. (2010). Data were binned into 25 size bins and 5 m vertical bins and converted to differential form (#/vol/bin_width). Initial PSD data were uploaded from the June 22, 2022 collection from EcoTaxa. The same particle bin boundaries were used for all three UVP instruments (Table 1). For the JC214 UVP, the first bin (0.09 mm) did not have any data and the 2nd bin (0.11mm) had data for only 3 of the casts; these channels were replaced by NaNs. For many of the larger bins, there were no particles counted due to low particle densities. This is especially important for the SdG data as the SdG left the experiment site on May 19 and abundances of larger particles increased dramatically after that time (see below).

The JC214 UVP data had known issues due to the discovery of a zip tie in the field of view. This was accounted for in the processing of PSD retrievals by identifying the impacted zone in images and defining coordinates for the impacted zone (since it was in the corner of the image we used coordinates of a triangle). The impacted area was calculated and the image volume in the header file was adjusted in accordance. The image volume of sn201 after its last calibration was 1.13L and the adjusted volume after removing the impacted area was 1.06L). A filtering tool was then applied, removing the impacted area from the BRU files and associated vignettes. The entire data set was then reprocessed in Zooprocess accounting for the new volume. Given these issues, the DY131 PSD data were selected as the “standard” for intercomparison purposes.

Table 1: Particle bin characteristics

Bin Number	D_center (mm)	D_min (mm)	D_max (mm)	Data Available for Match-Ups to JC214	Data Available for Match-Ups to SdG
1	0.09	0.08	0.10	No	No
2	0.11	0.10	0.13	No	Yes
3	0.14	0.13	0.16	Yes	Yes
4	0.18	0.16	0.20	Yes	Yes
5	0.23	0.20	0.26	Yes	Yes
6	0.29	0.26	0.32	Yes	Yes
7	0.36	0.32	0.41	Yes	Yes
8	0.46	0.41	0.51	Yes	Yes
9	0.57	0.51	0.65	Yes	Yes
10	0.72	0.65	0.81	Yes	Yes
11	0.91	0.81	1.02	Yes	Yes
12	1.15	1.02	1.29	Yes	Yes
13	1.45	1.29	1.63	Yes	Yes
14	11.82	1.63	2.05	Yes	Yes
15	2.30	2.05	2.58	Yes	Yes
16	2.90	2.58	3.25	Yes	Yes
17	3.65	3.25	4.10	Yes	Yes
18	4.60	4.10	5.16	Yes	Yes
19	5.79	5.16	6.50	Yes	Yes
20	7.30	6.50	8.19	Yes	No
21	9.19	8.19	10.30	No	No
22	11.58	10.30	13.00	No	No
23	14.59	13.00	16.40	No	No
24	18.38	16.40	20.60	No	No
25	23.16	20.60	26.00	No	No

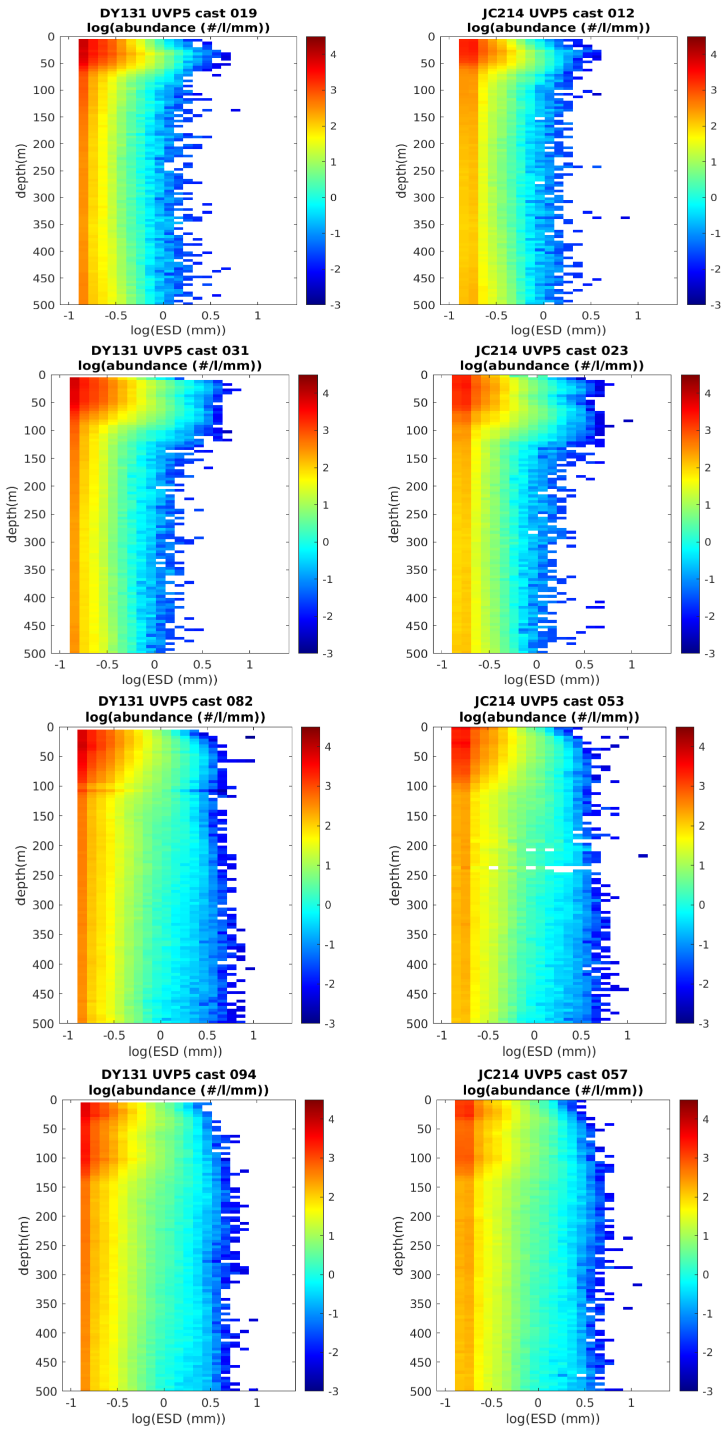
Match-Up Data:

Match-up casts were made between DY131 and either JC214 or SdG pairs were based upon distance and time. Maximum differences were set at 0.5 km and 0.5 hour for DY131 – JC214 pairs and 1.0 km and 0.5 hour for DY131 and SdG pairs. A total of 4 DY131 – JC214 pairs and 2 DY131-SdG pairs (Table 2). Note that the SdG match-ups did not span the entire EXPORTSNA campaign duration.

Table 2: Match up casts and time/distance separations

DY131-JC214 Pairs				DY131-SdG Pairs			
DY131 Cast	JC214 Cast	Dist (km)	Time (min)	DY131 Cast	SdG Cast	Dist (km)	Time (min)
19	12	0.47	0.6	19	6	0.50	10.2
31	23	0.48	2.2	31	10	0.90	6.4
82	53	0.32	2.2				
94	57	0.27	2.1				

The uncorrected match-up PSD spectral profiles are shown in Figure 1. A couple things to notice. At first glance, the JC214 UVP has considerably lower PSD values for the smallest few bins than the DY131 values; while the DY131 - SdG pair appear rather similar. Last, the DY131 - JC214 match-up pairs that were sampled towards the end of the cruise, shows considerably more large particles than was seen earlier in the cruise. That, and the known correction issues with the JC214 data set, necessitated the need to use DY131 as the standard.



