

Biogeosciences Discuss., author comment AC1  
<https://doi.org/10.5194/bg-2021-266-AC1>, 2022  
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## Reply on RC1

Wiley Evans et al.

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Author comment on "Marine CO<sub>2</sub> system variability along the northeast Pacific Inside Passage determined from an Alaskan ferry" by Wiley Evans et al., Biogeosciences Discuss., <https://doi.org/10.5194/bg-2021-266-AC1>, 2022

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Reviewer 1:

Review of Evans et al. "Marine CO<sub>2</sub> system variability along the Inside Passage of the Pacific Northwest coast of North America determined from an Alaskan ferry."

Evans et al. have prepared a massive manuscript detailing a suite of data collected opportunistically over two years in the Pacific Northwest. The core observations are temperature, salinity, and pCO<sub>2</sub>; however, the authors leverage a salinity-based estimate of total alkalinity (TA) to expand the analysis to other parameters of interest such as DIC, pH and  $\Delta\text{pCO}_2$ . This approach is clever and allows for some novel analysis of anthropogenic influences on the marine inorganic carbon system in this region, but has drawbacks which are highlighted. Speaking from my own experience, I appreciate that continuous data records from ships of opportunity can be challenging to assemble into a coherent scientific analysis. I applaud the authors' work here in that regard, and think this work achieves that end. This manuscript is well-written, but some details in the Methods might be moved to the Supplementary Material. There is a huge amount of variability in study region conditions, so some specific sub-regions of interest are highlighted. This regional variability is presented in a series of nice figures, but some statistics around months/seasons might help to reinforce the presentation of the data, perhaps in a couple tables.

**Thank you very much for the review of our paper. Your comments have been helpful and have improved the manuscript.**

MAJOR COMMENTS

-I am somewhat concerned with the length. For some journals this manuscript would be too long by perhaps 25%. The Methods section takes up more than 25% of the total manuscript text. These methods are important, but some of the description could be presented in the Supplementary Material. Perhaps Biogeosciences is a good fit, as being online-only the length is not a publication concern, but I do think readability would be helped with some length reduction and more concision.

**That you for this comment. We have worked to condense the introduction, added a "Study Region" section, condensed some of the Methods including moving the**

**description of calculating seasonal drivers to the Supplemental Material, and condensed portions of the discussion section.**

-Many of the Figures (2-4, 8 and 9) follow the same presentation style, showing the cruise track repeated over time and colored by data values. This is a style I haven't seen often before and overall I think it is really effective. However, I can't figure out the time component of these plots. For example, in Figure 2 each panel has dates listed along the x-axis (I'm going to ignore the longitude axis at the left side of these plots for now). The x-axis tick mark corresponds to Nov17, which agrees with the Introduction text as to when surveys began. However, as the ship travels 'north' (vertically along the y-axis), it also travels west, but seemingly back in time as well. Thus, the survey that departed Nov17 heading north appears to arrive at the northernmost point in Skagway a couple months earlier. This becomes confusing when seasonality is discussed: while the total north-south transit took one week, the northernmost data appear to precede the southernmost data by a couple months, even though the north-south total transit took one week. One solution might be to add a secondary x-axis on the top of each panel, corresponding to the date when the ship arrived at the northernmost point (basically the lower x-axis shifted to the left). These plots also seem to be done in a Matlab 3-D format (with short longitude z-axes appearing at the bottom), but I'm not sure the inclusion of the longitude adds much (although longitude is probably necessary to generate the plot). Can they be presented in a more 2-D format, or can the figure captions be expanded to provide more detail to the reader?

**We thank the reviewer for this comment. We maintain the 3-D structure of the figures because we believe this is important for representing the cruise track throughout southeast AK where it deviates from a mainly N-S orientation, and because this format provides a coastline and terminal positions that can be used to reference back to Figure 1. Therefore, we have edited the legends to better orient the reader to the 3 axes.**

MINOR COMMENTS

-The title itself is long. Could it be something like "Pacific Northwest marine CO<sub>2</sub> system variability along the Inside Passage coast"?

**Thank you, we have shortened the title to: Marine CO<sub>2</sub> system variability along the Northeast Pacific Inside Passage determined from an Alaskan ferry**

-L41-42: is 1765-present considered the industrial era?

**Thank you, we have clarified the definition of industrial era in the Lines 41-43.**

-L46: 0.1 decline over what period?

**Thank you, we have added "over the industrial era".**

-L52-55: not sure what this is getting at

**We have clarified the point that records of direct measurements of pH or omega are not long enough to constrain trends over the industrial era, but that the multi-decade long records that do exist indicate declining pH and omega.**

-L69: change in what?

**We have replaced "change" with "marine CO<sub>2</sub> system changes"**

-L71: was this mortality linked to upwelling of potentially anthropogenic CO<sub>2</sub>?

**Thank you, yes, the low omega conditions were linked to ocean acidification and the provided reference (Barton et al., 2012) reflects this.**

-L96-98: variability of what? This sentence may be so general as to be unnecessary.

