Interactive comment on “Carbon Export and Fate Beneath a Dynamic Upwelled Filament off the California Coast” *by* Hannah L. Bourne et al.

Anonymous Referee #2

Received and published: 4 December 2020

*Author responses are highlighted in blue. We denote major responses with [**Rn**]*

Summary: This paper describes measurements of sinking particle flux collected from the California Current Ecosystem – LTER site. A series of deployments of Carbon Flux Explorers, which are autonomous platforms that collect and image sinking particles, was conducted from onshore to offshore inside and outside of a high-chlorophyll filament. The data show a large particle flux signal and large differences inside and outside of the filament. Additionally, there appears to be a great deal of vertical variability of particle flux which departed from a traditional “Martin curve” flux profile in all cases and increased with depth in many of the observations.

General comments: The authors have collected a detailed, valuable set of data using state-of-the-art sampling technology. In situ imagery of sinking particles is difficult to collect and provides important information about particle origins and physical properties. In addition, this data set was collected within the context of the long-running CCE-LTER timeseries and will add a lot to our understanding of this complex system. For these reasons I hope to eventually see these data published.

However, the present interpretation of the observations is a difficult read, and many of the authors’ conclusions are not strongly supported by the data as they are currently presented. In general, the number of figures and length of the text need to be reduced to focus on the evidence that supports the authors’ main conclusions. Many of the methodological details relating to the CFE could be shortened and replaced with a reference to Bishop et al. (2016).

*[**R1**] – We will work on simplifying the text; however we feel that the figures are necessary to document our study. The number of lines of description similar to Bishop et al. (2016) methodology is small, those provided are for continuity.*

There are many qualitative or weakly-supported statements about the observations that should be removed, replaced with quantitative, statistically robust interpretations, or supported with additional references to other studies or data. Certain conclusions may need to be revised depending on whether they are actually supported by the data. For instance, while uncertainties in Martin “b” exponents were computed (Table 2), and are relatively large, they do not seem to have been considered in the interpretation. All discussion of Martin “b” values should take the uncertainties into account, and all statements made about the measured “b” values should first be evaluated for statistical significance given the very large relative uncertainties. The overall conclusions of the paper should be reevaluated once the uncertainties in the “b” values are considered

*[**R2**] – We have considered sources of error (see revised tables below), however, our conclusions have not changed appreciably. See our comment [**R7**] to Reviewer 1 and details provided below.*

A summary of this response is here: “We added p values which test if the regressions have a slope that is zero. 14 of 24 attenuance regressions, including all cases at L2, yielded significant non-zero slopes at a >95% confidence level. Similarly 17 of 24 regressions on number flux yielded significant non-zero slopes. The smallest size fractions at all locations have significant non-zero slopes. The regressions for larger sized particles typically have high p values and low R^2 values which together indicate that depth has little significance to the regression. Thus our main conclusions are not significantly changed. We will introduce wording in the text that reflects the statistical results.”

Table 2. Martin Curve Fits to Attenuance Flux (All Dives)