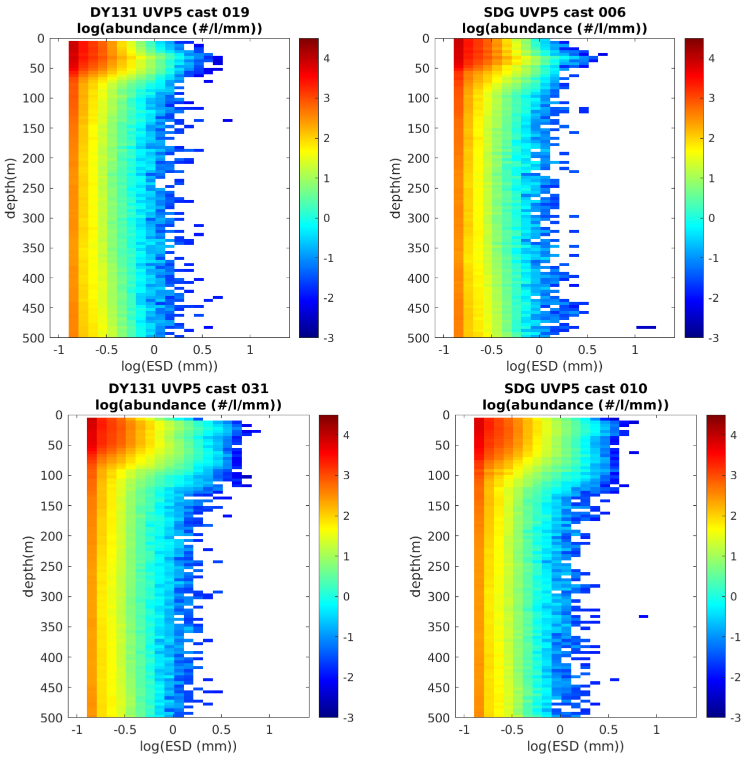
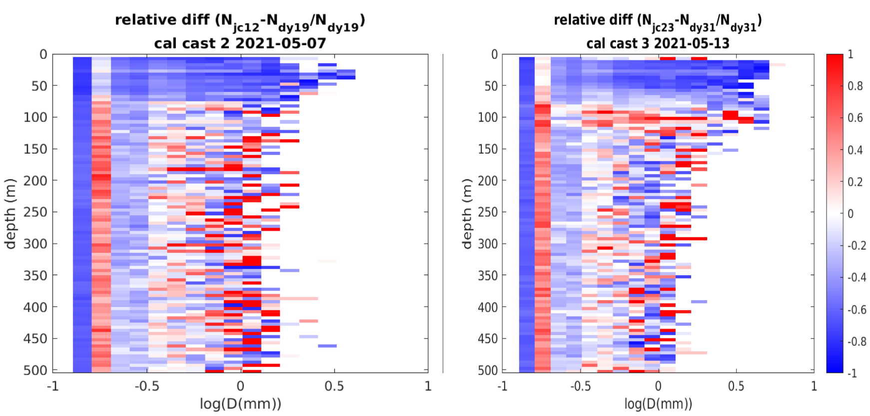


Figure 1: Match-up uncorrected PSD spectra profiles for the six paired casts. Top four rows are theJC214-DY131 pairs while the bottom two row are the- DY131-SdG pairs.



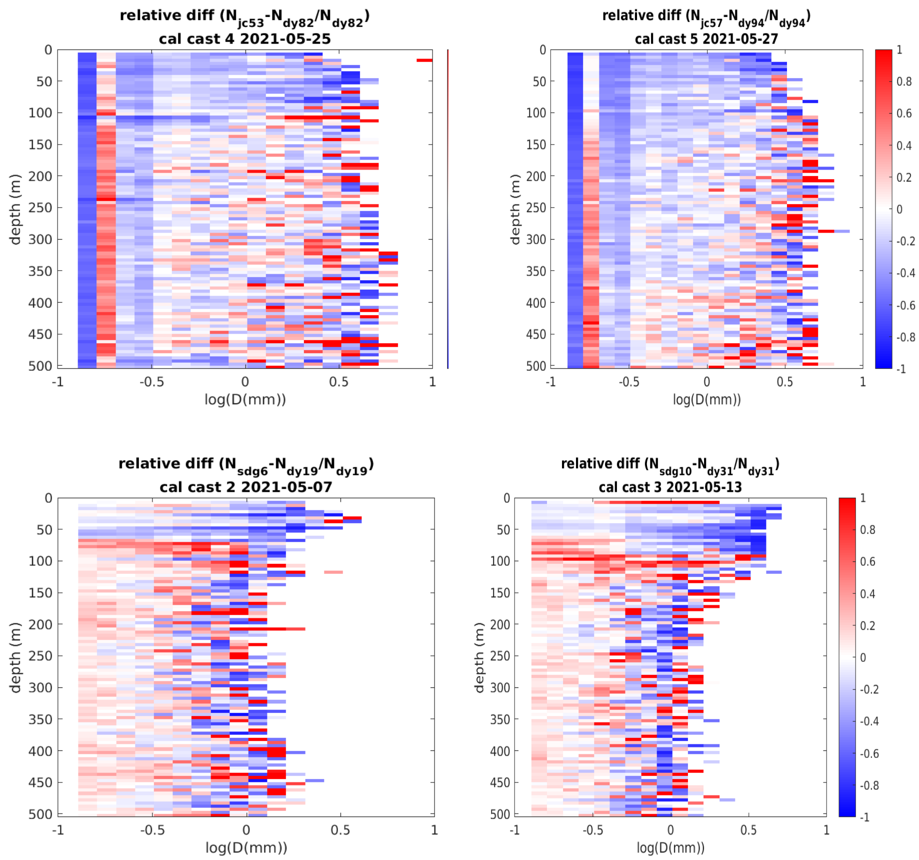


Figure 2: Relative difference (=(Data-Standard)/Standard) profiles for the 6 match-up profiles. Top two rows are the four JC214-DY131 pairs while the bottom row are the two DY131-SdG pairs. It is assumed here that the DY131 data are the reference standard.

Relative difference profiles (Figure 2) show that the JC214 PSD values in general underestimate the DY131 PSD values for particle bin sizes less than 1 mm by a factor of ≥ 50% with substantial bin-to-bin differences of both signs (note a positive normalized relative difference for bin 4). While the SDG slightly over-estimates (by a factor of roughly 15%) the DY131's PSD values for the smaller particle sizes. For all pairs there is a considerable amount of noise in the relative difference metrics for the largest 8 or so size bins where particles were counted. This is due to the sampling of rare large particles by the relatively small sample volume of the UVP (~1 L). This issue will be partially alleviated by binning both profiles over 25m intervals before comparison (see below).

Statistical comparisons were made in the 5 m binned log10-transformed abundance data for the six match-up PSD observations available (Supplemental Figure S1). The plots and fit parameters show good linear correspondence (fit $r^2 \geq 0.8$) for bin sizes of 0.72 mm and smaller throughout the experiment and for bin sizes up to 1 mm for the last pairs of DY131 - JC214 sampled. Correspondence in the plotted comparisons and regression coefficients are roughly similar for all same instrument match-up pairs. No obvious differences were seen in time.

