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Interactive comment on "Technical note: Measurements and data analysis of sediment-water oxygen flux using a new dual-optode eddy covariance instrument" *by* Markus Huettel et al.

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Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2020-172, 2020. Interactive comment on "Technical note: Measurements and data analysis of sediment-water oxygen flux using a new dual-optode eddy covariance instrument" by Markus Huettel et al. Karl Attard (Referee) karl.attard@biology.sdu.dk Received and published: 8 June 2020

General comments Huettel et al. present a technical study describing a new dual-

optode eddy covariance system. The authors integrate two independent O2 sensors within a standard eddy covariance setup to cross-check fluxes extracted using two independent O2 sensor output streams, and to identify any biases in the measurements which are most likely caused by sensor fouling. Dual O2 sensor eddy systems are not new per se (e.g. McGinnis et al. 2011, Attard et al. 2014), but it is the first time that the two sensor signals have been compared in the level of detail provided in this study. The authors also perform chamber incubator measurements in parallel with eddy covariance to resolve O2 fluxes using two different state-of-the-art methods. Finally, the authors also provide a comparison between the three most popular O2 sensor systems for eddy covariance measurements. The paper by Huettel et al will find broad interest among the growing community of aquatic eddy covariance users. The length of the paper and the angle of the study make it appropriate to be published as a Technical Note in Biogeosciences. The scientific methods are clearly outlined, language is fluent and precise, referencing is appropriate and up-to-date, and the overall presentation is well-structured and clear. I have one main comment and several smaller comments that the authors may wish to address.

Response: We thank Dr. Attard for the detailed review of our manuscript and the helpful comments and questions.

My main comment concerns how flux quality is evaluated. Currently, the authors determine quality based on (a) diel dynamics of O2 fluxes in relation to PAR, and (b) by comparison to chamber incubator measurements. If the quality-checking aspects could be expanded to include other metrics, then I foresee that the dual sensor approach would be useful in a broader range of settings.

Response: We agree with the reviewer that assessing the quality, validity and accuracy of the fluxes is central when conducting non-invasive eddy covariance measurements. In addition to the two methods mentioned by the reviewer (i.e. diel flux dynamics in relation to PAR, and comparison to chamber measurements), we use here the agreement/disagreement between the fluxes calculated from the signals of two independently measuring optodes as a tool to assess the quality of the measured fluxes. To make that point more clear, we added the following text to the conclusions: P11L350 "We propose using the agreement/disagreement between the fluxes calculated from the signals of two independently measuring optodes as a tool to assess the quality of the measured fluxes. The nearly identical cumulative fluxes calculated from the two optodes in our August (Case A) and April (Case B) deployments strongly imply that the dynamics of the fluxes were measured accurately by the system. Likewise, the linearity of the cumulative flux increase during daytime and decrease during nighttime (Figs. 3e, 5e) and the very similar slopes of these cumulative flux curves support that the measurements recorded representative fluxes. The good agreement of the fluxes measured with the eddy covariance instrument and the fluxes measured with independently with a very different method (advection chambers, Fig. 8a, b, d) indicate that the magnitudes of the fluxes recorded by the 2OEC are correct."

Specific comments Introduction L20-67: It would be fair to mention that dual O2 sensor eddy systems have been in use for years (e.g. McGinnis et al. 2011 L&O Methods, Attard et al. 2014 L&O) but that so far, no detailed comparison between sensor signal output has been presented.

Response: We thank the reviewer for pointing out the missing references to other dual sensor instruments. In a earlier version of the manuscript, we had an extended discussion of microlectrode-equipped eddy instruments, which included the dual electrode systems deployed by Attard et al (2014) and McGinnis et al. (2011). This matter was removed when shortening the paper and we now re-inserted these references. To the best of our knowledge, eddy instruments based on dual optode measurements have not been introduced, and we are not aware of publications that use the date evaluation approach explained here. The following section was inserted into the text: P2L35 "To improve the reliability of the flux measurements, eddy covariance with dual microelectrodes were developed, e.g. (Attard et al., 2014;McGinnis et al., 2011;Rodil et al., 2019;de Froe et al., 2019;Rovelli et al., 2015)"

Methods L70: It is worth mentioning that these meters only use half the potential voltage range of the Vector analog channels (0-2.5V), but developments are in place to increase this to the full range (0-5V).