**We have clarified "marine CO<sub>2</sub> system" variability in the sentence.**

-L117-118: awkward phrasing here

**Thank you, we have revised this statement entirely in the new "Study Region" section.**

-Figure 1: the arrows are hard to see in some cases. Can they be outlined in white, or made wider? Also, can full location names (instead of acronyms) be used in the map itself?

**Thank you, we have increased the width of the arrows to make them more visible. We have also added Sergius Narrows, Wrangell Pass, and Dixon Entrance to the map following a comment made by the reviewer below. However, we maintain the use of acronyms because otherwise the map would be crowded with text.**

-L134: I know I've mentioned the length of the manuscript, but a section here laying out the basic geography of the study area would be useful, especially since the discussion leans heavily on some specific geographic/oceanographic characteristics like areas of stronger tidal mixing and freshwater input.

**Following this comment, as well as a similar comment from Reviewer 2, we have added a "Study Region" section for these details.**

-L157: what is the water jacket for? Temperature control?

**The water-jacket around the primary equilibrator is used to minimize warming. A clarifying phrase has been added to this statement.**

-L170: "a LI-COR"

**Corrected.**

-L175: "calibrating a LI840A using the Praxair gases, then using...."

**Corrected.**

-L184-186: So was CO<sub>2</sub> measured an about a 2-minute interval? Were other data (SST, salinity) also measured or recorded at 2 minutes?

**Thank you, this point was clarified by saying "The software captured measurements from all ancillary sensors as well as analyses of the four gas standards of known CO<sub>2</sub> content, 12 measurements of atmospheric CO<sub>2</sub>, and 240 seawater CO<sub>2</sub> measurements in a cycle that was repeated every 8.5 hours with a 2-min measurement frequency."**

-L229-230: I'm not sure if the statement about the Alk composition is true, or even needed. CO<sub>2</sub>SYS certainly uses Alk contributions from sulfate and fluoride in the

determination of total Alk. A sentence about the possible effects of the presence of organic alkalinity, P or Si could illustrate the potential uncertainties from leaving these potential contributors out. I believe modified versions of CO2SYS are available that can model organic alkalinity inputs.

**Thank you for this comment. We have adjusted the statement to read "Alk computed in this way excluded contributions from organic acids, phosphate, and silicate."**

-L233: what compromised the pCO<sub>2</sub> data?

**Thank you, we have clarified the first few sentences of Section 3.3.1 to explain the data gaps, following the comment below, as well as describe that the direct pCO<sub>2</sub> measurements were compromised due to an issue with the LI-COR during late 2019.**

-L234: "pCO<sub>2</sub> was estimated indirectly..."

**Corrected.**

L248-255: Not sure the weather vs. climate distinction matters much, as the authors clearly present the actual uncertainty estimates

**Thank you for this comment. We maintain the description of weather vs climate data quality thresholds as these help frame our reported uncertainties.**

-L256-260: Could there be seasonal bias in the gridded means, CVs etc? For example, there were observations in March 2018 and March 2019, but only in November 2017 (not 2018)? Are the spring and summer months overrepresented relative to the fall and winter months, given the data gap between October 2018 and March 2019? Also, I think some explanation of the largest data gaps is warranted- what happened?

**Thank you, we agree the gridded means likely over-represent spring and summer relative to the autumn and winter conditions. We have added a statement in Section 3.3.1 to reflect this and a point in the conclusions about the need for more autumn and winter data.**

-L278: "three terms in Equation 1..."

**Corrected.**

-L288-291: these buffer factors should be defined and explained, and the global values provided. This would be a good job for the Supplementary Material.

**Thank you. We failed to include values for the salinity and alkalinity buffer factors. We have added these and moved this material to the Supplementary Material.**

-Section 2.3.2: I wonder if this whole section could go in the Supplementary. It's important, but does not directly tie into the results presented, and a small subset of this section referenced to the Supplementary might be able to orient the reader to the big picture (thermodynamic vs. biophysical pCO<sub>2</sub> drivers).

**Thank you, in order to decrease the length of the manuscript, we have followed the reviewer's suggestion and moved this section to the Supplemental Material.**

-L310: where did this growth rate come from?

**We have clarified that the 2.5 ppm/yr growth rate is the average of annual values from ESRL over the 2014-2019 period.**

-L310: or pCO<sub>2</sub> growth in coastal zones may not be apparent at all (i.e. Salisbury and Jonsson 2018)

**Thank you, we have added this reference.**

-L351-353: this sentence can be removed

**We have removed this sentence.**

-L354: the Alexander Archipelago isn't shown in Figure 1, as far as I can see

**We have removed the term Alexander Archipelago and instead use only southeast Alaska throughout the manuscript.**

-L393: can you estimate the relative strengths of the seasonal blooms in each year from satellite data?

