Response to reviewer 2

We would like to thank the reviewer for the very thorough comments and suggestions on how to improve the content for the reader's benefit. We agree with the reviewer in nearly all instances in this regard and have rewritten the manuscript to follow the format suggested by the reviewer. We hope that these changes are acceptable for publication.

Please find below our response to all comments and concerns raised by the reviewer in bold typeset.

Summary response and major concerns by the reviewer 2:

It takes a lot of work from the reader to understand how the system works. The fundamentals are buried in a lot of extraneous detail, and references to many figures that overlap in their content but are not unified in how they are presented and explained. It needs to be rebuilt starting with the main ideas that in interested reader would need to know including to following topics which map roughly into the introduction, methods, results and discussion.
-Under what circumstances is the system is most useful? (without implying that other less complex systems are no good)

1) What are the fundamentals of how the system works? (without getting into the weed too much). **We have added an "operational concept" section (2.1) which describes the capabilities of the system in a simplified manner.**

2) How does the system perform? (with more emphasis on the second use in the heat wave experiment when the improvements were in place and less on the difficulties of getting to that point.). **We have focused on the second deployment description in the newly written discussion to focus on the benefits of the improvements made.**

3) What are the best applications of the system and what are the main considerations for someone who might want to use to be able to make the best use of it? (without a tale of woe about things that went wrong in this build apart from those points). **This is summarized in the newly written 'operational concept' section (2.1) which gives a basic description of uses and capabilities. We also highlight the system potential in the newly written introduction.**

Specific Comments by reviewer 2:

The introduction would be stronger if it included a more robust (and generous) description of previous multi-stressor systems, particularly for salinity and temperature. There is no need to say these systems only had static changes or course automation. Instead, describe a couple of them without the devaluing adjectives. You can say systems include static conditions which can be appropriate for low variability systems, and that automation in existing systems is based on set patterns of fluctuation, on scales of hours to days (or something), producing regular pre-determined variability. This kind of system could certainly replicate tidal variability and

manageable human intervention could simulate spring and neep tides. There is nothing intrinsically inferior in these approaches. You need to make the case for why a system that creates and offset from naturally observed variability is valuable. (I believe it is, but you need to make a stronger case for it.)

The introduction should also include some information about the magnitude of the variability in salinity and temperature and the time scale of these changes so the reader can better understand why an autonomous system is needed instead of manual control.

We thank the reviewer for their comment and agree that the focus of the introduction be reoriented. We have substantially changed the introduction to reflect the comments by the reviewer including reference to other experimental systems, removing critiqued language of other systems, and a more detailed description of the variability observable in nearshore environments.

It's awkward for the methods to begin with the kelp experiment since that is not covered in this manuscript. Just talk about the system here, not the experiment if the experimental data are not also presented. Or at least don't lead with the experiment.
We have cut down on the amount of detail given to the biological experiment and focused more on the system itself. The methods section now begins with details about Kongsfjorden hydrography and explicit details about the biological experiment have been removed since we do not present these data.

Your approach for getting the salinity offset seems unnecessarily complicated. First of all, is there some reason to believe that the salinity/T relationship is non-linear? The summer data don't clearly indicate this, and could be fit to a linear equation (though with all the projection points on the graph it's kind of hard to tell – projected data should not be shown as points here.) But if we accept it's non-linear, which it certainly could be, then why fit new linear equations for each treatment when these are simply replotting the results of the projection from your quadratic equation against an offet temperature? (Or at least I think this is what you have done – though I can't be sure since it's not really explained.) This all needs to be better explained and better justified. Is the software only capable of using a linear model to generate the target salinity? **We agree with the reviewer that the original description was convoluted and unclear. We have reduced the text in the manuscript to point out that the salinity offsets were derived based on *in situ* temperature correlations with salinity in the summer of 2020 at 11 m in Kongsfjorden. We have provided a detailed description of the calculations now in Appendix A1 and have changed figure A1 as well. We feel the newly added description provides clarity on how these calculations were made as well as a strong association with what is now presented in Fig. A1.**

The explanation of the system would benefit from an overview at the start. For instance, you show pressure regulating valves in figure 1, but when the reader first looks at this figure when it is called out, their purpose is unclear and you have to wait a while till the pressure regulation section to understand what they are. And even then, while there is a lot of detail, the basic

function of the valves is not that clearly explained. Just start with an overview in the experimental system section that very briefly goes over the basic function of the whole system. Anything that is important enough to be in the schematic figure 1 gets a brief explanation here. And one schematic figure is enough, or a photo but not both and the photo is nice looking but harder to label and explain. **We thank the reviewer for this suggestion and have added a new section to the methods that gives a brief overview of the system concept. See the new 2.1 section in the revised manuscript.**

