Editor Response

Summary

We appreciate the detailed feedback provided by yourself and both reviewers 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and reduce (and sometimes remove) the dependence on data in which we have less confidence (such as data collected using outdated methods or river TA with high organic alkalinity uncertainty).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

1. 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.

2. Seasonal estuarine productivity reduces estuarine pH sensitivity to river chemistry during summer

3. 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.

List of proposed revisions

I Tighten writing and improve clarity throughout

II Add more study area background

III Reference recent and reviewer-recommended literature

IV Add more details of the model configuration including

- a motivation for the vertical domain rather than a horizontal domain along the estuary axis

- how the vertical formulation accounts for estuarine circulation
- how the simulations presented here are different from previously published results

V Add most recent TA and pH observations and remove all older TA data collected using outdated/uncertain methods or freshwater TA measurements where organic alkalinity uncertainty is high

VI Use only the total scale for pH - convert all freshwater pH to total scale for presentation in the manuscript

VII Revise freshwater endmember scenarios based on recently available new estuarine data, re-run sensitivity experiments, and remake sensitivity summary figure (4)

VIII Discuss river endmember chemistry in terms of DIC-TA rather than TA, and DIC:TA rather than pH

IX Add a timeseries figure of several (selected) individual years of model salinity, pH and Ω_A and overlay the result(s) of these single year runs on the whisker objects in the summary figure (4). This addition will clarify how figure (4) summarizes the $>$ 200 model sensitivity runs, 12 *for each* river chemistry scenario.

X Add selected model DIC, TA, DIC:TA, and pH at corresponding salinities on the theoretical end-member mixing plots in figure (5) so that the effect of sources and sinks in the estuary can be seen relative to pure mixing only.

XI Remove world river endmember analysis and figures 5d and 7

XII Discuss our results in the context of buffer factors (e.g., Hagens and Middelburg 2016, Hu and Cai 2013, Elgeston et al. 2010), and clarify why we do not use them

Proposed outline

(proposed additions, ~~proposed removals~~)

1 Introduction

Additional references (not all of which were available at the time that this manuscript was submitted) that the reviewers have suggested, will be cited here or where appropriate (**REVISION III**)

- **Motivation to study carbonate chemistry in estuaries**
  - Importance of carbonate chemistry in estuaries. We will acknowledge the new work by Cai et al. 2017, Xue et al. 2017 etc.
  - Complexity of estuarine systems and carbon chemistry within them
  - More explicit introduction of buffer factors and future sensitivity (add Hagens and Middleburg 2016)
- **River DIC and TA drivers**

- Seasonal river flow variability and its effect on carbonate chemistry
- Relationship to weathering with global context
- Influence of pollution/anthropogenic nutrients (add Cai et al. 2017)

- **Study premise**
  - Identify study region and lay out sensitivity analysis
  - Clarify that the model is vertical, parametrizes estuarine circulation, and contains phytoplankton/zooplankton functional groups (**REVISION IV**)
  - Revise description of data used (**REVISION V**)
  - Clarify paucity of accurate data as a motivation for the study

2 Methods

2.1 Study Area (REVISION II)

- **Figures**
  - Map (Fig 1 old numbering)
  - Hydrograph of Fraser (NEW FIGURE)
- **Describe the Fraser River and Strait of Georgia**
  - Seasonality, interannual variability, productivity, carbonate chemistry (Collins et al. 2009, Allen and Wolfe 2013, Moore-Maley et al. 2016, Ianson et al. 2016, Pawlowicz et al, 2007.)
  - Decoupling of productivity and respiration (deep fjordic system - respiration signal not seen at surface)
- **Fraser River carbonate chemistry**
- **Organic alkalinity discussion** (moved from 2.2)

2.2 Data

- **Figures**
  - TA vs salinity with extrapolation to S=0 (Fig 2 old numbering, + 2014, 2016, 2017 data **REVISION V**)
  - TA and pH vs river discharge (Fig 3 old numbering, ~~ECCC TA data~~, + 2014, 2016, 2017 data **REVISION V**)
- **Describe TA datasets used**
  - Ianson et al. 2016 (+ 2014, 2016, 2017 data previously unpublished)
  - ~~de Mora 1983 data~~ (uses outdated methods)
  - ~~ECCC TA data~~ (uses outdated methods and likely contains significant organic alkalinity)

- **Describe extrapolated endmembers**
- **Describe method for determining river DIC:TA**
  - Buoy pH (present in total scale **REVISION VI**)
  - Discuss pH sensor accuracy and provide errorbars for DIC:TA uncertainty
  - Discuss temperature dependence of DIC:TA calculation
- ~~**Organic alkalinity discussion**~~ (moved to 2.1)

2.3 Model

2.3.1 Overview

The physical model configuration is described and the biological and carbon model detail are given. In the new version we will also describe and justify the vertical 1-D model, provide more details of the physical part of the model including estuarine circulation and the importance of vertical mixing (**REVISION IV**)

2.3.2 Initialization and forcing

A description of how the model is initialized, the bottom boundary conditions and the surface forcing used to drive the model are given.

