

Reply to referee #1 of the manuscript
”High-frequency, year-round time series of the carbonate
chemistry in a high-Arctic fjord (Svalbard)”

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June 5, 2023

We are very grateful to referee Leif Anderson for his constructive comments which greatly improved the manuscript. Below is a point-by-point reply (**RC**: referee comment; **AR**: author reply)

RC: This manuscript presents a very valuable high-frequency data set of carbon system relevant parameters covering several years in the surface water of an Arctic fjord system. Never before has it been possible to observe the evolution of climate relevant parameters as pCO₂ and saturation state of aragonite in all seasons with this high time resolution. These data will set a very useful reference point for other studies of the carbon system in the Arctic Ocean. Hence, well deserve to be published, but can be improved by making some minor changes as specified below.

AR: Thank you.

RC: Section 2.4. The SeaFET sensor is pressure sensitive and it therefore valuable to give information on how long the profiling system was kept at the depth before recording. On line 2018 it is given as 24 hours but this information would be valuable also here.

AR: The sensing element of the seaFET sensor is solid state and therefore insensitive to pressure (according to the supplier and within specifications). In any case, the median time spent by the sensor at each depth interval was 6 h rather than 24 h. the manuscript has been revised accordingly.

RC: Line 106. The uncertainties given, I guess, is a result of analytical imprecision of the input parameters, but no information of these imprecisions are given in 2.2. Please do that, and also give the accuracy, which is as important for the computation of the other C-parameters. The same should be done for the discrete pH measurements.

AR: The uncertainties given are the results of the propagation of the analytical uncertainties of A_T and C_T as well as the uncertainties of salinity, temperature, total boron, and of the 7 key dissociation constants. We agree that the analytical accuracy and precision of A_T and C_T should be given in Section 2.2 and have done so in the revised version of the manuscript:

The average accuracy of C_T and A_T measurements was 2.6 and 3 $\mu\text{mol kg}^{-1}$, respectively, compared to seawater certified reference material (CRM) provided by A. Dickson (Scripps Institution of Oceanography). Repeatability of replicate samples was better than 3 $\mu\text{mol kg}^{-1}$.

Concerning the pH measurement of discrete samples, a TRIS standard was measured 6 times. The deviation between the theoretical and measured pH ranged between -0.0033 and +0.0012 pH units (mean = -0.0015). This information is provided in the revised version of the manuscript.

RC: Section on lines 173-175. I cannot follow this text. From the figures 3 & 4 as well as tables 3&4 I only see marginal differences in the results when using Lueker et al (2000) and Papadimitriou et al. (2018). The authors need to better describe what they mean.

AR: The manuscript was revised accordingly as follows.

In conclusion, the formulations of Lueker et al. (2000) and Papadimitriou et al. (2018) have similar performances with our dataset and generally perform better than those of Millero et al. (2002) and Sulpis et al. (2020). The formulation of Papadimitriou et al. (2018) is seldom used and the de facto standard has become the formulations of Lueker et al. (2000), which we have used in the present study.

RC: Fig. 6. Add the orange lines as noted in the legend. Also specify what the red dots in C, D and E are. I guess that for D and E it is the measured values in water samples and thus the blue dots in E must be computed; from salinity? For pCO₂ the situation must be different as it was only measured by the ferry box. Please give information on this.

AR: Lines were added. We agree that the legend was incomplete. It now reads :*A-E: Time-series (A-E) and monthly distribution (F-J) of key environmental parameters (hourly means). Panel C: pCO₂ measured (red) and calculated using A_T and C_T (blue). Panel D: pH_T measured (red) and calculated using A_T and C_T (blue). Panel E: A_T measured by potentiometric titration (red) and calculated from the A_T—salinity relationship (blue). In panels F-J, the cyan lines indicate the medians, boxes show the first and third quartiles and the interquartile range, whiskers extend to the 5–95th percentiles. The light blue circles highlight values above the 90th percentile and below the 10th percentile.*

RC: In line 207 it reads “salinity below 8 m ..” while it in line 211 reads “Temperature at 11 m ..”. I hope that all the high time resolution data, except that of pH, is from the ferry box. If not any comparison is prone to uncertainties in water masses variability. Please specify the depth of sampling in detail.

AR: The salinity shown in Fig. 6 is indeed salinity below 8 m (the label of the Y-axis has been revised accordingly). The reason is that the salinity sensor in the FerryBox had some failures. The gaps were filled by salinity values measured with the *in situ* CTD when the REMOS was below 8 m. Such gap filling was not performed for temperature which warms by about 1°C before reaching the FerryBox.

The following paragraph was added in the Material and Methods section: *The salinity (conductivity) sensor in the FerryBox had some failures. The gaps were filled by salinity values measured with the in situ CTD when the REMOS was below 8 m. Such gap filling was not performed for temperature which warms by about 1°C before reaching the FerryBox.*

RC: The first paragraph of 3.9 needs to be looked over. The data that is not available in May to July are pH, not the ferry box pCO₂. Hence that information needs no be after how the pCO₂ vertical profile is computed. Then it finishes off with a comment that temperature is partly driving the vertical gradient. However, Fig. 7 show that non-thermal drivers exert a greater control than temperature.

