A modeling study of temporal and spatial pCO2 variability on the biologically active and temperature-dominated Scotian Shelf

Response to Comments by Reviewer 2

(Reviews are included in black font; Responses are in blue font)

The authors use output from a regional oceanic biogeochemical model and mooring/ship-board observations to study the seasonal cycle of surface pCO2 and sea-air CO2 fluxes. The general findings are that the Scotian Shelf acts as a net annual source of CO2 to the atmosphere and that biological activity and temperature are the main drivers of the pCO2 variability. The authors also try to show that coastal upwelling is responsible for low near-shore surface pCO2 in summer. Overall, I find the manuscript well organized. However, I have several concerns (see below) that need to be addressed.

Response: We appreciate the constructive comments and propose to address them as described below.

Line 14: Might be good to mention here by how much pCO2 changes due to this steep increase in temperature.

Response: Agree, we will modify the text as follows (addition in bold italics): "*Surface pCO_2 undergoes a strong seasonal cycle* ***with an amplitude of ~200-250 µatm***. ***These changes are*** *associated with both a strong biological drawdown of Dissolved Inorganic Carbon (DIC) in spring* ***(corresponding to a decrease in pCO_2 of 100-200 µatm)***, *and pronounced effects of temperature, which ranges from 0°C in the winter to near 20°C in the summer****, resulting in an increase in pCO_2 of ~ 200-250 µatm.***"

Lines 33-36: Since you specify the type of measurements that suggest that the Scotian Shelf is a net CO2 source, it would be interesting to know what type of data suggests that it is a net sink.

Response: It is the same type of measurement (surface ocean pCO_2), but different data sets are used in these studies. We propose to clarify this by stating explicitly that these other studies use the SOCAT database.

Line 63: I would be careful calling any model "accurate"! If the model has been evaluated properly (if the region has an adequate amount of observations), then I bet these studies identified some deficiencies. I would suggest to briefly summarizing the previous model evaluation here and state unknowns due to lack of data, if applicable.

Response: Agree, we will modify this as follows (added/modified text in bold italics):

"In the present study, we employ a high-resolution biogeochemical model of the northwest North Atlantic to examine the magnitude, variability and sign of the air-sea CO_2 flux on the Scotian Shelf. Previous studies ***evaluated*** *our* ***model's ability to*** *represent the physical (Brennan et al. 2016, Rutherford & Fennel 2018) and biological (Laurent et al. 2020) dynamics of the region."*

We will also add more detail about these evaluations in the methods, where we describe the physical and biological model set up.

Line 105: What are the possible implications of using a river climatology to force the model? Is anything known about interannual or longterm changes to the riverine input?

Response: The intended purpose of this paper is to focus on the seasonal variability not interannual or long-term changes. River inputs make up a very small fraction of the water on the Scotian Shelf (see Rutherford & Fennel 2018) and variations in riverine chemistry over this short period would be negligible. We will emphasize in the revised manuscript that the focus of this study is on a seasonal scale.

Line 102: Again, a brief summary of deficiencies and skills of the model would be good.
Response: Agree, we will add the following (addition/modification in bold italics):

"*For a detailed description and validation of the biological model, we refer to Laurent et al. (2021),* ***who compared the model output with glider transects of temperature, salinity and chlorophyll, and in situ measurements of chlorophyll and nitrate. They showed that the model outperforms global models in this region for all variables and that the timing of the spring bloom is well represented, but the model slightly underestimates the magnitude of the bloom and tends to slightly overestimate nitrate throughout the year.*** "

"Full details on the physical model setup and its validation can be found in Brennan et al. (2016) and Rutherford & Fennel (2018). ***These studies have shown that our model simulates the vertical structure and seasonal cycling of temperature and salinity on the shelf well. The model captures mesoscale features and coastal upwelling events, and simulates the volume transport throughout the region in agreement with observation-based estimates.***"

Line123: Why is it drifting and how does the nudging impact the actual model skill. I was surprised that so much nudging was done for a relatively small model domain. Are the nudged areas not used in the analysis? And if these areas are used, how do you deal with them? Would be helpful to show the nudged areas in Figure 1.
Response: The nudging zones along the boundary are not used in the analysis, which we will state explicitly in the revised manuscript. It is common to apply boundary nudging in regional domains. The nudging timescale is long (60 days at the boundary, linearly decreasing to zero at the inner edge of the nudging zone). This means that nudging is weak. Since the internal dynamics of the Labrador Sea, which set the seasonal cycle of physical and biogeochemical conditions at the northeastern boundary, are not represented in our regional shelf-focussed domain, it is not surprising that conditions would be drifting slowly without nudging. Nudging benefits model skill by eliminating unrealistic drifts.

Line 131: Model spin-up of a biogeochemical model usually takes 6-10 years. Can you show that 1 year is enough and the model won't drift anymore? For example run the model for 10 years perpetually, using the 2000 conditions. Does DIC remain relatively stable, without drifting?
Response: We have now run a longer simulation (1999-2014), which we will analyze to replace the current 6-year simulation (1999-2004) presented in the manuscript. We will focus on the later years of this simulation and can include a figure in the supplement with a timeseries of DIC to illustrate the spin-up period.

Line 147: Need to label the location of the Halifax and Deep Panuke gas platform.
Response: Agree, we can add this.

Line 163: “from top to bottom…” belongs into caption and not into main text. Also, describe method you used to temperature normalize pCO2 in caption.
Response: Agree, we will modify this.