Location	Zref	size bin	Martin Curve 'b'	b-Error	Intercept	intercept Error	SE_y	R2	n	p
1	50	30-100	-1.57	0.51	-0.280	0.297	0.263	0.735	13	**0.0002**
1	50	100-200	-0.97	0.38	-0.175	0.224	0.199	0.648	13	**0.0009**
1	50	200-400	-0.24	0.37	0.201	0.216	0.191	0.106	13	0.2771
1	50	400-1000	-0.23	0.54	0.081	0.317	0.281	0.048	13	0.4728
1	50	>1000	0.62	0.66	0.974	0.386	0.342	0.204	13	0.1214
1	50	Total	0.37	0.59	1.176	0.344	0.305	0.105	13	0.2791
2	100	30-100	-0.58	0.19	-1.020	0.074	0.130	0.505	29	**<0.0001**
2	100	100-200	-0.80	0.26	-0.455	0.101	0.177	0.510	29	**<0.0001**
2	100	200-400	-1.98	0.41	0.871	0.162	0.283	0.717	29	**<0.0001**
2	100	400-1000	0.80	0.34	-0.330	0.134	0.234	0.373	29	**0.0004**
2	100	>1000	1.57	0.58	0.444	0.232	0.395	0.452	28	**<0.0001**
2	100	Total	0.85	0.31	0.925	0.122	0.214	0.451	28	**0.0001**
3	100	30-100	-1.61	0.59	-1.026	0.206	0.245	0.657	14	**0.0004**
3	100	100-200	-1.57	0.59	-0.586	0.205	0.244	0.646	14	**0.0005**
3	100	200-400	-1.10	0.58	-0.277	0.200	0.238	0.485	14	**0.0056**
3	100	400-1000	0.05	0.83	-0.755	0.286	0.341	0.001	14	0.9198
3	100	>1000	-0.44	0.85	0.486	0.304	0.347	0.071	13	0.3797
3	100	Total	-0.45	0.70	0.583	0.242	0.288	0.099	14	0.1653
4	100	30-100	-0.97	0.42	-0.833	0.145	0.229	0.492	19	**0.0008**
4	100	100-200	-0.75	0.50	-0.573	0.174	0.276	0.283	19	**0.0190**
4	100	200-400	-0.66	0.54	-0.225	0.187	0.296	0.213	19	**0.0466**
4	100	400-1000	-0.42	0.66	0.172	0.230	0.364	0.068	19	0.2827
4	100	>1000	-0.21	0.71	1.307	0.246	0.390	0.015	19	0.6180
4	100	Total	-0.24	0.68	1.376	0.238	0.377	0.021	19	0.5538

Notes: errors are 95% confidence intervals. p value denotes the probability that the slope is zero. ***Bold****: better than <5% probability*

Table 3. Martin Curve Fits to Number Flux (All Dives)

Location	Zref	size bin	Martin Curve 'b'	b-Error	Intercept	intercept Error	SE_y	R2	n	p
1	50	30-100	-1.57	0.47	6.486	0.278	0.247	0.759	13	**0.0001**
1	50	100-200	-1.26	0.42	5.632	0.245	0.217	0.723	13	**0.0002**
1	50	200-400	-0.73	0.38	5.099	0.224	0.199	0.511	13	**0.0060**
1	50	400-1000	-0.85	0.43	4.386	0.252	0.224	0.531	13	**0.0047**
1	50	>1000	0.14	0.45	3.834	0.267	0.236	0.028	13	0.5826
1	50	Total	-1.43	0.44	6.560	0.261	0.231	0.750	13	**0.0001**
2	100	30-100	-0.55	0.18	5.761	0.072	0.125	0.494	29	**<0.0001**
2	100	100-200	-0.53	0.24	5.068	0.096	0.168	0.341	29	**0.0009**
2	100	200-400	-1.69	0.41	5.440	0.162	0.283	0.646	29	**<0.0001**
2	100	400-1000	0.31	0.30	3.833	0.120	0.211	0.102	29	0.0907
2	100	>1000	1.26	0.46	3.414	0.183	0.312	0.462	28	**<0.0001**
2	100	Total	-0.67	0.17	5.993	0.066	0.115	0.638	28	**<0.0001**
3	100	30-100	-1.30	0.47	5.537	0.162	0.193	0.669	14	**0.0003**
3	100	100-200	-2.17	0.71	5.269	0.247	0.293	0.708	14	**0.0002**
3	100	200-400	-1.32	0.53	4.441	0.184	0.219	0.618	14	**0.0009**
3	100	400-1000	-0.49	0.61	3.480	0.212	0.252	0.144	14	0.1802
3	100	>1000	-0.31	0.60	3.235	0.215	0.245	0.071	13	0.3799
3	100	Total	-1.47	0.51	5.748	0.177	0.211	0.683	13	**0.0004**
4	100	30-100	-0.91	0.42	5.915	0.145	0.230	0.459	19	**0.0014**
4	100	100-200	-0.78	0.53	5.190	0.183	0.291	0.277	19	**0.0206**
4	100	200-400	-0.69	0.60	4.698	0.209	0.332	0.188	19	0.0638
4	100	400-1000	-0.45	0.71	4.189	0.248	0.394	0.064	19	0.2946
4	100	>1000	-0.29	0.56	4.018	0.195	0.309	0.045	19	0.3829
4	100	Total	-0.86	0.45	6.024	0.155	0.246	0.395	19	**0.0004**

Notes: errors are 95% confidence intervals. p value denotes the probability that the slope is zero. **Bold**: better than <5% probability

I offer a few specific comments below to suggest places where revisions should be made, and places where statements are not strongly supported by the data as presented and additional references are necessary

Line 107: Please provide the trap funnel aspect ratio or a reference describing this.