**We thank the reviewer for this comment but believe the additional analysis of satellite data is beyond the scope of our study and rely on the biogeochemical signals described to explain the inter-annual variability in the dataset. We note that our description of the inter-annual variability is limited to the 2018 and 2019 spring and summer, and now highlight more clearly that inter-annual variability needs to be further evaluated with future research.**

-Figure 4 caption: these pHT values are at in-situ temperature, correct? In general, I think the figure captions can be expanded to explain the plots more, and perhaps even take some of the explanation out of the text itself

**Thank you. Section 3.3.1 explains that  $\text{pH}_T$  is computed using intake temperature (i.e. SST) and so all discussion of pH in this manuscript is at in-situ/SST conditions. We have carefully reviewed all legends and expanded them to include better explanation of the axes to help orient the reader, as was previously suggested by the reviewer.**

-L449: were temperature and salinity the same between years?

**Thank you, we have added a statement to Section 4.1 explaining that patterns in temperature and salinity appeared similar between the spring and summer seasons in 2018 and 2019 despite the occurrence of a marine heatwave beginning in late 2019 in the North Pacific basin.**

-L465-466: I think this is repeated from earlier.

**Section 3.3.2 describing the calculation of thermodynamic and biophysical drivers has been relocated to the Supplemental Material, and the remaining sentences now are no longer repetitive with this statement.**

-L548: Serguis Narrows and Wrangall Pass are not on the map in Figure 1

**These locations have been added to the map in Figure 1.**

-L590: do previous studies indicate that seater pCO<sub>2</sub> in this area is increasing at the rate of the atmospheric increase?

**There are no previous studies examining rates of change in seawater pCO<sub>2</sub> in this area. This is why we highlight for the reader the difference between “forced” and observed trends. Our ToD estimates are “forced” values based on a prescribed pCO<sub>2</sub> increase. Over time, observed rates of change in pCO<sub>2</sub> may lead to ToD determinations that differ from the “forced” estimates we provide. However, we argue that ToD estimates provided here are meant to guide observing efforts and make the case for particular regions being established as monitoring sites because of the short “forced” ToD values.**

-L600: “additional change might be anticipated is greenhouse gas emissions are reduced to reach...”

**Corrected.**

-L626-644: this section had me a little confused. What do the changes in Figure 8 over time indicate? Different surface water sources? Direct addition of anthropogenic CO<sub>2</sub> via summer pCO<sub>2</sub> drawdown vs. longer time scales for mixing/advection?

**Thank you for this comment. The top panel of Figure 8 shows how the anthropogenic CO<sub>2</sub> content varies along the ferry transit over the time span of the dataset. The lower panel of Figure 8 shows the year when omega\_arag < 1 first appeared. This was estimated by first calculating the preindustrial omega values, and then the anthropogenic CO<sub>2</sub> content and resulting change in omega\_arag for each year over the industrial era. We use this calculation to show that the most weakly-buffered areas have likely exhibited corrosive conditions over the entire industrial era, and that these hot spots are being amplified by continued anthropogenic CO<sub>2</sub> addition. We have revised this paragraph to clarify these points.**

-L650 “limit”

**Corrected.**

-L663: the analysis of 2035 acidification levels don’t consider temperature increase, correct?

**Yes this is correct. Our theoretical calculations only consider changing atmospheric CO<sub>2</sub>, as stated in the second sentence of Section 4.4.**

-L669-671: I wonder if averages are the best indicator here. What about a median with range, or one standard deviation? There is surely some variability that these averages are not capturing.

**Thank you, we have adjusted these statements to include the average +/- 1 standard deviation.**

-L673: “have been”

**Corrected.**

-L673: should pH change values be negative?

**Corrected.**

-L725-727: I think the freshwater alkalinity variability is discussed, but could be highlighted more.

**Thank you, we have highlighted that this is an important next step for research in this area, particularly in southeast AK. We have also included a point about considering deviations from the global S-Ca<sup>2+</sup> relationship following comments from Reviewer 2.**

-L728: "dominant"

**Corrected.**

-L740: large portions of the Inside Passage show  $\omega < 1$  beyond 2035, right?

**This is true, but we limit our theoretical evaluation of 1.5C acidification conditions to 2035, as going beyond 2035 with our current emissions trajectory (SSP5-like scenario) implies even higher atmospheric CO<sub>2</sub> achieved by exhausting more than the 1.5C remaining carbon budget.**

-This conclusions section summarizes the paper well, but doesn't do much to point the way forward from here. Some of that is done in the Discussion, which could be moved here instead.

**Thank you, we have enhanced the discussion of the path forward in the conclusions section to reflect this comment.**

Supplementary Figure S2: Could the bottle alk here below salinity 22 be used to refine the Alk(S) relationship, by basically developing a different relationship at  $S < 22$ ?

**We thank the reviewer for this comment and feel that it is an excellent next step for this research. For our current analysis, we do not employ this approach because we felt the number of data points is still too limited. But future efforts will work to expand marine CO<sub>2</sub> system measurements within the low S waters of southeast Alaska.**

Supplementary Figure S11 caption: "therefore"

**We have made this correction.**