Line 164: To me it is confusing to talk about days and months. I would just stick to months, since days are less obvious – The reader would have to first convert to the month before understanding what time of the year you are referring to. I don’t see how pCo2 is relatively constant between day 0 to 75. Are you referring to the temp normalized pCO2? But even temp normalized pCO2 is increasing during this time. Might be better to give a range here?
Response: We prefer to use the day of year for this section because it is more specific than referring to months and believe it is clear.

Line178: add “buoy” to “… at the low end of the **buoy** observations
Response: Agree.

Line 182: I don’t think the word “consistent” is appropriate here? The model seems to underestimate the DIC drawdown due to primary production compared to both types of observations (temp norm. pCO2).
Response: Agree. We will modify this line to “The bloom-related minimum in pCO_2 in the model is approximately 50-75 µatm higher than the buoy observations and approximately 25-50 µatm higher than the Atlantic Condor observations.”

Line 189: verb is missing.
Response: We will correct this.

Line 209: Figure 4 shows how the model struggles to simulate the spatial variability, which should be pointed out.
Response: Agree, we will add a sentence at the end of the first paragraph stating that the model does not show the small scale variations in pCO_2 that are seen in the Condor transect. However, we would like to add that this is not surprising. It is common that models produce much less variations than underway pCO_2 observations. We would also point out that underway measurements are prone to many errors and that the variations may at least partly be due to measurement artifacts.

Line 212: add east or west to longitude description
Response: Yes, we will add this throughout the paper.

Line 216: I don’t think these events are all that obvious in the observations. There were only a total 3 inner shelf observations during this time period, two of which are actually higher than an outer shelf observation point (also the only one during this period). I agree, that this is obvious in the model, but would be more careful with this statement for the observations. I just don’t think that the observations can be interpreted that way… Im also not conviced by the proposed mechanism that leads to low pCO2, despite high DIC. What does the salinity profile look like? I think this section needs something like a Taylor decomposition to show that what is responsible for the low pCO2 (see details in
Rheuban, J. E., Doney, S. C., McCorkle, D. C., and Jakuba, R. W.: Quantifying the effects of nutrient enrichment and freshwater mixing on coastal ocean acidification, J. Geophys. Res.-Oceans, 124, 9085–9100, https://doi.org/10.1029/2019JC015556, 2019.

Or
Hauri, C., Schultz, C., Hedstrom, K., Danielson, S., Irving, B., Doney, S.C., Dussin, R., Curchitser, E.N., Hill, D.F, and Stock, C.A.: A regional hindcast model simulating ecosystem dynamics, inorganic carbon chemistry, and ocean acidification in the Gulf of Alaska, Biogeosciences, 17, 3837–3857, https://doi.org/10.5194/bg-17-3837-2020, 2020.
Response: The observations with higher pCO_2 nearshore have been removed from the analysis, due to sensor error. There is 1 instance in the observations where this low pCO_2 signal is very clear, which is associated with cold temperatures (refer to Figure 5). We agree that with only 1 instance in the observations of low pCO_2 nearshore, it is difficult to draw unequivocal conclusions about the mechanisms driving this. We will therefore rephrase this section as using the model to hypothesize what could be driving this low pCO_2 nearshore.

We additionally plan to add more variables along the transect to the supplementary info. We also really like the idea of doing a Taylor Decomposition and plan to add this as well.

Line 264: "Accurate" means: "correct in all details; exact"- as menti0oned earlier, I yet have to see a model that can be described as "accurate". I would tone it down… especially because you start the sentence with "This limitation aside…"
Response: Agreed, will remove the word "accurately."

Line 270: would be nice to calculate how much the temperature change affects pCO2 and how much DIC increases affect pCO2….
Response: Agreed, we think adding the Taylor Decomposition will accomplish this.

Figures – I really like the color choices of the figures!
Response: Thank you!

Figure 1: It would be nice to give the reader a better understanding of where the Scotian Shelf is located. Maybe a zoomed-out map as an insert? Label all location names you are mentioning in the paper e.g. Halifax Harbor. What are bin 1 and bin 2? Please describe in caption. Also, LAt and Lon labels are missing, including whether it is north or south, and east or west. This should be adjusted for all figures throughout.
Response: We will make these changes.

Figure 2: Correct "Glider observations"
Identify grey band in legend for consistency.
What are the two different x-axis?
Response: We can make these changes. We included a DOY and month x-axis to help the reader (since we refer to DOY in the text).

Figure 4: What are these inserts? Zoom in? Does not seem to show what you see in the smaller box below. This figure is kind of confusing. What are we actually looking at? Are there 365/5 lines total per figure?
Response: We will make the caption for this figure clearer and more descriptive.

Figure 5: On the left, there is no top and lower panel... please adjust accordingly. Also, maybe identify "thick black line" as "vertical black line"
Response: Agree, these have been modified.

Figure 6:Please identify the variable that goes with each unit next to the colorbar. Always good to specify units of all variables in the caption too. Also, define abbreviations in all figures e.g. dissolved inorganic carbon (DIC). Figures and captions should be readable without reading the manuscript. Since you refer from figure 5 to this figure, you should mention here that July 11, 2000 is indicated in figure 5. Please show the transect line again in the map and label it with lat and lon. Why not also show a profile of pCO2 here to make the point that pCO2 decreases during upwelling event.
Response: Agree. We will make these changes.

Figure 7: Add "the" to …the values from **the** nearshore bin…
Response: Done.

Figure 8: What do the error bars mean? What are they based on? What are the numbers behind +/-? 1 STD? Needs to be defined in caption.
Response: Error bars are standard deviation between years. We will add this to the figure caption.

Figure 9: Why are some bars faded? Are all ingassing bars faded? Needs to be defined.
Response: Yes, all ingassing bars are faded. We will add this to the figure caption.