AR: In section 3.9 we discuss the vertical gradient in pCO₂ or, more precisely, the difference between pCO₂ at 0-to-4 m and pCO₂ at 8-to-12 m. To do that one uses pCO₂ calculated from pH and A_T as pCO₂ is only measured in the Ferrybox (from water at 11 m depth). Unfortunately, there is no surface pH data between May and July. For clarity, the following sentence has been added to the legend of Fig. 9: *Data are missing in May to July because no surface pH data is available during this period.*

RC: Paragraph starting on line 240. I have difficulties with the signs here. First in the paragraph above it reads that the 11 m pCO₂ overestimate the surface water values by 17 uatm (clear from Fig. 10), but in this paragraph it reads “correcting for the underestimation of 17 uatm ..”. This in combination with the first presented air-sea flux of 20 mol/(m²yr) and the second -17 mol/(m²yr) does not make sense. To control if the pCO₂ estimated from pH and salinity derived AT at 0-4 m depth is comparable to the measured it would be nice to see how the pCO₂ estimated from pH and salinity derived AT at 11 m compare to the measured.

AR: This paragraph is indeed inaccurate and confusing. An additional source of confusion is that the figures are not correctly located in the text. Additionally, David Ho also brought to our attention that it would be useful to bracket the air-sea CO₂ flux using the gas exchange parameterisation by wind speed designed in offshore settings that we had initially used and another parameterisation for wind-fetch-limited environments. The text has been extensively edited and the paragraphs now read:

For the 9 months when data are available, monthly median pCO₂ normalized at in situ temperature at 11 m vs 0-4 m are well correlated ($r^2 = 0.81$) but pCO₂ is higher at the surface than at 11 m, with a median difference of 17 μ atm (Fig. 10).

The air-sea CO₂ flux estimated from pCO₂ at 11 m is negative, indicating a CO₂ influx from the atmosphere, every month of a composite year (Fig. 11). The gas exchange coefficient k is notoriously difficult to measure. It is often parameterised by wind speed which is known to work well in deep waters offshore (Ho, 2006). In shallow areas, parameters other than wind speed become important. Dobashi and Ho (2023) proposed a formulation which might work better in wind-fetch-limited environments. Here we are bracketing the air-sea CO₂ flux using these two parameterisations. The annual air-sea flux ranges from -10.2 to -20.2 mol CO₂ m⁻² yr⁻¹, respectively with the formulations of Dobashi and Ho (2023) and Ho (2006). Correcting for the fact, discussed above, that surface pCO₂ is higher than pCO₂ at 11 m above leads to fluxes of -16.8 and -9 mol CO₂ m⁻² yr⁻¹ with the two parameterisations.

RC: Abstract: Not all the parameters mentioned are determined every hour.

AR: That is correct. The text has been revised accordingly.

RC: Line 5 of abstract. Specify that 11 m is the bottom/sampling depth.

AR: Done.

RC: Line 19. Spell out what fastest and largest changes the Arctic Ocean exhibit.

AR: This is spelled out in the subsequent sentences.

RC: Line 25-26. Delete the first “projected” in the text “The projected decrease in pH is projected to be larger in”.

AR: Done.

RC: Fig 1. Add (C) to legend and change a, b, c and d to 1, 2, 3 and 4.

AR: Done.

RC: Line 63. Set the number of outliers in relation to the total number of determinations.

AR: Good point. The sentence now reads *The number of outliers discarded was 38 and 41, respectively for C_T and A_T (out of a total number of samples of 229 and 236).*

RC: Table 1. Use the letter μ instead of mu for pCO₂, as in the text.

AR: Done.

RC: Line 155. Fig. 3 should be Fig. 4.

AR: Changed, see below.

RC: Fig. 4. Wrong figure has been posted, is the same as Fig.3. Legend. One AT should be CT.

AR: Thanks for spotting that. These mistakes have been fixed.

RC: Table 3. Give information of what Q1 and Q3 stands for.

AR: Done.: *Q1 and Q3 are the first and third quartiles.*

RC: Line 2001. Add C after Fig. 5, and in next line insert 5 instead of ?? after Fig.

AR: Sone.

RC: Line 210 mention that numerous streams add freshwater in June to August. Another important source is melting sea ice and calving glaciers that add freshwater to the fjord system.

AR: Agreed. Text changed accordingly.

RC: In line 220 it reads that pH information should be given in Fig. 8, but it is not. It would have been nice to see that but if the data do not allow then delete pH here.

AR: Agreed, "pH" deleted.

RC: Fig 8. It states that the density gradient is given in C. But it cannot be, but maybe sigma. Please clarify.

AR: The legend is actually correct. Fig. 8C shows the difference in seawater **density** between surface and deep.

RC: Line 250. Change "Its it ranges.."

AR: Done.