bg-2018-335: “Spatiotemporal variability of light attenuation and net ecosystem metabolism in a back-barrier estuary”

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Response to Reviewers, comments in plain text, response in bold

Anonymous Referee #1

The manuscript “Spatiotemporal variability of light attenuation and net ecosystem metabolism in a back-barrier estuary” presents the results of a comprehensive water quality sampling program situated in Chincoteague Bay, Maryland/Virginia. The manuscript is well-written and all results are presented clearly. There are three main concerns I have with the manuscript as it currently stands:

1. There appears to be no clear conclusion apart from the point that measuring quantities with high spatiotemporal resolution is useful – so the manuscript in its current form lacks novelty. For example, consider the last sentence of the Introduction, “Our conclusions highlight the importance of quantifying spatiotemporal variability in these processes, which indicate feedbacks between physical and ecological processes in marine environments that should be considered when evaluating future ecosystem response.” However, there is no explicit consideration of feedbacks in the manuscript apart from a brief mention in the Discussion.

In the abstract and elsewhere, we failed to include the feedback between SAV density and resuspension, which was quantified and discussed in Fig. 8 and Sec. 4.1. We intend to more fully integrate this result into the abstract and conclusion, as well as the new analyses discussed below.

We have expanded the analysis to quantitatively address the influence of temporal resolution on discerning spatial gradients (see below), and conducted a wavelet analysis to quantify difference between SAV and non-SAV sites (also see below). We believe these two new analyses make appropriate use of the data to inform future studies.

Alternatively, consider the last sentence of the Abstract, “This study demonstrates how extensive continuous physical and biological measurements can help determine metabolic properties in a shallow estuary, including differences in metabolism and oxygen variability between SAV and phytoplankton-dominated habitats.” The first half of this sentence is a self-evident point, but regarding the second half of this sentence, there is no specific quantitative analysis in the paper comparing sites that are SAV- and phytoplankton-dominated.

Regarding that sentence specifically, we can revise to:

> ***“This study quantifies differences in the timescales of co-variation of key water-column properties that represent controls on light availability and ecosystem metabolism in a back barrier estuary. The analysis reveals how light availability and ecosystem metabolism varies across habitats spanning nutrient-enrichment gradients and different dominant primary producers. Through these analyses, we document the dynamics of self-reinforcing growth feedbacks associated with marcrophyte-induced decreases in suspended particles and associated light attenuation.”***

In addition, we will include more in-depth analysis of the spectral results, specifically noting the following:

1) **With regards to dissolved oxygen, there is a stronger diurnal signal at shoal sites relative to channel sites, indicating higher local production/respiration**
2) **With regards to turbidity, the highest spectral density is in the low-frequency band at CB06, which demonstrates the spatial integration of resuspension process throughout the estuary at this main channel site.**

3) **With regards to chlorophyll, CB11, the eutrophic site, has highest low-frequency spectral density due to increased nitrogen inputs and eutrophication.**

4) **With regards to fDOM, the two northern sites (CB10, CB11) have highest low-frequency spectral density, indicating a spatial gradient in freshwater input from north to south.**

We will also include a more involved wavelet analysis to quantitatively link the processes. For example, wavelet coherence between dissolved oxygen (DO) and turbidity indicates how resuspension processes and light attenuation influence production/respiration. We find that shoal sites have a stronger coherence between DO and turbidity over multi-day frequencies than channel sites, indicating a de-coupling of sediment transport and biogeochemical processes in the channels (Fig. AC1). We also find a strong coherence between chl-a and turbidity at all sites, suggesting that the chl-a signal during periods with increased wind-wave forcing may be mostly resuspension of benthic microalgae.