There are too many references to the appendix material in the main text. This is an issue when the text is not that easy to understand without reference to these, and it's inconvenient to make these references into an appendix. You should consider what the general reader who is interested in the method in a general sense need to know. Keep that in the main text. Things that someone who might be interested in building a similar system of their own can refer to more detailed information in the appendix. This will mean moving some parts of the text to the appendix. For instance – the whole menu bar section is more like a user manual for the software. This is just not needed to understand the system and its merits. It should be moved to supplementary materials. **We thank the reviewer for this comment and have streamlined what is necessary to keep in the main text and what should be moved to the appendix. We have now moved many parts of the methods (Temperature and Salinity Regulation, Pressure and Flow Regulation, Automation, Software development) to the appendix. The methods section now retains the necessary information to understand the system without extraneous details.**

The figures need to be consolidated to just what is needed to convey the material. Too many figures make it difficult to navigate and labeling varies in the text and between figures. All this needs to be streamlined. **We have combined figures 1 and 2 to aid the reader in understanding the system. The appendix maintains the previously presented figures, but these figures are now referenced in the appendix so as to not complicate the main text.**

Another example of a section with too much detail is section 3.2 in which you dissect the reasons for different instances of the system not meeting the set point. This needs to be greatly simplified and framed not as an explanation for deviations in the data but perhaps a very brief record of improvements that were made to the system and an account of areas that the user must pay attention to for optimal operation such as clogging or loss of pressure in the system. The point of the paper should be about how the system can best be used, not looking under the microscope at every bump in this deployment of it. **We agree with the reviewer's comment and have reduced significantly the description of technical issues and have moved them to a brief part in the discussion. Section 3.2 has now been streamlined to highlight the performance of the system as suggested.**

Figure 6 appears as a kind of add on, but should be featured more prominently. Why spend the whole thing focusing on the shake-down use of the system in which the bugs were worked out, and then not really talk about the one where it seems to have worked really well? Yes, all the work happened in the first experiment but the data from this heat wave application are more compelling as to how this system can be really useful and powerful. **We appreciate the insight and comment by the reviewer. We have chosen to retain the presentation of Figure 6 in the discussion as it is well suited to show how the adjustments made to the system improved its**

functionality. Since we moved the text describing the technical issues into the discussion, which were followed by suggestions on optimal operation (as per the reviewer's previous comment), the presentation of Figure 6 at this junction seems appropriate. Please see lines 326 – 331 in the revised manuscript on how this figure was incorporated into the new version of the discussion.

It is not explained how adding freshwater after the temperature is adjusted does not influence the ability of the system to meet temperature set points. **The tap water was warmer than the fjord water. The freshwater was mixed alongside the incoming temperature adjusted water. However, the system would regulate the inflow of warmed water to compensate for any temperature change induced by the freshwater supply. We have added a brief explanation of this in the revised manuscript. Please see line 201 – 202 in the revised manuscript.**

Wording in general is often not concise and phrasing is awkward especially in the use of passive voice, such as "Challenges… were able to be resolved henceforth". Just say challenges were resolved. **We have done a comprehensive rewrite of the manuscript and feel many of these adjustments have been made.**

Response to line comments by reviewer 2:

44 Wording is unclear. Flow rates of chilled or heated ambient seawater and freshwater? Not clear what is chilled and/or heated. **We have changed this sentence to make clear the intended message. See line 47 – 50 in the revised manuscript.**

48 Eliminate the start of this sentence about versatility. It's unclear and redundant with the second half of the sentence. **We have rewritten this sentence. See line 59 – 60 in the revised manuscript.**

62 Why not just say extreme variation in temperature and salinity? "physiochemical conditions" is vague. Another statement can establish that these changes are physiologically and ecologically relevant if you like: **We thank the reviewer for their suggestion and considered changing this phrasing, however, these processes induce several changes beyond temperature and salinity such that we think physicochemical is appropriate.**

66 Awkward – need to add "how" species richness… or reword: **We have removed 's' from 'functions' to correct this sentence.**

83 This sentence is long and tangled. Generally the use of the word "various" is a red flag. **This sentence has been split in two and reworded. See lines 84 – 89 in the revised manuscript.**

87 I don't understand what this sentence is trying to say, and if I did – it would only be one advantage. **This sentence has been revised. Please see line 99 – 103 in the revised manuscript.**

89 Not sure about this sentence either – not requiring constant human observation seems good and a clearly part of an autonomous system. That is what makes it autonomous. Doesn't seem like it needs a lot of explanation, and the caveats about new programs and rapid adjustments are muddying the waters here. **This sentence has been changed. See lines 103 – 105 in the revised manuscript.**

93 That acronym is a stretch. Do you really need it? **This acronym could be changed but we feel the current one doesn't really retract from the content of the manuscript**.