Response: We thank the reviewer for this suggestion and added the following sentence to Table A1 in Appendix A: "the meter presently uses half the potential voltage range of the Vector analog input, but developments are in place to increase this to the full range (0-5V)"

L71: I cannot find this model on the Pyroscience website. Do you mean the FSO2-SUBPORT? https://www.pyroscience.com/en/products/all-meters/fso2-subport

Response: We thank the reviewer for pointing this out. The Pyroscience™ FireStingO2-Mini oxygen meter recently has been replaced by the Pyroscience™ PICO-O2, which is similar to the meter we used but more compact. The FireStingO2-Mini oxygen meter is still available in combination with the Pyroscience™ FSO2-SUBPORT. We added the following text to the legend of Table A1 in Appendix A:

This oxygen meter recently has been replaced by the Pyroscience™ PICO-O2, which is similar to the FireStingO2-Mini but more compact. The FireStingO2-Mini oxygen meter is still available in combination with the Pyroscience™ subport (FSO2-SUBPORT).

L86-87: It would be useful to specify whether you powered the analog channels through the Vector

Response: Thank you for this suggestion. We added P3L86 "The FireSting O2-Mini oxygen meters were supplied with the output power of the ADV (see below)."

L95: Firesting O2Mini: Again here, please check that this is the right model, or specify whether this was an older model that has since been replaced by the FSO2-SUBPORT.

Response: To avoid confusion we added the following text: P3L84 "(specifications listed in Table A1 in Appendix A, now sold in combination with the Pyroscience™ subport (FSO2-SUBPORT)"

L97: 30 mm is quite a large distance. Any reason for not moving closer to the measurement volume (e.g. 1 cm)?

Response: We chose this distance to prevent any potential interference with the flow and acoustic pulses of the Vector ADV. We added the following sentence to make this clear P4L114 "This distance prevents any disturbance of the flow in the measuring volume of the ADV and any interference with the acoustic pulses of the Vector."

L143-145: This reads like Results.

Response: We agree and moved this sentence to the results section.

L148-161: It would be useful to describe the chamber measurements in more detail. How were the chamber O2 fluxes calculated? Did you have an optode inside the chamber measuring O2 concentration continuously? How long did the deployments last? Ultimately, what are we comparing in Fig. 7?

Response: We added the following paragraph providing more detail about the chamber measurements: P6L179 "The acrylic cylinder of the chambers was pushed 12 cm into the sand sediment, resulting in a chamber water volume of 5 L. A Hach-Rigid-O2-Optode mounted in the chamber lid collected oxygen concentrations at 15 minute time intervals. The fluxes were calculated from the changes of the oxygen concentration in the water column of the chamber over time. Chamber incubations ran for 24 h, then the lid was opened to allow re-equilibration with the ambient water before starting the next measurement cycle."

L156: Do the chambers attenuate PAR? Results

Response: Thank you for asking this question. We measured a 10% loss in PAR caused by the acrylic chamber lids and added this information to the text P6L178 "(10% loss in PAR through light attenuation caused by the acrylic)"

L164: The first sentence seems out of place here.

Response: We structured the Results sections by these subtitles, and the purpose of these subtitles becomes more clear when reading the related paragraphs.

L171-172: What deployment hours did you use for this analysis? Was it all of daylight hours i.e. until approx. 20:00? If so, does linear regression adequately represent these dynamics?

Response: We used all daylight hours and the flux increase during daylight could be represented well by linear regression ($R2 > 0.9$). The same applied to the nighttime fluxes. When calculating the fluxes, we avoided sections with disturbances in the cumulative flux curves. We added the following explanation to the text: P7L199 "The flux increase during daylight and decrease during nighttime could be represented well by linear regression ($R2 > 0.9$)."

L179-183: I would expect that both optodes located at 35 cm above the seafloor and 1 cm apart would capture these variations, though?

Response: They do capture these variations, however, the higher heterogeneity of the oxygen distribution in the water still causes larger differences between the simultaneous readings of the two optodes during daylight hours (Fig. 4a)

L231: Fig 6E: I suppose that the jump at hour 22 in the cumulative flux for sensor P is not real, but it was offset in post processing to indicate that the two sensors match one another very well beyond this point. I understand the wish to illustrate this, but I think it is confusing, because it suggests that despite the fluxes from both sensors being very different prior to hour 22, the daily integrated flux is very similar, which cannot be the case.

Response: With all due respect, we disagree with the reviewer here. As pointed out in the legend of the figure, P cumulative flux at 18:00 was intentionally reduced by 5 mmol m-2 to allow comparison of the two cumulative fluxes based on P and Q data

(Panel E). After excluding the time period during which sensor P was compromised by biofouling, the daily integrated fluxes based on the two sensor signals were very similar (P8L335) (daytime: 3.4 ± 0.6 mmol m-2 h-1(P), 3.3 ± 0.3 mmol m-2 h-1 (Q), nighttime -0.9 ± 0.1 mmol m-2 h-1 (P), -0.9 ± 0. 7 mmol m-2 h-1 (Q); daytime average 3.3 ± 0.7 mmol m-2 h-1 (P, Q), nighttime average -0.9 ± 0. 7 mmol m-2 h-1 (P, Q)).