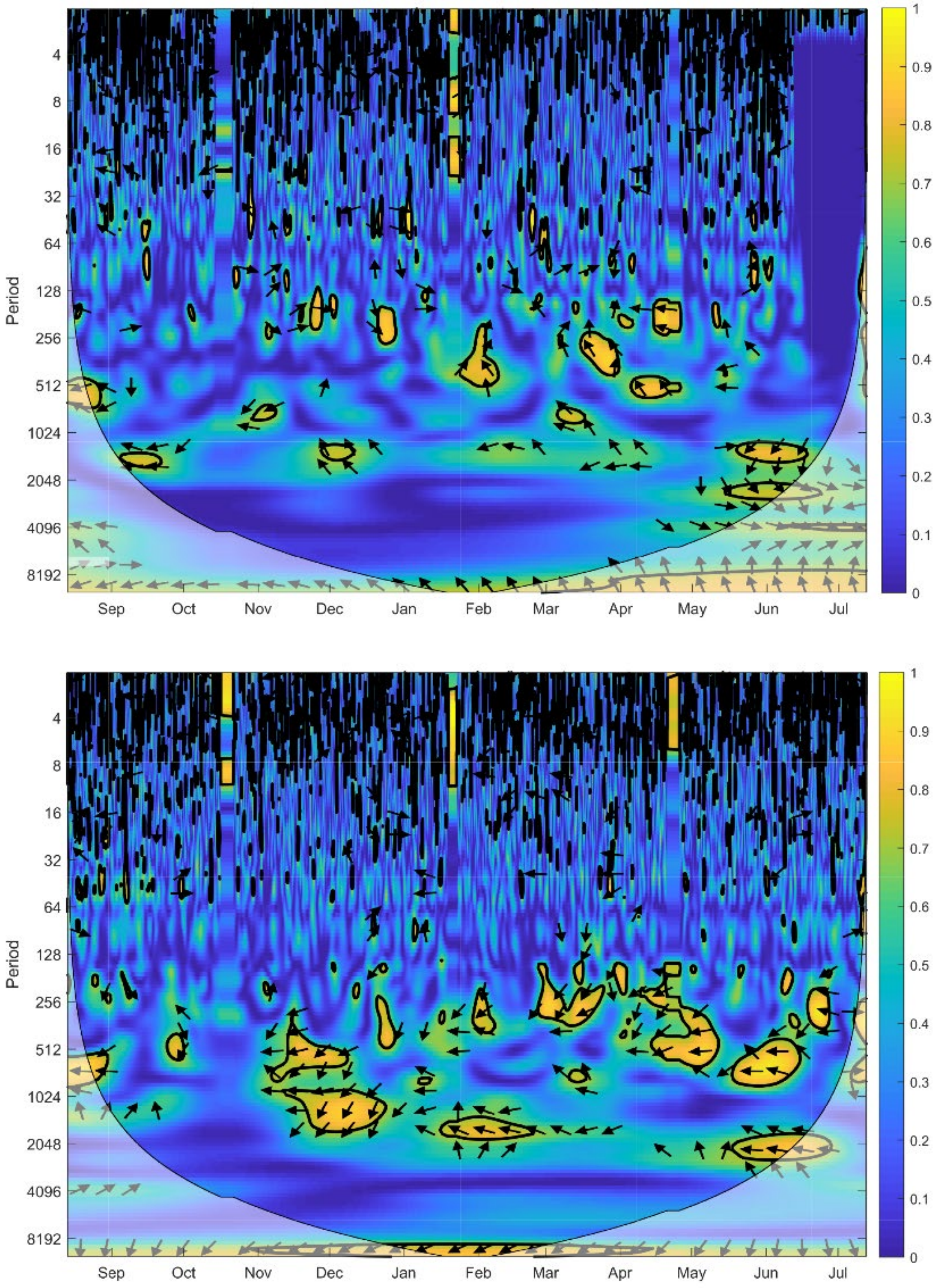

Figure AC1. Wavelet coherence between dissolved oxygen (%) and turbidity at channel site CB06 (upper) and shoal site CB03 (lower). Increased coherence at CB03 for periods between ~128 and 2048 correspond to timescale of 1 to 21 days (respectively), and suggest a coupling between resuspension, light availability, and production/respiration that is not observed at channel sites.

We have also resampled the four main water quality parameters (DO, turbidity, chlorophyll, and fDOM) at 1-h, 2-h, and daily intervals, to explore how temporal resolution affects means, minima, and maxima (Table AC1; Fig. AC2). We observe that mean values are relatively insensitive to sampling interval, however maximum values are significantly modulated for all parameters, while minimum values for DO are significantly modulated as well. With regards to dissolved oxygen specifically, we find that daily sampling dampens the spatial variability in maxima and minima between sites. This is an important finding, given the ubiquitous daily sampling programs in many estuaries which cover many sites. This result suggests that characterizing differences in water-column conditions across space requires sampling at timescales finer than 1 day, especially in highly metabolic environments.