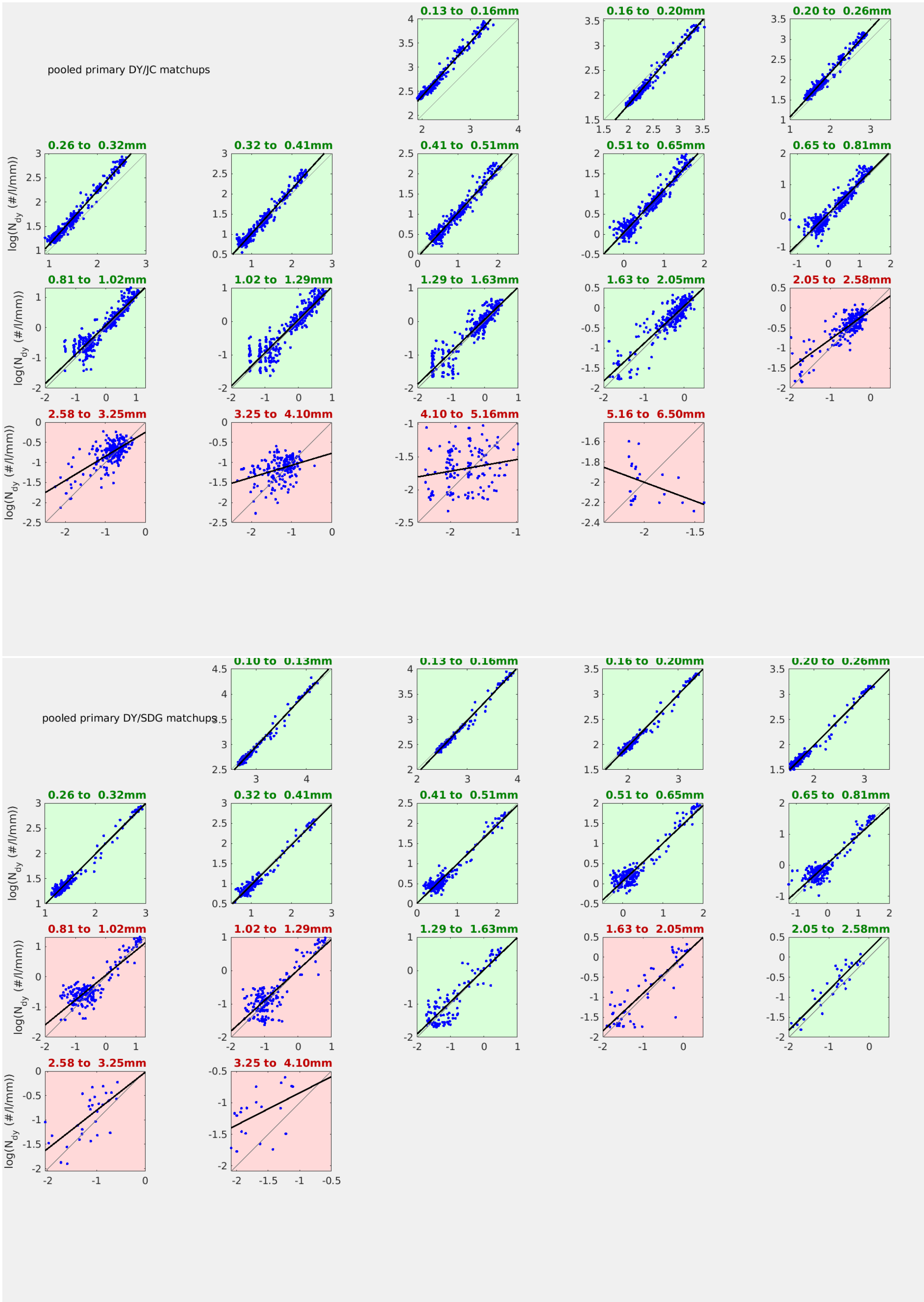


Figure 3: Pooled match-up casts for the JC214-DY131 pairs while the bottom two rows are the DY131-SdG. Match-ups are shown for UVP bins 2 to 17. The DY131 data is on the y-axis in both cases.

Based upon the broad correspondence among the individual pairs (Supplemental Figure 1), it was decided to pool among all available data (Figure 3). This improved the fits for the larger size bins without sacrificing the goodness of fit metrics for the smaller size PSD bins. In fact, reasonable correspondence (fit $r^2 \geq 0.8$) is found up to 2 mm for both pairs of instruments when pooled (see blue lines in figure 4). Perfect correspondence would be a slope value of zero and an offset of zero. Slopes for the DY131 - JC214 pairs are significantly greater than 1 for particle bins of ~1.5 mm and smaller, while they are much closer to one with the DY131 - SdG pairs. Given the close similarity of the DY131 - SdG pairs (see figures to follow), it was decided not to map the SdG PSD data to the DY131 observations.