This is graphically shown in Bishop (2016); The slope is 75° (15% from vertical). Will add to text.

Line 126: How is the weight of the shark known? Unless it was actually measured, please use a word like "large" instead. If it was measured, please provide a reference.

Based on our observations at the time, the shark was at least 50% longer than the height of the float including its antennas (2.3 m). In other words about ~3.5 m. They can grow to a length of almost 4-meters and a weight of 550-kilograms according to the California Dept of Fish and Game. We will clarify the sentence.

Line 141: What is the physical meaning of these "volume attenuance" units?

Described in (Bishop et al. (2016). We will repeat this description.

Section 2.2.2: Please add a few additional words to clarify that the calibration from Bourne et al. (2019) was reused here.

Yes.

Line 154-155: Both methods 1 and 3 (after modification) would be possible to run on the CFE during deployment and are described in more detail below.

This statement should go in the Discussion instead of the Methods.

We'll consider the best place.

Line 166: Replace "now in progress" with a reference.

we will remove "now in progress"; however this work is in progress.

Lines 169-227: Much of this text should be reduced. First, statements about the possible caveats, future developments or applications of these methods need to be moved to the Discussion (and, consider referencing the Giering et al., 2020 review which considers some of the same issues). Second, presentation of results and descriptions of identified particles should be moved to the Results. Or, to reduce the length of the paper, consider moving all of this material to an appendix or supplement.

We believe that methodology of particle identification is fundamentally important to this paper. We believe it should stay in the main body of the paper. Will consider best placement. The discussion of particle identification issues logically follows from Bishop's earlier work (e.g. Bishop et al. 1986), but in the context of autonomous methods, from Bishop et al. 2016, and Bourne 2018. We will evaluate Giering et al., 2020 which we had not seen at the time our paper was submitted and will reference as appropriate.

Line 182,183,213 (and elsewhere): It is unclear how particles were assigned to the "aggregate" and "ovoid fecal pellet" categories, except for size and attenuance thresholds. At a minimum it would be helpful to include some representative images. There are also particle categories referred to later on that are not introduced, here.

Figure 6. shows imagery of the particle classes we refer to. We will also modify the caption for figure 14 to point out the classes.

Line 246: Were UVP particles at least classified into living and non-living prior to analysis here?

Yes, we used the 'non-living' class.

Lines 357-363 (and elsewhere): Reference is made to a number of particle types (anchovy pellets, copepod pellets, larvacean houses) whose assignments and definitions are not described in the Methods section. How were they identified? Give some example figures.

Figure 14. and Fig 6 show these classes. Will add arrows as appropriate

Line 360: What method was used to determine that copepod fecal pellets contributed 50% of the flux?

We determined cumulative attenuance size distributions, these were partitioned into 30-100, 100-200, 200-400,400-1000,and>1000µm contributions which were normalized to total attenuance flux. The ovoid pellets accounted for ~50% of total flux at 150 m at L2. This is shown in Fig 7. And Fig. 16 (L2 (b)). We will clarify the text.

Lines 365-369: The description of how Martin curve exponents were calculated should go in the Methods. Uncertainties are presented in Table 2 but no mention is made of how these were determined. Note that a linear fit to log-transformed data will tend to amplify the influence of lower points relative to higher ones, but a nonlinear least-squares method will avoid this.

We are evaluating the hypothesis that the Martin formula can be used to fit the data. A non-linear least squares method is not appropriate. The Martin formula requires a fit to the relationship shown in Equation 2: $\log_{10}(F) = b*\log_{10}(z/z_{Ref}) + \log_{10}(FRef)$. *Z/Zref is precisely known. So its choice as X parameter is valid. Our results show that the function performs well for particle classes that clearly have their origin the euphotic layer – although 'b' factors are often different from Martin. Specifically, the ovoid copepod fecal pellets follow this formula well. We've provided fit results (including errors) for pooled results in Tables 2 and 3 above in R1-**R7**. [see also R1-**R4**].*

Line 380-381: "SEM imagery of CFE-Cal samples . . ." Please provide the data and methods, or a reference to them.