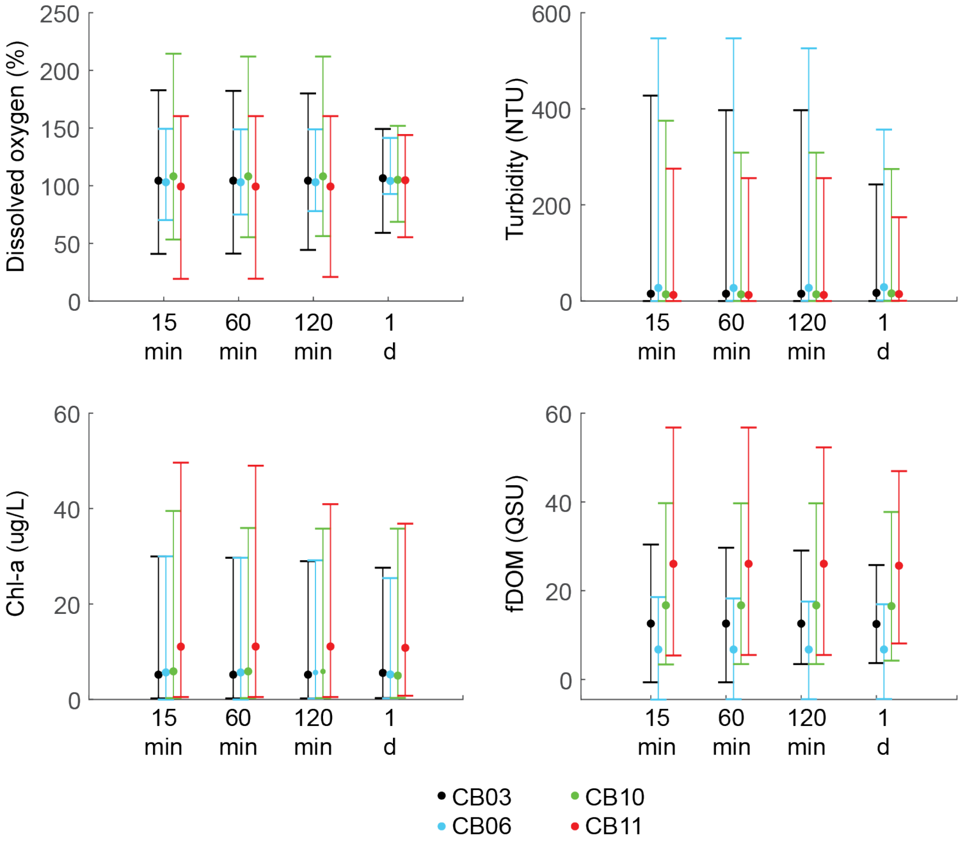

Figure AC2. Mean (dots), maxima and minima (bars) for each parameter using different temporal sampling intervals (15 min, 60 min, 120 min, 1d). Spatial gradients in dissolved oxygen are most impacted by coarse temporal resolution, with differences in minima and maxima largely eliminated at resolution of 1 d.

Table AC1. Mean, minima, and maxima for four water-quality parameters at four sites.