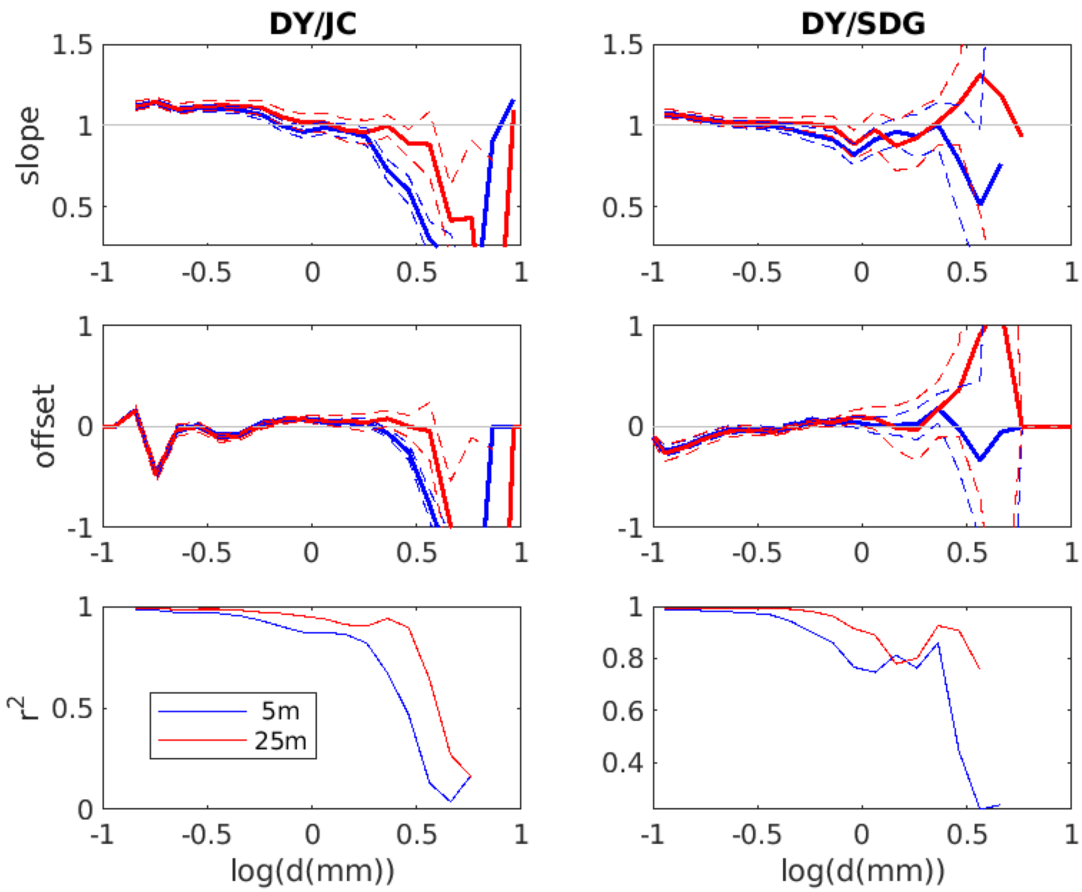


Figure 4: Slope, offset and r2 of the log-log fits between pooled instrument pairs as a function of bin size. Left panels are DY131/JC214 pairs and right panels are DY131/SdG pairs. The 5 m binned data are in blue while 25 m vertical bins are red. The dashed lines are 95% confidence intervals for the fit.

In an attempt to increase the validity of the larger sized bins, the PSD observations were vertically into 25 m bins before comparison (Figure 4). This reduces the noise seen in Figure 2 of the 5m differences, but does not affect the coefficient values substantively. Based upon these results, it was decided that the 25 m binned PSD observations would be used to correct the JC214 UVP PSD observations to best match the DY131 UVP PSD values (Figure 5). Regression models were applied to correct the UVP data only if the fit r^2 values were greater than 0.8 (these are shown in green). For those bins where the pairs do not give good fits, corrections were not made for these channels. Tables of regression coefficients and uncertainty estimates for the coefficients are in the supplementary section.

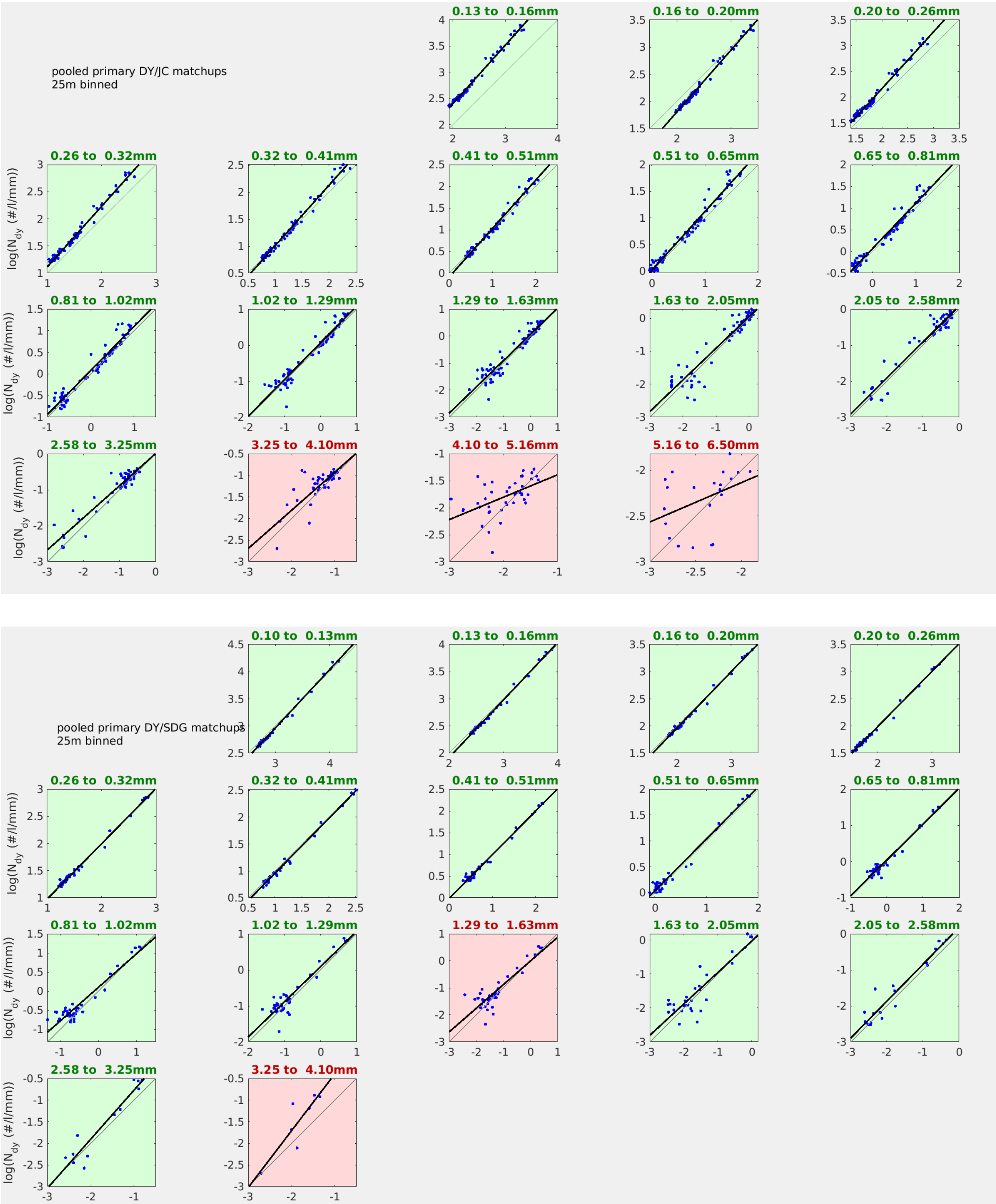


Figure 5: Comparison of the 25 m binned DY131/JC214 pairs (upper) and the DY131/SdG pairs (lower). Match-ups are created for UVP bins 3 to 19 for DY131/JC214 and bins 2 to 17 for DY131/SdG. Green boxes mean that the fit r2 value is greater than 0.8. Red boxes refer to poorer fits and these channel corrections were not made. Corrections were only performed on the JC214 UVP data.

Results:

Examples of the impacts of the correction are shown in Figures 6 and 7 for small (0.14 mm) and large (0.91 mm) particle abundances all from within 15 km of the A2 eddy center (selected to minimize spatial variations). Upper panels are uncorrected abundances, middle panel corrected and bottom panel the ratio of corrected to uncorrected abundances. Changes to the JC214's small particle bins are quite large, a factor of about 3.5 near the sea surface and decreasing to ~2.7 at depth (Figure 6). The correction procedure makes the small particle abundance sequence in time more logical with much less flipping back and forth due to data sources. Changes in larger particle sizes are less striking (more like factors of 17 to 25%) although the corrected JC214 values are larger.