We will add imagery to Appendix. See our response to Reviewer 1. The reference is Bourne 2018.

Line 386: By "particle flux" do you specifically mean "attenuance flux"?

Yes. However, the ratio of volume attenuance flux to POC flux is 1. Will clarify.

Line 388-389 (also Line 565): The inference about particle sinking speed is speculative – are there other tests that were done to support this, or a reference that confirmed this behavior?

For pellets we used - Komar, P.O., Morse, A.P., Small, L.F. and Fowler, S.W. An analysis of the sinking rates of copepod and euphausiid fecal pellets. Limnol. Oceanography. ***26,*** *172-180,1981. https://doi.org/10.4319/lo.1981.26.1.0172.*

$v_s = 0.079/viscocity*\Delta\rho*g*l^2*(w/l)^{-1.664}$ (cm sec). All values in cgs units.

Ovoid pellets were typically ~250 µm (ECD) and had an L/W ratio of about 1.5. This implies a Length(l) ~270 µm and width(w) ~180 µm. Viscosity of 10C water=0.0144 poise. Assuming a particle excess density ($\Delta\rho$) *= 0.2 (estimates range from 0.2 to 0.5). We calculate settling speed of 0.4 cm* sec^{-1} *or ~350 m/day. The smallest particle in this category (ECD=200 µm) would sink at 200 m/day. This is entirly consistent with these particles forming a ring at the edges of the sample stage.*

For aggregates. We can use the Bishop et al. (1978) modification of the broad side sheet settling model of Lerman et al. (1975).

Lerman A., D. Lal And M. F. Dacey (1975) Stokes' settling and chemical reactivity of suspended particles in natural waters. In: Suspended solids in water. R. J. GIBBS, editor, Plenum Press, pp. 17 47.

$Vs=0.098/viscosity*\Delta\rho*g*(ECD*0.052+0.0045)*ECD*EXP(-7.38*ECD)$

To calculate settling rates for the > 1 mm aggregates. A particle with an ECD of 1500 µm with a $\Delta\rho = 0.087$*, would settle at about 300 m/day.*

The aim was to present an analysis of displacements.

175 to 300 $m\ d^{-1}$

Wong, C.S., Whitney, F.A. , Crawford, D.W., Iseki, K., Matear, R.J., Johnson, W.K., Page, J.S., Timothy, D. Seasonal and interannual variability in particle fluxes of carbon, nitrogen and silicon from time series of sediment traps at Ocean Station P, 1982 - ì1993: relationship to changes in subarctic primary productivity, Deep Sea Research Part II: Topical Studies in Oceanography, 46 (11-12), 2735-2760, 1999. https://doi.org/10.1016/S0967-0645(99)00082-X.

>190m/d.

Conte, M.H., Ralph, N. & Ross, E.H. Seasonal and interannual variability in deep ocean particle *fluxes at the Oceanic Flux Program (OFP)/Bermuda Atlantic Time Series (BATS) site in the western Sargasso Sea near Bermuda, Deep Sea Research Part II: Topical Studies in Oceanography,48 (8–9), 1471-1505. 2001. https://doi.org/10.1016/S0967-0645(00)00150-8. The choice of 100 m d^{-1} is a reasonable estimate. We will clarify the discussion.*

Line 423-433: Please move the description of the calculation method to the Methods section, and make sure that the nitrate data are either in an appendix or provide a reference.

The nitrate data are in the CCE-LTER data repository as indicated in our methods. We feel that the description of the calculation is short and is appropriately placed in the discussion. We will add a file with averaged nitrate bottle data as supplemental materials.

Table X. Nitrate data from CCE-LTER P1706.