		DO (%)			TURB (NTU)			Chl-a (ug/L)			fDOM (QSU)		
		mean	min	max	mean	min	max	mean	min	max	mean	min	max
CB03	15 min	104.4	40.9	182.8	14.9	0.0	427.4	5.2	0.2	29.9	12.6	0.0	30.4
	60 min	104.4	41.2	182.3	14.9	0.0	396.9	5.2	0.2	29.7	12.6	0.0	29.7
	120 min	104.4	44.4	180.1	14.9	0.0	396.9	5.2	0.2	29.0	12.6	3.4	29.0
	1 day	106.5	59.1	149.2	16.7	0.0	242.7	5.5	0.2	27.6	12.5	3.7	25.8
CB06	15 min	103.0	70.2	149.4	27.1	0.0	546.8	5.6	0.0	30.0	6.7	0.0	18.6
	60 min	103.0	75.0	149.0	27.0	0.0	546.8	5.6	0.0	29.7	6.7	0.0	18.2
	120 min	103.0	77.9	149.0	27.2	0.0	525.7	5.6	0.1	29.1	6.7	0.0	17.5
	1 day	104.2	92.8	141.5	28.7	0.0	356.7	5.2	0.2	25.4	6.7	0.0	17.0
CB10	15 min	108.1	53.4	214.5	13.6	0.0	375.0	5.9	0.2	39.5	16.7	3.4	39.7
	60 min	108.1	55.3	212.0	13.6	0.0	308.8	5.9	0.3	35.9	16.7	3.4	39.7
	120 min	108.1	56.3	212.0	13.6	0.0	308.8	5.8	0.3	35.8	16.7	3.4	39.7
	1 day	105.1	68.7	151.9	15.7	0.0	274.5	5.0	0.3	35.8	16.5	4.2	37.7
CB11	15 min	99.3	19.2	160.3	12.4	0.0	275.2	11.0	0.5	49.6	26.0	5.4	56.8
	60 min	99.3	19.4	160.3	12.4	0.0	255.5	11.1	0.5	49.0	26.0	5.5	56.8
	120 min	99.3	20.9	160.3	12.4	0.0	255.5	11.1	0.5	40.9	26.1	5.5	52.3
	1 day	104.7	55.3	143.9	14.2	0.0	174.3	10.8	0.7	36.8	25.6	8.1	46.9

2. Time series data presented in the manuscript has already been published in a technical report available online – this would be fine if there was sufficient quantitative analysis of this data (see next point), but the figures showing these time series data also do not explicitly acknowledge that this data is already published elsewhere. Most of the data presented in Figures 2-5 and 7 is identical to data presented in Figures 46, 49, 50, 52-56 of the technical report Suttles et al. (2017) cited within the manuscript. Furthermore, there appear to be other water quality stations present at the study site (see Figures 2 and 3 of Suttles et al. 2017) that measured relevant quantities during the time periods of the study whose data was not considered in the manuscript – the reasons for this also need to be addressed.

USGS policy requires release of data before submission of a peer-reviewed journal article. The report of Suttles et al. is a non-interpretive data release report that contains figures simply to connect the distributed data with time-series plots to ensure consistency. Every peer-reviewed journal article submitted by USGS authors has an associated data release. The figures are not identical to figures in the data release; they have been generated for this publication.

We only used the sites from our field campaign that allowed a comparison between SAV-dominated sites with light measurements (of which there were only two, CB03 and CB10), along with partner non-SAV sites that had continuous water quality measurements (of which there were only two, CB06 and CB11). The other sites only had velocity, waves,

and/or suspended-sediment measurements, which means they could not be used to estimate light attenuation.

3. There is very little quantitative analysis of the results, and conclusions appear to be drawn from the presented figures without sufficient justification. Consider the first paragraph of the Results. The first sentence states that “Turbidity ranged from near zero to a maximum of over 400 NTU at site CB06 during a winter storm that induced waves exceeding 0.7 m (Figs. 2-5).” However, there is no indication in the manuscript (or figures) of when this winter storm took place, and no data presented for wave heights. The second sentence states that “sites CB03, CB10, and CB11 had similar statistical distributions of turbidity”, but there is no statistical analysis of turbidity present in the manuscript, only time series data.

We will clarify such details throughout, and will add wave data to the figures. We have performed more thorough statistical analyses for all parameters and sites, see above.

If this manuscript were rewritten for future publication, one possible focus could be on the spectral signals shown in Figure 6 to potentially give advice to the broader scientific community regarding the temporal scales for which water quality quantities need to be measured in order to sufficiently capture their “true” values, e.g. for comparison between sites and/or time periods.

We intend to add two main points to the discussion, presenting the wavelet analysis results and the influence of temporal sampling resolution on interpreting spatial differences, as indicated above.

Overall, the manuscript needs to go beyond the presented time series and undertake further statistical (or other relevant) analyses of these time series to reveal differences between sites. With such analysis, it may be possible from the excellent data, obtained from this monitoring program, to yield conclusions that are novel and broadly applicable to the scientific community.