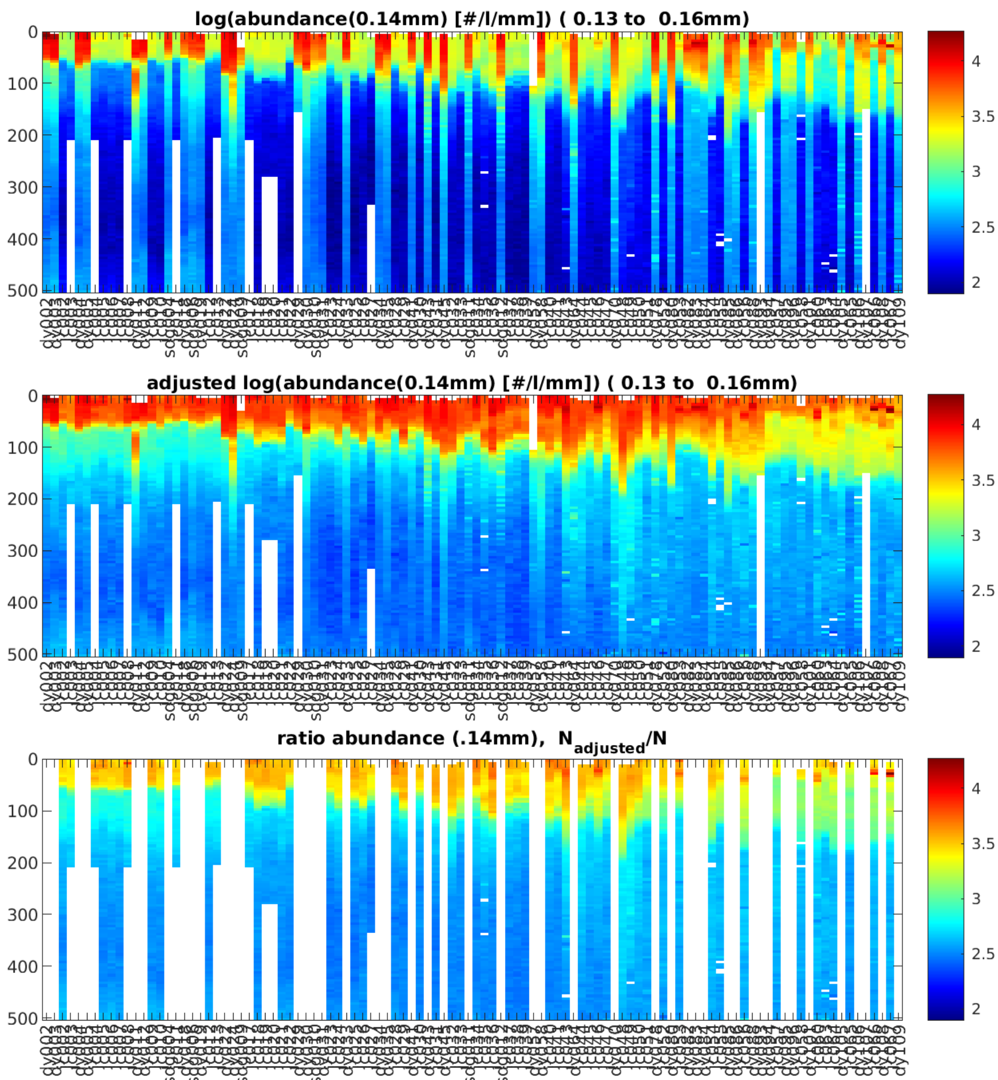


Figure 6: Sequential time series of profiles near eddy center (within 15 km) of the abundances of 0.14 mm particles (bin 3; in #/L/mm). Upper panel are the uncorrected abundances, middle panel the corrected and bottom panel the ratio of corrected to uncorrected values (the DY131

& SdG profiles are whited out). Ship and cast numbers are in the x-labels. These observations are in sequential cast order but are not a regular time series.

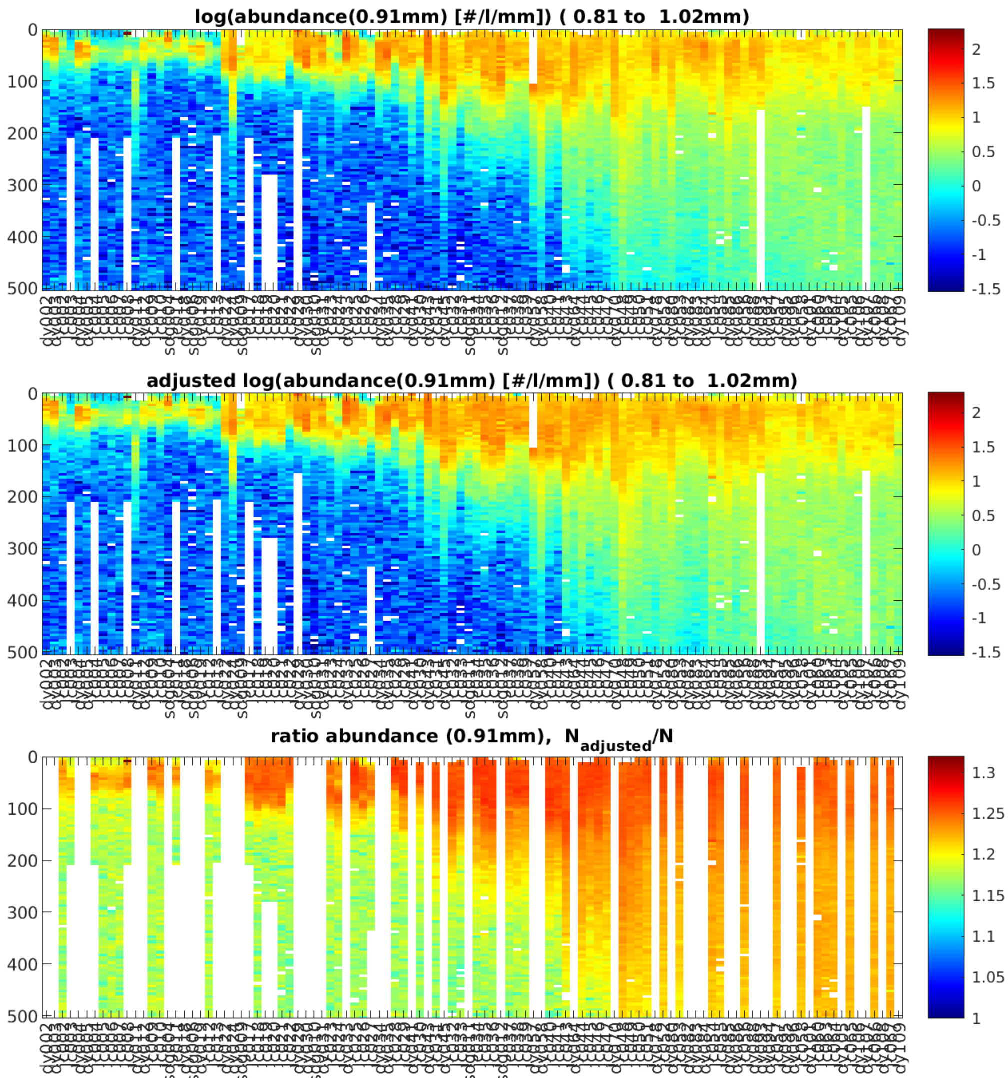


Figure 7: Sequential series of profiles near eddy center (within 15 km) of the abundances of 0.91 mm particles (bin 11; in #/L/mm). Upper panel are the uncorrected abundances, middle panel the corrected and bottom panel the ratio of corrected to uncorrected values (the DY131 & SdG profiles are whited out). Ship and cast numbers are in the x-labels.

