Reviewer 1 Response

(*Reviewer Comments*, Response, Proposed Changes)

1. *This paper deals with the effect of variable boundary conditions in a river on the estuarine pH and saturation state. It does so by applying a previously described model that is used to run a large number of scenarios of feasible riverine conditions. Obviously the subject is an important one, and the tools used, modeling, are suitable to achieve the goals in the manuscript. However, I found this paper particularly difficult to read and to keep focus on the findings that it describes. In the end I even wonder what it is that I have learned here that I did not already know ... while the subject is an important one, the way the manuscript is structured does not lead to a large enough increase in insight for this paper to be accepted in its current state.*

   We appreciate the detailed feedback provided by yourself, the other reviewer and the editor, and would enjoy the opportunity to revise the manuscript in accordance. We agree that we have extended some of our analyses beyond their scope and in doing so have unwittingly lost focus in the manuscript. We propose that we scale back to focus our analyses only on the Fraser River. We will still place it in the context of other global rivers (Figure 6) however we will remove the end-member analysis that relied on DIC and TA from other world rivers (Figures 5-d and 7).

   Specifically, we will provide additional detail concerning the Fraser and its estuary, including what is known and less known regarding the drivers of the inorganic carbon cycle. The river is a key driver and yet we have few reliable carbon data in the fresh and brackish waters in the study region. This paucity provides a strong motivation for our analysis. By clarifying this motivation in the text, the key results will be highlighted. We will include the additional references (not all of which were available at the time that this manuscript was submitted) that the reviewers have suggested, where appropriate. We also will define new sensitivity scenarios to include more recent and newly acquired data where possible and reduce (and sometimes remove) the dependence on data in which we have less confidence (such as data collected using outdated methods or river TA with high organic alkalinity uncertainty). We will re-run all the simulations with these new scenarios and produce a new sensitivity summary figure (4), with clarified presentation, to reflect these new results. Finally, we will strengthen the delivery of our main findings and highlight the importance of using the biogeochemical coupled model by refocusing our results (3), discussion (4), and conclusion (5) sections to target the key points below.

   Key points

   (a) Responses of estuarine pH and Ω_A to Fraser River DIC-TA are asynchronous and strongest at opposite ends of the Fraser DIC:TA range.

   (b) Seasonal estuarine productivity reduces estuarine pH sensitivity to river chemistry during summer

   (c) Future Fraser River flow regimes with lower flow in the biologically productive season will favor lower estuarine pH and Ω_A, but the river will dominate a smaller areal region in the estuary.

2. *... figure 4 is particularly difficult to interpret. A few well-chosen scenarios would have been much easier to explain and to depict.*

   Figure 4 depicts our key results (which will be clarified/focused) from the model sensitivity study, and is critical to the paper. We have constructed new scenarios based on current (rather than old/suspect) data. We plan to improve the accessibility of this figure by strengthening its description in the text (Section 3.2), and by making the following modifications

   - The new scenarios will simply be numbered, with a table of associated freshwater pH, TA, DIC:TA, and DIC-TA values. We will plot the box and whisker objects against these scenario numbers in order of increasing freshwater TA or DIC:TA
   - We will add a figure that shows a few selected years as timeseries plots and explain how these timeseries map to points on Figure 4 to clarify where this synopsis figure comes from.
   - We will overplot selected individual years of salinity (a), DIC:TA (b, c), pH (d, e), and aragonite undersaturation duration (f, g) on top of the salinity climatology (a) and box statistics (b-g). These individual years will illustrate how each year fits into the box plot.

3. *... too little information is given about the system under study, so that it is not clear what processes might actually produce the patterns or how relevant these findings are for other systems.*

   We wrote our study area section (2.1) with the intention of introducing the relevant processes in the Fraser-Strait of Georgia system for later discussion, but we now agree with the reviewers that the level of background presented and the degree to which that background is addressed in the discussion are inadequate. Specifically, it is important for the reader to recognize that the Fraser is globally significant (largest Pacific-draining river in Canada) and strongly seasonal, yet confined to a long residence time in the estuarine Strait of Georgia by tides and topography, the results of which are strong seasonal stratification, productivity, and near-surface aragonite undersaturation in the Strait. These processes are all resolved or parameterized in the model and present fundamental differences between the modelling results in Section 3.2 and the endmember mixing exercise in Section 4.1. Furthermore, these processes are not equally important in all estuaries and thus provide indicators for the applicability of this study to other systems. In the new manuscript, we will refocus Section 2.1 so that it supports the narrative that we have described here.

4. *it is even unclear if the 1-D model resolves the vertical extent (which I think it does) or has the dimension arranged along the estuarine length axis (which I think it should).*

   The model is 1-D vertical. This vertical model was used rather than an estuarine length axis model because local phytoplankton seasonality is more sensitive to the wind and light climatology than to the river (but the river is still important). The vertical mixing model resolves these wind (stratification within a deep fjordic system) and light effects on phytoplankton mechanistically. In contrast, a (1-D) horizontal model would have to parameterize these effects. We will add more details of the model configuration including the above motivation. Also we will highlight the uniqueness of our vertical formulation, specifically how it accounts for estuarine circulation (originally only cited - Collins et al 2009.)

5. *The 2008 paper from Salisbury et al, that is used to back up the scarcity of papers on estuarine carbonate chemistry is outdated by 10 years, and there are indeed some recent papers on this subject that are not mentioned in the manuscript, e.g., Volta et al., 2015 (Hydrol. Earth Sys. Sci.), Cai et al., 2017 (Nat. Comm.) to name a few. There is also older work e.g., Regnier et al., 1997 (Mar Chem.)*

   Agreed. We have thoroughly reviewed these suggested studies and will integrate them into the Introduction and Discussion sections of this manuscript.

6. *while the paper shows that, under some conditions of freshwater influence, the estuarine pH and [aragonite] saturation appears more sensitive, it is not clear why this is so ... procedures to formalize the attribution of processes on pH shifts have been ... recently put in a consistent framework by Hagens and Middelburg, 2016 (Geochim. Cosmochim. Acta)*

   We did explore the use of sensitivity (or buffer) factors - e.g., Egleston et al., 2010 (GBC), Soetaert et al., 2007 (Mar. Chem.) - particularly in discussing our sensitivity results along the salinity gradient - e.g., Hu and Cai, 2013 (GRL). Ultimately we decided against using these sensitivity factors since we were trying to communicate the effects of *freshwater* chemistry on properties within a dynamic and productive estuary, which in the endmember mixing case (Section 4.1) are simply caused by the surplus (or deficit) of DIC at the freshwater endmember being mixed into the estuarine zone. We realize that this endmember behavior alone is not new research, but our intention was to put our model sensitivity results in the context of simple mixing. We believe that the endmember mixing analysis supports these results and helps to highlight the important effects of our model sources and sinks within the estuary. We will clarify our intention for the endmember analysis in Section 4.1 and include a brief discussion of why we used that analysis rather than sensitivity factors.