L233-234: I generally agree with this interpretation, it makes intuitive sense. One concern I have is that identifying what sensor works best at what time seems somewhat subjective. For instance, in Fig 6D hour 15, PAR drops from 150 to below 50 umol m-2 s-1, and sensor P registers a concurrent decrease in flux, but sensor Q does not. After hour 16 the fluxes from sensor P are clearly 'compromised', but then again, this assessment is based upon what we'd typically expect to see. I would otherwise be tempted to interpret the drop in fluxes at hour 15 in sensor P as 'real', unless there is some other metric we could use to establish flux quality. Overall, I fear that if we do not adopt some quantitative metrics for establishing flux quality beyond what we expect to see (e.g. diel dynamics in relation to PAR), then we might miss out on something new and interesting. This is especially true during the nighttime or in non-photic habitats. In the absence of light, would we be able to say with the same certainty what flux dynamics is 'true' and what isn't? We've been using a two-sensor setup since we started using eddy covariance in 2010, and I fully agree that this setup drastically increases the chances of obtaining good data. I typically evaluate the two sensor signals for their performance throughout the deployment by (a) comparing the mean O2 microsensor concentration to the O2 optode, (b) point-to-point noise in the 8 Hz data streams, and (c) linearity of the instantaneous cumulative fluxes for each 15 min flux period (Attard et al MEPS in press https://doi.org/10.3354/meps13372). Yamamoto et al (2015) L&O (https://doi.org/10.1002/lno.10018, Fig. 3) adopt a similar approach. Would fitting linear regressions to the cumulative instantaneous fluxes for each 15 min flux for sensors P and Q, and evaluating the coefficient of determination (R2 value), help to shed light on this? An additional analysis could be to fit P-I relationships to the data and see which sensor produces the best R2 value, like the approach described

in Attard & Glud (2020) Biogeosciences Discussions (https://doi.org/10.5194/bg-2020-140, Fig. 2).

Response: We agree with the reviewer that it would be good to develop more quantitative metrics for assessing the quality of the fluxes we measure with the EC systems. We do similar quality checks as described by the reviewer (comparison with reference sensors, noise monitoring, acoustic beam correlation checks), and we here use comparison with benthic chamber incubations and the agreement of independently measuring oxygen sensors to support the flux estimates. Although the chamber fluxes are biased due to the isolation of the incubated sediment, the magnitude of the fluxes can be considered near the true flux. A very close agreement of eddy fluxes based on two independent sensor readings further supports the fluxes we measured. Our experience is that using the linearity of the instantaneous cumulative fluxes for each 15 min flux period can be tricky and time consuming as these cumulative fluxes often change direction midway without producing artifacts and the linearity is dependent on the environment (e.g. homogeneity of the oxygen distribution in the water column) meaning that some of the observed variability is real and not a reflection of low-quality data.

L243-244: Also here, it would be good to mention what part of the integrated curve was used for this analysis.

Response: We added the information as requested by the reviewer: P9L274 "After exclusion of flux intervals compromised by biofouling (Case A: no exclusion, Case B: 14:00-18:00, Case C: 12:00-22:00, 5:00-9:00), the differences between P and Q optode fluxes derived from the slopes of the cumulative flux curves (Figs. 2E, 4E, 6E)"

Discussion

L222-271: A two sensor setup provides redundancy and cross comparison, no question about that. However, it is also twice the cost in hardware, and twice the amount of work in postprocessing. If fouling seems to be such an issue, wouldn't the right approach be to try to eliminate fouling, rather than to add more sensors? I believe there is scope in the Discussion and in the Conclusion to comment on what future modifications might be valuable. For instance, should we install a pump and back-flush the sensors before each measurement burst? Can we monitor buildup of sensor fouling in some other way?

Response: We appreciate the comment of the reviewer and added the following sentence to the conclusions: P12L357 "The deployments of the 2OEC in the Florida Keys sandflat revealed that biofouling frequently affects the aquatic eddy covariance measurements even in such an oligotrophic environment with very clear water. Further developments of the aquatic eddy covariance technique therefore may benefit from installations of devices that monitor (e.g. with a camera) and reduce or prevent biofouling (e.g. through a cleaning mechanism)."

Technical corrections L78: Remove extra 'relative'

Response: Thanks! Done.

L81: . . .established using the jet-nozzle method. . .

Response: Done.

L86: Analogue should read 'analog'

Response: Biogeosciences uses British English spelling

L127: Apostrophes should be replaced with primes

Response: Done.

L137: should read 'products of instantaneous. . .'

Response: Done.

L156: 'permitting' rather than 'facilitating'

Response: Done.

L174: Should read 'The close agreement. . .'

Response: Done.

Please also note the supplement to this comment: https://www.biogeosciences-discuss.net/bg-2020-172/bg-2020-172-RC2- supplement.pdf

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