Normalized differences for the eddy center mean profiles between JC214 and DY131 PSD before and after correction are shown in Figure 8. The linear mapping performed greatly reduced the underestimates and bin-to-bin inconsistencies between the two data sets. Good consistency in the remapped JC214 PSD data is found up to about bin 17 (3.65 mm bin center). No remapping was done for JC214 bins 17 and higher as discussed above. Hence, an underestimate between the two data sources is observed.

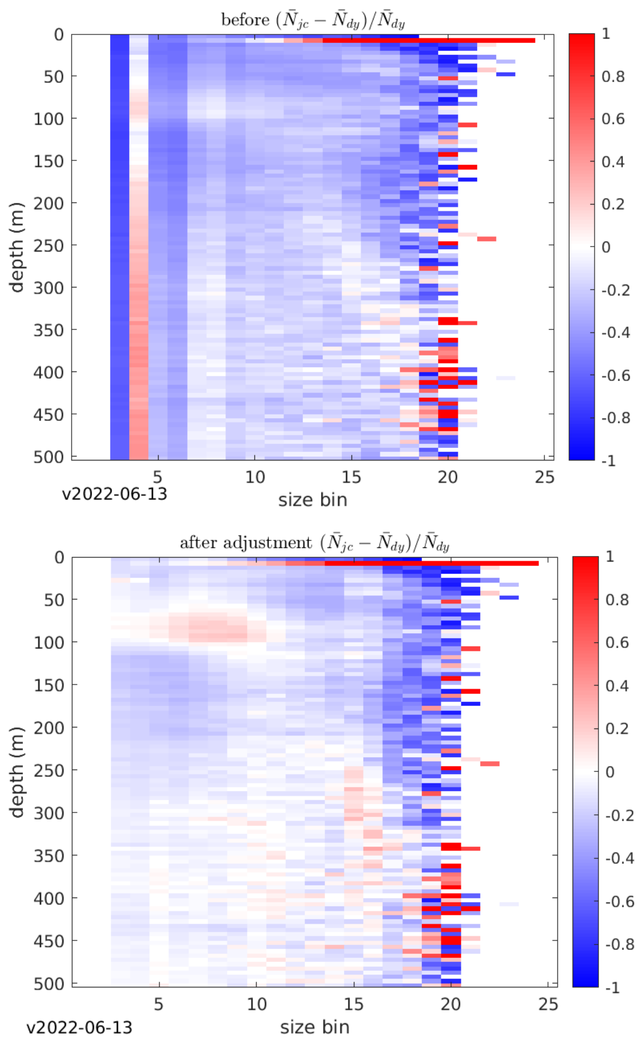


Figure 8. Normalized difference of the cruise-mean abundance (within eddy) before (top) and after (bottom) adjustment to the Cook data (bins 3-16).

Data Availability:

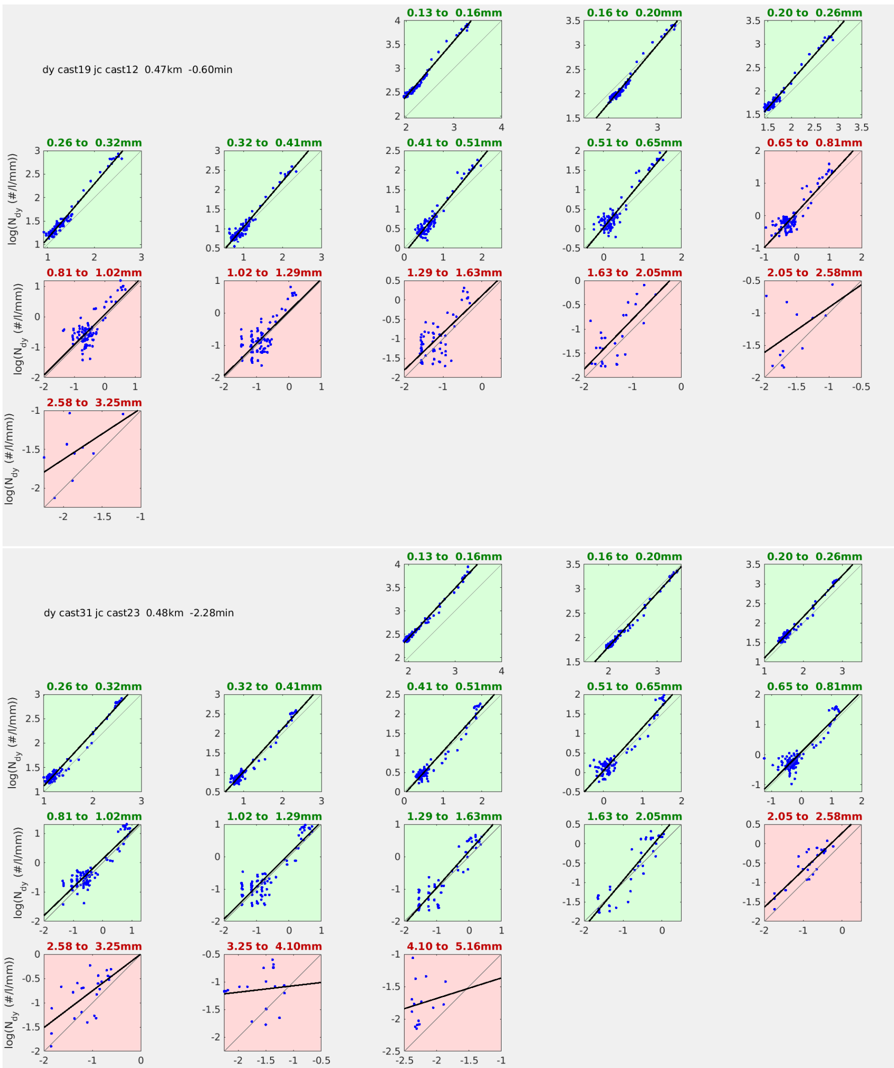
Given the consistency of the corrected JC214 PSD observations with the DY131 and the consistency of the uncorrected DY131/SdG pairs, it was decided to release an interim corrected UVP PSD data set for EXPORTSNA. Data in Matlab .mat format with example m-file are available on the EXPORTS google drive in the 'North Atlantic / UVP / Merged UVP PSD data July 2022' shared data folder.