113 the word "following" is confusing here. Wordy overall. Just say Temperature anomalies from the X and Y scenarios were selected for this test of the system. **We have reworded this sentence to simplify the message. We have chosen to retain the brief explanation that the chosen conditions were informed by the projected temperature anomalies predicted for the Arctic as this adds relevance for the applied anomalies. See lines 158 – 163 in the revised manuscript.**

123 Figure S2? **This has been removed**.

135 (3 treatments, 1 control, x3 replicates) Just give the mean diameter to simplify. **We have provided the mean diameter as a suggested simplification.**

137 it is more standard to give the make and model of this kind of instrument in the text though a parts list as supplement is nice too. **We have added the instrument description to the text as well.**

139 This sentence is confusing and since the offet from in-situ conditions is key to the idea here, it should be highlighted and clarified. **This sentence has been removed and the description of the applied temperature offset to a measured *in situ* condition has been highlighted in section 2.2 as well as at the end of the introduction**.

147 Confusing- if the flow is constant from each header to the mesocosm then there would be no variation. **This sentence has been changed to express constant pressure and maximum flow rates for each sub-header tank.**

149 This makes it sound like you are guessing how much heat is added in transport. Make it clear that the chilled water is added by the control system to match measured in-situ conditions. **We have adjusted this sentence for clarity given the confusing wording suggested by the reviewer.**

159 What does this mean? Eliminate minutely, but even then its not clear. The inflow pressure of each of the water sources pre-mixing? It's not clear exactly what the pressure and the outflow rates tell you. **Briefly, the monitoring of pressure for each sub-header tank ensured that**

sufficient flow rates could be maintained in order to meet setpoint targets. Outflow rates were measured to monitor the turnover in each tank. These were set to be 7 – 8 L min^{-1}. We feel this is now properly explained in the new 2.3 section.

164- wordy and tangled sentence. I am not going to stop commenting on style and grammar at this point since there is going to be some reworking of the whole needed and more attention needs to go into the writing before that level of review is appropriate but this is a good example – it should read " Temperature and Salinity in mesocosms were tuned to match hourly in-situ readings from…" or similar. **This sentence has been removed and the section rewritten**.

182 How can the error be the integral and the derivative of itself? This just doesn't make any sense. I think you mean the error, it's derivative are factors in a prefit equation to determine the appropriate adjustment to the valve? **We apologize for this typo. We have made the correction in the manuscript to state: "The PID controller measures the difference between the measured value and the setpoint (i.e., the error). This calculates the position and adjustment of the valve opening by multiplying the error, the integral of this error, and the derivative of the error over time, ….|"**

193 Kp, Ki and Kd are coefficients (line 183) but here you refer to them as sensors, or so it seems. But also it seems like this is meant to be a pressure set point that is the same for the system regulating the 3 temperatures? **The latter comment by the reviewer is correct. This was meant to state the pressure regulation followed the same method as the temperature regulation. This has been changed in section A2.1 of the revised manuscript.**

196 Why would the flow to the mesocosm be adjusted? What is the goal of these adjustments? Does flow vary that much depending on the mixing valves that this is necessary? This section needs some explanation. **This section has been completely rewritten. The purpose of regulating flow to each mesocosm with a final hand crank valve is to regulate the turnover time in each tank. This should be clearer in the new 2.3 section.**

301 and 309 Eliminating part of the data because the system was not capable of correcting the issue is not really valid. Instead you should describe the start period, the ramp up of T but not include these in the time you cite the system was controlling conditions. Instead, report the period after the 10 m pump came back on as the time when the system was fully operational creating the experimental treatment conditions. **We thank the reviewer for their thoughtful comment, but we do not agree that part of the data was erroneously removed, nor do we necessarily agree with removal of regulation during the ramp up period as suggested by the reviewer. Data here were not omitted and we refer readers to figures 3 and 4 as well as table 2. We believe this error in the understanding of the text comes from the incorrect wording referencing table 2. We have only chosen to omit the calculation of the percent time of deviation greater than the mean (figure 5) during use of the 90 m pump due to an exaggerated deviation between the control temperature and setpoint during this period. Further, the temperature ramp-up period is certainly part of the design and, thus, necessary for reporting the performance of the system. We do not feel a need to separate this into three different conjunctions but rather report the results during the period in which the system was operating. We have, however, changed the text to correct the**

potential misunderstanding readers may have of us removing data when utilizing the 90 m pump.