We believe that the additional statistical analyses and wavelet coherence analyses have yielded new linkages that highlight the differences between the sites.

Anonymous Referee #2

This paper investigated spatio-temporal variability of light attenuation, of Pgros and R in Chincoteague Bay, Maryland/Virginia, USA. The authors have valuable long-term data and the paper is overall well-written, however I have some concerns on this version of the manuscript. Firstly, the result section could be substantially improved. As it is, there is limited quantitative data. For instance, ranges and means of Pgross, Pnet and R should be clearly reported.

We did include means and standard deviations of all derived metabolic rates in Table 2 for the August to September period. We will include a new Table, either in the main body or as supplemental material (Table AC2), that summarizes more details of these estimates over the entire year and we will include the key features of these values in the results.

Table AC2. Summary of metabolic rate estimates at the four study sites, including monthly means, standard deviation, minimum and maximum values. All rates in mmol O_2 m^{-2} d^{-1}.

		CB03			CB06			CB10			CB11		
		P_g	R_t	P_n	P_g	R_t	P_n	P_g	R_t	P_n	P_g	R_t	P_n
January	*Mean (±SD)*	44.76 *(±35)*	41.69 *(±35.8)*	3.07 *(±24.81)*	11.95 *(±52.79)*	4.62 *(±65.26)*	7.33 *(±28.07)*	37.27 *(±73.44)*	31.55 *(±82.98)*	5.72 *(±27.19)*	52.84 *(±9.6)*	36.74 *(±8.61)*	16.10 *(±7.05)*
	Minimum	4.62	2.85	-46.02	1.33	1.30	-51.79	13.62	10.10	-51.74	37.35	25.02	6.57
	Maximum	113.65	104.39	53.92	84.29	109.13	66.12	166.57	196.32	58.50	64.22	43.15	25.95
February	*Mean (±SD)*	21.73 *(±17.9)*	13.00 *(±19.76)*	8.73 *(±8.85)*	17.72 *(±20.27)*	9.70 *(±22.4)*	8.02 *(±12.17)*	46.86 *(±29.53)*	41.28 *(±34.07)*	5.58 *(±9.51)*	63.13 *(±38.38)*	55.32 *(±42.32)*	7.81 *(±10.42)*
	Minimum	0.74	1.15	-6.56	0.66	6.64	-14.04	10.88	5.29	-12.57	11.08	10.39	-11.98
	Maximum	54.19	48.82	30.95	56.86	47.67	50.23	122.55	127.75	40.23	140.83	152.81	43.97
March	*Mean (±SD)*	61.25 *(±61.4)*	61.61 *(±55.28)*	-0.36 *(±21.39)*	52.45 *(±34.92)*	54.98 *(±44.06)*	-2.54 *(±20.4)*	36.12 *(±75.76)*	34.98 *(±70.46)*	1.14 *(±14.17)*	133.50 *(±27.64)*	139.12 *(±25.72)*	-5.62 *(±15.55)*
	Minimum	28.28	2.55	-66.70	15.26	6.67	-71.49	17.93	12.35	-41.94	87.15	91.41	-29.87
	Maximum	162.50	145.89	31.04	121.08	185.61	23.68	121.63	108.83	44.34	198.99	196.66	26.00
April	*Mean (±SD)*	125.06 *(±72.4)*	114.54 *(±72.17)*	10.53 *(±19.04)*	106.12 *(±72.98)*	113.17 *(±73.74)*	-7.04 *(±27.87)*	129.30 *(±51.3)*	126.15 *(±47.51)*	3.15 *(±34.1)*	122.29 *(±38.18)*	116.49 *(±42.53)*	5.80 *(±17.13)*
	Minimum	19.49	3.26	-16.43	38.91	12.37	-96.89	59.40	50.83	-137.79	45.66	29.54	-25.89
	Maximum	284.89	263.19	86.13	299.18	327.50	35.00	238.54	238.84	58.45	196.30	197.49	33.48
May	*Mean (±SD)*	232.09 *(±84.76)*	221.45 *(±87.63)*	10.64 *(±19.57)*	113.71 *(±68.60)*	114.93 *(±62.85)*	-1.21 *(±12.9)*	233.96 *(±106.35)*	226.60 *(±101.84)*	7.36 *(±12.33)*	N/A	N/A	N/A
	Minimum	100.94	67.31	-33.61	71.46	51.59	-32.32	22.94	35.40	-16.00	N/A	N/A	N/A
	Maximum	359.46	355.89	57.05	215.87	219.11	22.63	381.95	369.99	30.21	N/A	N/A	N/A
June	*Mean (±SD)*	237.11 *(±85.29)*	232.17 *(±84.72)*	4.94 *(±14.39)*	109.72 *(±15.14)*	104.53 *(±34.87)*	5.19 *(±23.74)*	232.80 *(±87.72)*	231.43 *(±89.33)*	1.38 *(±19.19)*	N/A	N/A	N/A
	Minimum	59.70	82.49	-22.79	91.22	72.36	-52.86	93.25	122.96	-32.17	N/A	N/A	N/A
	Maximum	401.62	393.89	55.29	136.62	189.48	24.41	416.03	400.18	39.66	N/A	N/A	N/A
July	*Mean (±SD)*	182.72 *(±82.9)*	183.56 *(±75.85)*	-0.83 *(±12.4)*	N/A	N/A	N/A	179.69 *(±138.97)*	173.03 *(±124.99)*	6.66 *(±30.83)*	N/A	N/A	N/A
	Minimum	56.72	73.34	-18.12	N/A	N/A	N/A	75.63	0.35	-43.01	N/A	N/A	N/A
	Maximum	302.17	299.71	26.33	N/A	N/A	N/A	381.61	373.88	74.33	N/A	N/A	N/A
August	*Mean (±SD)*	344.85 *(±154.49)*	355.40 *(±157.25)*	-10.55 *(±23.19)*	100.66 *(±56.15)*	105.91 *(±38.33)*	-5.24 *(±41.22)*	334.79 *(±256.96)*	323.77 *(±246.55)*	11.02 *(±45.9)*	289.36 *(±124.99)*	317.37 *(±94.08)*	-28.01 *(±93.62)*
	Minimum	129.45	139.56	-51.69	59.12	33.63	-145.80	81.41	24.84	-115.35	188.52	199.70	-372.23
	Maximum	575.94	612.93	37.94	162.47	173.16	34.20	850.14	812.87	111.49	449.78	492.57	21.63
September	*Mean (±SD)*	292.56 *(±165.9)*	276.69 *(±187.30)*	15.87 *(±39.71)*	89.22 *(±52.93)*	85.89 *(±61.99)*	3.32 *(±15.19)*	253.74 *(±157.03)*	236.73 *(±163.69)*	17.01 *(±47.56)*	213.65 *(±132.99)*	217.51 *(±139.56)*	-3.87 *(±20.89)*