location	depth	avg_no3_umol/L	no3_sd	count
1	3.6	6.23	1.87	9
1	8.4	7.56	3.14	5
1	12.5	7.84	3.12	6
1	20.9	10.33	3.45	7
1	27.2	11.75	3.55	5
1	30.0	16.82	0.97	2
1	38.3	16.93	2.28	7
1	49.7	19.23	3.11	7
1	70.0	21.29	4.35	4
2a	3.4	7.69	0.83	5
2a	8.0	7.70	1.22	2
2a	13.0	7.94	0.75	4
2a	19.5	8.74	1.68	4
2a	28.3	13.10	4.44	4
2a	38.3	16.45	5.15	4
2a	49.8	20.49	2.86	4
2a	72.7	25.96	0.47	3
2b	3.4	7.78	0.15	5
2b	8.7	7.81	0.10	3
2b	13.5	7.85	0.19	4
2b	20.8	7.82	0.21	5
2b	26.5	9.50	3.06	4
2b	31.7	9.27	2.14	3
2b	39.0	13.44	6.53	2
2b	49.0	18.21	2.00	5
2b	62.0	21.78	1.95	3
2b	71.5	23.90	0.50	4
3	2.7	1.62	1.53	7
3	11.9	1.97	1.63	7
3	20.6	2.27	1.74	7
3	30.4	2.83	1.76	5
3	42.5	2.52	1.56	6
3	50.5	4.68	1.28	2
3	61.0	3.33	2.38	6
3	74.4	7.97	4.55	7
4	2.4	2.90	0.36	5
4	12.0	3.11	0.75	5
4	20.0	3.70	1.58	5
4	30.2	7.18	4.38	5
4	40.0	12.27	5.38	5
4	49.8	19.05	2.40	5
4	70.0	23.52	0.66	4

Lines 444-445: “As CFEs are Lagrangian . . .” Please provide a reference to support this statement.

Figure 9 confirms agreement of CFE trajectories and ADCP currents.

Lines 485-486: coupled with a near horizontal encounter with the trap opening would cause aggregates to bounce back into the flow and thus not be sampled. This was observed using surface-tethered OSR instruments during quiescent conditions in the Santa Cruz Basin.

Please provide a reference to this statement.

We did (Bishop et al., 2016)

Lines 493-499: Figure 16 depicts PIT fluxes extrapolated to depth using the best fit b factor for the 50-150 m results. At L1, L2, L4, and L3 Martin b values were -0.31, -0.85, -0.31, and -2.12, respectively.
This section should reflect the uncertainties in the computed "b" values (see above)

Apart from the typo for L1 (-0.31 should be -0.35). The point is the PIT traps also saw reduced slopes at L1 and L4. In all cases except at L2, the b parameters are significantly different from Martin's b = -0.86.

Below are Martin fits to Mike Stukel's data.

Table 4. Martin Curve Fit parameters for PIT trap data.

	Martin Curve 'b'	b-Error	Intercept	intercept Error	SE_y	R2	n	p
L1	-0.3516	0.2265	1.4094	0.0749	0.066	0.710	3	0.3622
L2	-0.8529	0.2115	1.2869	0.0531	0.062	0.943	3	**0.0260**
L3	-2.1188	0.2739	1.1709	0.0448	0.054	0.984	3	0.0812
L4	-0.3069	0.0912	1.4510	0.0184	0.022	0.920	3	0.1825

Notes: errors are 95% confidence intervals. p denotes the probability that slope is zero. **Bold**: <0.05

Lines 521-524: Figure 18 depicts four mechanisms. I suggest including some references to the literature here; most of these mechanisms have been discussed in other settings as well.

The references are included in our discussion but we will add to the figure caption

Figure 18. Four mechanisms that can lead to non-classical particle flux profiles. (A) Temporal Delay (Giering et al., 2016); (B) Vertical Migrators (Turner, 2015, Bishop et al., 2016); (C) Physical Subduction (Omand et al., 2015, Stukel et al., 2018); and (D) Lateral Advection (Alonso-Gonzalez et al., 2009, Pak et al., 1980, McPhee-Shaw et al., 2004, Chase et al., 2007).

Lines 552-554: Fish can also transport consumed material to depths below the euphotic zone. Some heterotrophs produce fecal material that is much more efficient at being exported from the euphotic zone. Organisms such as krill and fish produce large dense fecal pellets which sink very efficiently.

These statements should be supported by references.

Saba and Steinberg, 2012.

Lines 625-627: Please provide some supporting references.

References are provided in the paragraph.

Lines 689-690: "The efficiency of export was clearly affected by trophic structure". This statement needs to be more strongly connected to observations of trophic structure, which are not presented in this study. Please provide a reference to such observations.

We'll change wording. "Based on particle classes observed, there is strong evidence that the dominant organisms mediating flux had shifted over the life time of the filament.

Line 691: Please provide a reference to the measurements of phosphorus in the sinking particles.

Bourne et al. 2019