2.3.3 Evaluation

We describe how the model was evaluated and the statistics of that evaluation. In the new version we will discuss the implications of the evaluation. In particular, we will clarify that although RMSE is not small, the positive bias prevents overestimating severity of corrosive conditions

2.4 Sensitivity analysis

- **Describe the freshwater carbonate chemistry scenarios.**
  - We will define two new sets of scenarios: one independent of river flow and one dependent on river flow. Although it is intuitive to vary river DIC and TA across the scenarios, the impact is due to DIC-TA and DIC:TA. Thus for each set of scenarios we will provide a table with all four of DIC, TA, DIC-TA and DIC:TA for each scenario. (**REVISION VIII**)
  - Instead of basing our flow dependent scenarios on statistical fits to our observations, we will construct these flow dependent scenarios based on what we expect the flow dependent curves to look like across the range of observations summarized in section 2.2. (**REVISION VII**)
- **Describe the model runs**
  - Each scenario will be run across all of our years, giving more than 200 total simulations.

- We will provide more detail about the different annual forcing combinations instead of referencing Moore-Maley et al. 2016 (which used a single river chemistry scenario) to emphasize uniqueness of this study.

3 Results

3.1 ~~Data analysis and sensitivity scenarios~~

(Moved to sections 2.2, 2.4, 3.2)

3.2 Sensitivity analysis

- **Figures** (**REVISION IX**)
  - NEW FIGURE: timeseries of selected individual years (from > 200 different runs) of each of model forcing, model salinity, pH and Ω_A to show model behavior at low and high river flow, in extremes in river chemistry
  - Boxplot (Fig 4, old numbering): remake figure to show new sensitivity runs, add years shown in the new timeseries figure overlaid in the box and whisker objects
- **Describe the seasonal and interannual dynamics of salinity, pH, and Ω_A according to the new model timeseries figure (REVISION IX)**
- **Introduce the reader to Figure 4 (old numbering) including what the boxes mean and how the model scenarios are organized along the axes (REVISION VII)**
- **Highlight the key points in the results:**
  - Trends of the boxes across all scenarios (**KEY POINT 1**)
  - Length of each box across the 12 different years (**KEY POINT 2**)

4 Discussion

4.1 Two-endmember conservative mixing (Fraser only)

- **Figures**
  - Salinity space plots ~~panel d~~ (Fig 5, old numbering) (**REVISION XI**)
  - Add results from summary figure (Fig 4, old numbering) at corresponding salinities in Fig 5 (old numbering) (**REVISION X**)
- Discuss similarities of model results and mixing exercise We will make this text more concise and target **KEY POINT 1**
- Separate importance of biogeochemical sources and sinks within the estuary from simple mixing scenarios (add reference to Regnier et al. 1997) **KEY POINT 2**
- Relevance of DIC/TA ratios (add reference to Xue et al. 2017) (**REVISION III**)

- Compare/contrast our endmember mixing example with the use of buffer factors (e.g. Hagens and Middleburg 2016) and briefly explain why we don't use them (**REVISION XII**)

4.2 ~~Implications for other estuaries~~ (REVISION XI)

- ~~**Figures**~~
  - ~~DIC/TA world rivers (Fig 6, old numbering)~~
  - ~~dTA/TA plots (Fig 7, old numbering)~~
- ~~**World river/estuary discussion**~~

4.3 Implications for future climate (REVISIONS I and III)

- Merge this section with Fraser comparison to world rivers
  - Place DIC/TA world rivers (Fig 6, old numbering) here
- Discuss predictions for future flow regimes We will make this discussion more quantitative by referencing the new timeseries figure and Fig 4 (old numbering) from the results section (3.2) **KEY POINT 3**
- Discuss sensitivity to increasing T (add Hagens and Middleburg 2016)
- Discuss impact of future increases in atmospheric CO_2 scenarios on estuaries (Volta et al. 2016)

5 Conclusions (REVISION I)

We will rewrite the conclusions in truncated form to (1) restate our study premise from the final paragraph of the introduction, and (2) highlight our key points