	Minimum	44.69	131.45	-38.05	5.71	28.71	-32.78	7.76	74.83	-76.46	2.67	28.04	-49.79
	Maximum	584.92	564.66	145.06	165.74	173.93	47.45	788.71	795.48	117.17	451.94	479.71	35.39
October	*Mean (±SD)*	133.08 *(±84.29)*	129.62 *(±69.26)*	3.46 *(±42.05)*	34.63 *(±49.0)*	23.80 *(±35.88)*	10.83 *(±32.75)*	82.91 *(±61.18)*	69.74 *(±62.71)*	13.17 *(±20.6)*	88.68 *(±45.05)*	81.93 *(±35.62)*	6.75 *(±23.29)*
	Minimum	53.3	5.24	-154.65	9.59	9.41	-17.02	18.22	7.93	-29.23	53.90	31.59	-54.24
	Maximum	323.11	268.09	76.23	176.73	74.83	158.44	191.25	178.44	42.91	209.12	171.12	40.71
November	*Mean (±SD)*	67.45 *(±19.42)*	57.79 *(±15.62)*	9.66 *(±35.8)*	25.14 *(±16.76)*	17.50 *(±16.32)*	7.64 *(±9.24)*	81.76 *(±40.59)*	71.52 *(±47.23)*	10.23 *(±12.92)*	47.54 *(±42.61)*	36.88 *(±50.24)*	10.65 *(±17.83)*
	Minimum	34.28	29.37	-2.89	1.69	1.23	-5.10	21.77	13.85	-7.94	0.86	1.59	-20.65
	Maximum	120.15	93.52	34.59	60.97	54.32	27.83	155.66	159.77	41.03	97.75	99.72	43.32
December	*Mean (±SD)*	54.19 *(±32.97)*	45.32 *(±37.68)*	8.87 *(±19.14)*	30.01 *(±32.34)*	27.84 *(±33.34)*	2.17 *(±6.45)*	58.31 *(±44.15)*	50.12 *(±43.67)*	8.19 *(±16.16)*	N/A	N/A	N/A
	Minimum	15.58	12.93	-59.61	2.14	6.02	-10.98	6.08	3.75	-21.36	N/A	N/A	N/A
	Maximum	123.94	128.21	52.98	79.63	77.46	15.25	131.48	136.35	55.04	N/A	N/A	N/A