287 and 320 Why report the general performance for Temperature first, then again together with salinity? Steamline this and either do T and then S separately or present together once. **The first section of the results refers specifically to regulation of the control condition while the second section refers to the treatment conditions. We can see where this may be confusing based on the topic sentence for both sections. We have revised the topic sentence for the second section to make this clearer. Please see section 3.2 in the revised manuscript.**

322 I said I wasn't going to comment on this kind of thing, but this sentence is another example of the kind of thing you need to eliminate from your writing. The sentence starting on this line has no information in it and also a grammatical error. **This sentence has been removed.**

Table 1/Figure A1 – If the salinity offets are negative, make that clear here. Also the equations to determine the salinity setpoints should be in terms of S, not y. In the figure, it is not entirely clear what you did. The colors are hard to distinguish but it looks like you fit a curve to summer data with T between 2 and 6 degrees and then predicted salinity values for the projected future temperatures using that curve. If you don't plot the points for the projections, perhaps this would be more clear. Just showing the range of T for each projection would be enough, or not breaking them out at all in this plot (A1a). Part b here also requires a bit of leap to understand what you did. This seems unnecessary. See comments in main text. **We have made mention of the negative values in the Table 1 caption as well as changed "y' to ' delta S'. For figure A1a, we have remade the figure to show the measured *in situ* relationship for which the 2nd order polynomial was fit. We have also added a more descriptive text to the figure (section A1) which better describes the process that was applied to calculate the salinity offset values.**

Figure 1- why is the ambient seawater not just in line with the chilled and warmed ones? The lines are crossing a lot for no reason in this figure. The sensors are really not adding anything meaningful here – only keep if you are going to include the feedback to the control system/valves conceptually in the figure but that might be hard without making it too messy. Figures 1 and 2 are really not needed. They seem to be giving two views of the same info. Make one that is more clear. **We have combined figures 1 and 2 into a more logical description of the system flow. Please see Figure 1 and caption in the revised manuscript.**

Figure 2- The role of T and pressure regulation valves is not clear. I am guessing the pressure regulation valves are back pressure regulators, to ensure that the pressure on the upstream side of the main control valves remains constant. You should explain that if so. Then the T regulation valves are using a pressure drop to measure the flow allowed through, which is determined by the control system and the feedback from the sensors. Explain it! **The pressure regulation has been better described in the new methods section (2.1 and 2.3). Briefly, the pressure regulators were put in-line to monitor the flow from the header tanks which first passed through a valve regulator. Pressure at this point needed to be maintained at approximately 0.3 bars to ensure sustained flow rates of 7 – 8 L min^{-1} to each mesocosm.**

Figures in Appendix in general – there are so many of them. This is an issue when the text is not that easy to understand without reference to these, and it's inconvenient to make these references into an appendix. **We have substantially reduced the references to the appendix and have moved a significant part of the descriptive methods to the appendix section as per your previous comment. We feel this has greatly improved the readability of the manuscript.**

Figure 3 – the flow rate heat map feature on this figure is not intelligible. There does not appear to be any difference in color in the different values for flow rate. I guess the shaded areas are when flow is greater than 2 l/m but the legend does not indicate that in any way, and the text and caption don't explain why this is and important threshold or how flow rate would influence the performance of the system. **The reviewer is correct, there is no color difference in the heat map. However, there was no intention to indicate these differences, but rather, to show when flow rates were ≤ 2 L min^{-1}. We have added a more descriptive caption to indicate that the shaded regions are when flow rates were ≤ 2 L min^{-1}. The 2 L min^{-1} threshold indicates the minimal flow rate needed to avoid large deviations (> 2.0 salinity or °C). This threshold was determined by observation of the timeseries. This information also appears in the discussion section in the revised manuscript.**

Table 2 – The manipulated water section of this table takes a lot of space and doesn't really add much. The info that convey is methods of how the treatments. **We feel that the "manipulated water" portion of the table assists the reader in determining why the table only shows salinity deviations for treatments 1 and 2. This is beneficial for the reader if they are quickly looking through the figures and tables while skimming the text.**