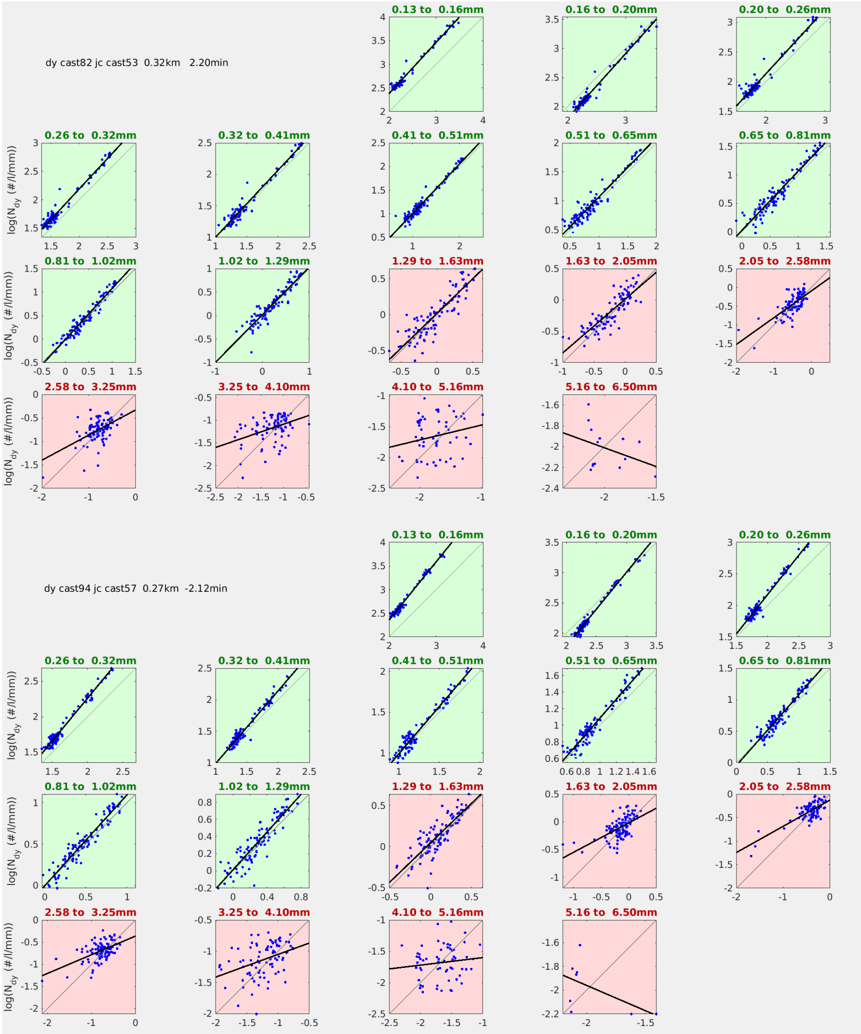
References:

Picheral, M., Guidi, L., Stemmann, L., Karl, D.M., Iddaoud, G. and Gorsky, G., 2010. The Underwater Vision Profiler 5: An advanced instrument for high spatial resolution studies of particle size spectra and zooplankton. *Limnology and Oceanography: Methods*, *8*(9), pp.462-473.

Supplementary Figures:

Figure S1: Band by band match-up comparisons using 5 m binned data for the DY131-JC214 (top four panels) and the DY131-SdG (lower two panels). DY131 observations on the y-axis. All Data are log10-transformed before the fits.




dy cast82 jc cast53 0.32km 2.20min
0.13 to 0.16mm
0.16 to 0.20mm
0.20 to 0.26mm
0.26 to 0.32mm
0.32 to 0.41mm
0.41 to 0.51mm
0.51 to 0.65mm
0.65 to 0.81mm
0.81 to 1.02mm
1.02 to 1.29mm
1.29 to 1.63mm
1.63 to 2.05mm
2.05 to 2.58mm
2.58 to 3.25mm
3.25 to 4.10mm
4.10 to 5.16mm
5.16 to 6.50mm
log(N_dy (#/l/mm))
dy cast94 jc cast57 0.27km -2.12min
0.13 to 0.16mm
0.16 to 0.20mm
0.20 to 0.26mm
0.26 to 0.32mm
0.32 to 0.41mm
0.41 to 0.51mm
0.51 to 0.65mm
0.65 to 0.81mm
0.81 to 1.02mm
1.02 to 1.29mm
1.29 to 1.63mm
1.63 to 2.05mm
2.05 to 2.58mm
2.58 to 3.25mm
3.25 to 4.10mm
4.10 to 5.16mm
5.16 to 6.50mm
log(N_dy (#/l/mm))

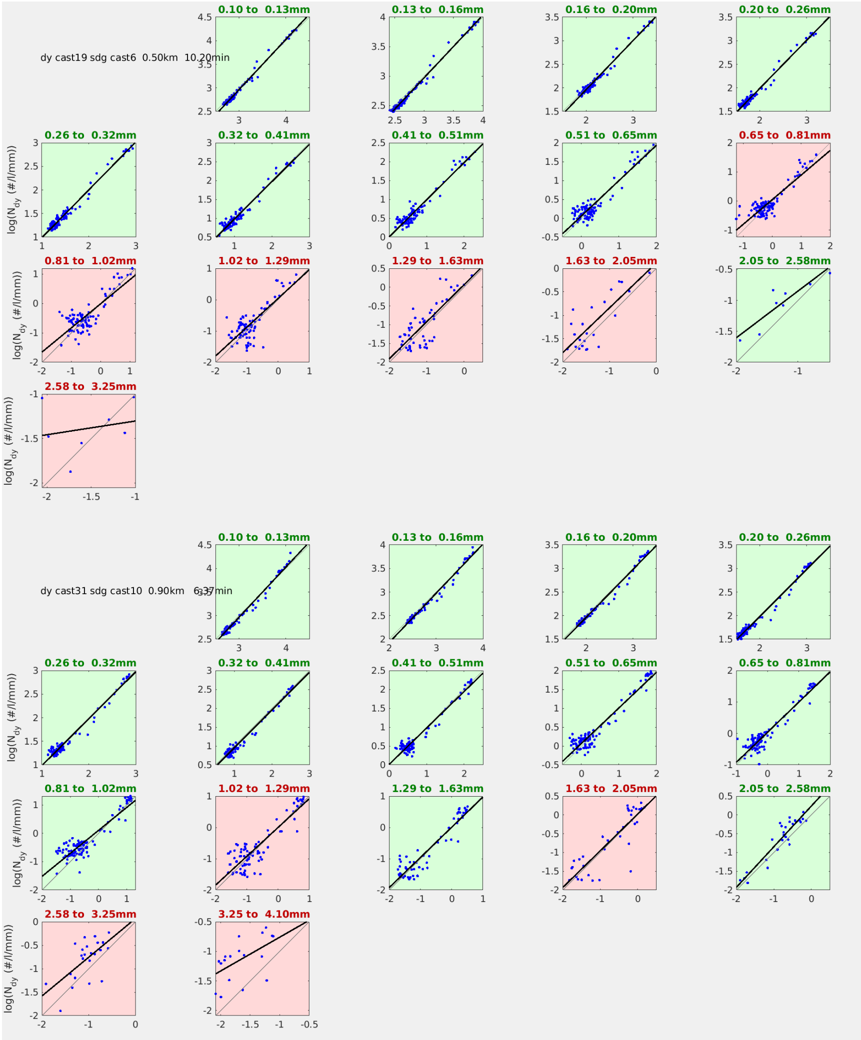

dy cast19 sdg cast6 0.50km 10.20min
0.10 to 0.13mm
0.13 to 0.16mm
0.16 to 0.20mm
0.20 to 0.26mm
0.26 to 0.32mm
0.32 to 0.41mm
0.41 to 0.51mm
0.51 to 0.65mm
0.65 to 0.81mm
0.81 to 1.02mm
1.02 to 1.29mm
1.29 to 1.63mm
1.63 to 2.05mm
2.05 to 2.58mm
2.58 to 3.25mm
log(N_dy (#/l/mm))
dy cast31 sdg cast10 0.90km 6.37min
0.10 to 0.13mm
0.13 to 0.16mm
0.16 to 0.20mm
0.20 to 0.26mm
0.26 to 0.32mm
0.32 to 0.41mm
0.41 to 0.51mm
0.51 to 0.65mm
0.65 to 0.81mm
0.81 to 1.02mm
1.02 to 1.29mm
1.29 to 1.63mm
1.63 to 2.05mm
2.05 to 2.58mm
2.58 to 3.25mm
3.25 to 4.10mm
log(N_dy (#/l/mm))