To calculate Pnet, Pgross and R the authors need flow speed and direction, oxygen, PAR, and wind data. I assume wind data were used in the calculations, however the authors should explicitly report the formula and variables used in their calculations.

We agree that this is an important detail of the calculation and will add this information in the methods section of the revised manuscript.

> ***"The changes in dissolved oxygen concentrations used to compute metabolic rates were corrected for air-water gas exchange using the equation $D = k_a(C_s-C)$, where D is the rate of air-water oxygen exchange (mg O_2 L^{-1} h^{-1}), K_a volumetric aeration coefficient (h^{-1}), and C_s and C are the oxygen saturation concentration and observed oxygen concentration (mg O_2 L^{-1}), respectively. K_a was computed as a function of wind speed measured at a weather station installed at a dock at Public Landing, Maryland (western shore of Chincoteague Bay near station 10) during the course of the sensor deployment. Details of the air-water gas calculation are incorporated into the R package WtRegDO (Beck et al. 2015) and described in detail in Thebault et al. (2008), and we utilized atmospheric pressure and air temperature data for these calculations from a nearby buoy (OCIM2 - 8570283 at the Ocean City Inlet, Maryland)."***

Also, the authors have a valuable long-term data-set. My main concerns is that the instruments recorded data every 15 min, which is not an ideal resolution, it would be good to comment on this.

It is not clear why 15 min resolution is not ideal. To our knowledge, there are few, if any studies that examine time-series at these short- time scales for waves, water-column physical and biogeochemical variables, and light availability. While a subset of these variables may have been examined in previous estuarine studies, The comprehensive nature of this continuously-measured variable suite is unique. At this timescale, all tidal

variations are resolved; wave measurements are collected with burst samples that resolve waves with periods between approximately 1 and 15 seconds. And our newly included statistical analysis (above) shows that mean/minimum/maximum values with 1 and 2 h sampling interval are similar.

The conclusions and overall significance of the study could also be improved substantially.

We believe the conclusions and significance have been enhanced with our new proposed analyses (see above).

There is not a clear and compelling "take home message" at the moment. Importantly, a great limitation of many studies on community metabolism is the lack of data on community structure. The authors could extrapolate data on benthic communities in their study sites and discuss the role of community structure in greater detail, this would strengthen the paper.

We unfortunately do not have data of this type to combine with our measurements. The SAV beds we studied were uniformly *composed of Zostera marina,* but the macroalgae and epiphytes that also occupied the habitat were not quantified and identified, as this was outside of the scope of our study. We agree, however, that we should make clearer statements regarding what is compelling about our analysis. In the revised manuscript, we now state how our analysis clearly quantifies the (1) the timescales in which dissolved oxygen dynamics correlate to factors driving light availability, (2) how the strength of relationships between physical and biological properties varies between vegetated and non-vegetated habitats, (3) the identification of the primary drivers of light attenuation in the different habitats, and (4) how ecosystem metabolism varies across habitats spanning nutrient-enrichment gradients and different dominant primary producers.

Our two proposed analyses, using wavelet coherence and resampling of means, maxima, and minima, explore the differences between channel and shoal sites, and the influence of temporal resolution on interpretation of spatial gradients.