Table S1: Excel table of the regression coefficients and uncertainty bounds for the DY131/JC214 pairs (upper) and the DY131/SdG pairs (lower)

d	binEdges_1	binEdges_2	slope	slopeCI_1	slopeCI_2	offset	offsetCI_1	offsetCI_2	npts	r2	rmsDiff	rmsNDiff	s
0.0905	0.0806	0.1020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0				
0.1140	0.1020	0.1280	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0				
0.1437	0.1280	0.1610	1.1193	1.0918	1.1469	0.1577	0.0932	0.2222	80	0.9882	0.0461	0.0158	
0.1810	0.1610	0.2030	1.1433	1.1167	1.1698	-0.4808	-0.5446	-0.4170	80	0.9895	0.0438	0.0180	
0.2280	0.2030	0.2560	1.1006	1.0686	1.1326	-0.0354	-0.0953	0.0246	80	0.9836	0.0541	0.0265	
0.2873	0.2560	0.3230	1.1168	1.0863	1.1472	-0.0024	-0.0504	0.0457	80	0.9856	0.0545	0.0308	
0.3620	0.3230	0.4060	1.1220	1.0915	1.1526	-0.1137	-0.1553	-0.0721	80	0.9856	0.0589	0.0435	
0.4561	0.4060	0.5120	1.1193	1.0834	1.1553	-0.0947	-0.1337	-0.0557	80	0.9801	0.0731	0.0777	
0.5746	0.5120	0.6450	1.1070	1.0635	1.1505	0.0120	-0.0230	0.0469	80	0.9705	0.0951	5.6471	
0.7239	0.6450	0.8130	1.0499	1.0042	1.0956	0.0586	0.0298	0.0874	80	0.9641	0.1119	0.3802	
0.9121	0.8130	1.0200	1.0171	0.9651	1.0690	0.0813	0.0507	0.1120	80	0.9512	0.1360	0.9212	
1.1492	1.0200	1.2900	1.0165	0.9576	1.0754	0.0617	0.0200	0.1034	80	0.9380	0.1735	4.4931	
1.4478	1.2900	1.6300	0.9701	0.9012	1.0389	0.0556	-0.0113	0.1226	80	0.9097	0.2364	1.2297	
1.8241	1.6300	2.0500	0.9569	0.8826	1.0312	0.0435	-0.0472	0.1341	74	0.9015	0.2748	36.5052	
2.2983	2.0500	2.5800	0.9972	0.9311	1.0633	0.0804	0.0021	0.1587	60	0.9402	0.1955	0.6046	
2.8956	2.5800	3.2500	0.8901	0.8051	0.9750	0.0038	-0.1054	0.1129	54	0.8947	0.1984	0.2321	
3.6482	3.2500	4.1000	0.8827	0.6813	1.0840	-0.0443	-0.3281	0.2395	46	0.6395	0.2474	0.1997	
4.5964	4.1000	5.1600	0.4146	0.1964	0.6327	-0.9779	-1.4159	-0.5399	42	0.2694	0.2738	0.1471	
5.7911	5.1600	6.5000	0.4303	-0.0467	0.9073	-1.2740	-2.4397	-0.1083	21	0.1580	0.2909	0.1211	
7.2963	6.5000	8.1900	-0.9291	-2.6402	0.7821	-5.0962	-9.9685	-0.2239	4	0.7318	0.0710	0.0297	
9.1927	8.1900	10.3000	1.0935			0.0000	0.0000	0.0000	1		0.0000	0.0000	
11.5820	10.3000	13.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0				
14.5923	13.0000	16.4000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0				
18.3850	16.4000	20.6000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0				
23.1634	20.6000	26.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0				

d	binEdges_1	binEdges_2	slope	slopeCI_1	slopeCI_2	offset	offsetCI_1	offsetCI_2	npts	r2	rmsDiff	rmsNDiff
0.0905	0.0806	0.1020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0			
0.1140	0.1020	0.1280	1.0743	1.0470	1.1016	-0.2604	-0.3426	-0.1782	40	0.9941	0.0340	0.0107
0.1437	0.1280	0.1610	1.0586	1.0317	1.0856	-0.2008	-0.2753	-0.1263	40	0.9940	0.0339	0.0118
0.1810	0.1610	0.2030	1.0372	1.0088	1.0656	-0.1118	-0.1752	-0.0484	40	0.9931	0.0373	0.0164
0.2280	0.2030	0.2560	1.0191	0.9928	1.0454	-0.0509	-0.1022	0.0004	40	0.9939	0.0357	0.0183
0.2873	0.2560	0.3230	1.0162	0.9878	1.0446	-0.0361	-0.0826	0.0103	40	0.9928	0.0424	0.0271
0.3620	0.3230	0.4060	1.0172	0.9898	1.0446	-0.0591	-0.0944	-0.0239	40	0.9933	0.0440	0.0444
0.4561	0.4060	0.5120	1.0107	0.9753	1.0462	-0.0192	-0.0526	0.0143	40	0.9887	0.0588	0.1127
0.5746	0.5120	0.6450	1.0074	0.9602	1.0545	0.0328	0.0006	0.0650	40	0.9801	0.0812	8.4933
0.7239	0.6450	0.8130	0.9908	0.9265	1.0550	0.0429	0.0055	0.0803	40	0.9625	0.1139	0.7184
0.9121	0.8130	1.0200	0.8819	0.7932	0.9707	0.0972	0.0282	0.1662	40	0.9142	0.1712	1.1585
1.1492	1.0200	1.2900	0.9732	0.8609	1.0856	0.0860	-0.0260	0.1979	40	0.8901	0.2067	0.2801
1.4478	1.2900	1.6300	0.8731	0.7205	1.0256	-0.0117	-0.2306	0.2072	40	0.7795	0.3175	0.3763
1.8241	1.6300	2.0500	0.9246	0.7457	1.1035	-0.0284	-0.3393	0.2825	30	0.8001	0.3418	0.5561
2.2983	2.0500	2.5800	1.0210	0.8776	1.1645	0.1717	-0.1075	0.4510	20	0.9255	0.2312	0.2563
2.8956	2.5800	3.2500	1.1333	0.8772	1.3894	0.3641	-0.1012	0.8294	12	0.9068	0.2403	0.1817
3.6482	3.2500	4.1000	1.3116	0.4577	2.1655	0.9174	-0.7037	2.5385	7	0.7572	0.3117	0.2346
4.5964	4.1000	5.1600	1.1834	-0.1918	2.5586	1.1830	-2.3806	4.7465	4	0.8727	0.1444	0.0805
5.7911	5.1600	6.5000	0.9288			0.0000	0.0000	0.0000	1		0.0000	0.0000
7.2963	6.5000	8.1900	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0			
9.1927	8.1900	10.3000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0			
11.5820	10.3000	13.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0			
14.5923	13.0000	16.4000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0			
18.3850	16.4000	20.6000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0			
23.1634	20.6000	26.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0			