High frequency broadband acoustic systems as a tool for high latitude glacial fjord research

Response to RC3

We have reviewed the suggestions made by RC3. We thank the reviewers for the detailed review of the paper and their suggestions, in particular the reviewer's concerns regarding deployment of broadband echosounders in proximity to actively calving glaciers. We appreciate the suggestion to make clear the safety consideration that must be made prior to collection in this hazardous region. Following their notes and suggestions, we have made changes in the manuscript using tracked changes and provided a clean version with all edits incorporated. We have responded to each comment/suggestion below (in red), noting where we incorporated the suggestions and noting the few instances where we disagreed with the suggestion and the reasoning behind our disagreement.

Major Revision

The claim that high-frequency broadband echosounders are a “low-cost, low-effort addition” to experimental field kits (line 19) significantly understates the logistical and safety challenges of operating near marine-termina ng glaciers. Actively calving glacier termini are extremely hazardous, and current safety guidelines typically recommend maintaining a minimum distance of at least 200–500 meters for crewed vessels depending on the glacier/location. The suggests on that this system could be routinely used in close proximity to the ice face without acknowledging these constraints is misleading and potentially dangerous. If the goal is to promote glacier-proximal observations, the authors should clearly state that such surveys must be conducted with uncrewed or remotely operated platforms to ensure safety. However, doing so would also require revising the argument about the system being low-cost and low-effort, since deploying autonomous vehicles in these environments is neither trivial nor inexpensive. This issue must be addressed directly to avoid mischaracterizing the feasibility of the method.

We appreciate the reviewer’s perspective and suggestions on data collection in proximity to actively calving termini. Upon review of the manuscript, we can see why the reviewer is concerned we do not properly acknowledge safety considerations, particularly for very actively calving glaciers. We agree that safety should be the first consideration in planning field data collection.

We want to mention that for many glacial systems a minimum safety distance of 200 m is regularly used (as noted by the reviewer) and this does not preclude the use of ship-based deployment of these systems. A 200 kHz (center frequency) broadband scientific echosounder can operate up to 250 m range with reasonable signal to noise ratio and should the user be willing to drop the frequency range (for example to an ES120-7CD or ES70-7CD, both commercially available systems with the same price tag) the usable range increases to 450 and 750 m, respectively. While there are limitations that come with an increased range from the target, these system can collect the data described here without an uncrewed surface vehicle. We agree that remote surface vehicle deployment has the potential to improve data quality because of the possibility of closer deployment. But we believe that it is not necessary to state that one must use a remotely operated vehicle in all cases as it is very much dependent on the safety distance and the glacier in question.

However, we understand the concerns the reviewer has raised and have modified the manuscript to acknowledge the complexity (and safety concerns) related to working near glacial termini. To provide more context on the deployment potential of these systems we have added a section (5.4) on near-terminus deployments to our considerations section 5. Where we discuss the safety distance, range considerations, and potential for uncrewed

surface vehicle deployment. We reference this discussion in the introduction and section 4.2 – so that readers are aware of the need for safety considerations, the impact these considerations may have on data collection/processing/analysis and the limitation created by systems with very high ice cliffs and/or high calving rates. We do mention the possibility of using uncrewed surface vehicles and we acknowledge that incorporating a vehicle would bring up the cost of deploying these echosounders – should a user be starting their field kit from scratch.

Minor Revisions

The overall clarity and readability of the manuscript could be improved by more clearly distinguishing between background, methods, results, and interpretation. For instance, the sec on between lines 190-210, which provides helpful background on the echosounder system, might be better suited to a dedicated background or methods sec on rather than appearing in "Interpretation and analysis." As a reader, I would find it clearer if the results and interpretation were more distinctly separated, or if transitions between observation and analysis were made more explicit. Additionally, some content in lines 525–540 reads more like methodological detail and could be moved to the methods or an appendix. While these changes aren't strictly necessary, they would likely strengthen the manuscript's organization and make it easier to follow.

Based on feedback from all three reviewers we have significantly altered the structure of this paper – expanding the introduction, including the lines suggested here, to more broadly introduce echosounders as a tool for ocean science. We've also tightened up the analysis sections (section 4) and the discussion of deployment considerations (section 5). We believe these changes strengthen the manuscript's readability and thank the reviewer for their suggestions.

Specific Line Edits

Line 190–210: Move the echosounder background material into a dedicated methods or background section. It currently appears in "Interpretation and analysis," which is conceptually inconsistent.

As mentioned in above response, the manuscript has been significantly restructured, so this is now fixed.

Line 364: "ice bergs" → "icebergs"

Fixed.

Line 430: “Generally agreed…” lacks details → Were the extents the same size? Were they located in the same area? Quantifying this agreement would strengthen the claim (e.g., “Surface expression width was within X% of the width measured acoustically”).

We have added to this sentence to clarify what basic agreements were observed – same position along the calving front and approximately the same surface expression (pool) extent as measured from time lapse time stamps and ship position compared against the acoustic observations.

Sec on 4.3: Consider moving this sec on before Sec on 4.2 to provide context on what geophysical parameters can be inferred from the acoustic signal before discussing plume/ice-face interpretations. I was curious as to what you think is scattering the signal within the plume a er reading section 4.3. Do you think it's sediment? Can you see that from the surface expression?

We feel that the discussion of broadband acoustic inversion is by far the most complex of all the analyses we discuss, which is why we left this section at the end. Since there is not a deep discussion of inversion efforts for the ice-face/plume data (and since we moved the introduction of inversion to the introduction of the paper), we feel the order of sections 4.1-4.3 should stay as is.

The mechanism responsible for the elevated scattering from the plume is still being investigated. This is a great question – we have not completed this analysis and so did not add in much beyond noting the possible scattering mechanisms. Given the scattering intensity and the frequency band in question, the scattering is likely not from suspended sediment, as the intensity is too high. There could be a component of suspended sediment adding to the overall scattering – we think it is likely that a combination of gas bubbles and intense mixing from the buoyant overturns are driving the scattering.

Line 489: Missing closing parenthesis after citation.

Fixed.

Line 525–540: This section mixes methodological description with results and interpretation. Consider moving parts of this to the methods sec on or appendix.

This section has been updated in the manuscript. The description and explanation of acoustic inversion (including previous examples) has been moved to the introduction of the paper. The analysis of the Hornsund fjord sill data remains in section 4.3, which does include method and results. This was purposeful, as this paper does not have a traditional methods section and separate results section. We have tightened section 4.3 significantly

and have moved some of the more technical acoustic equations and derivation to the appendix.

Line 565–574: Quantify agreement between model and observation (“within a factor of 2”?), and consider plotting predicted vs. modeled.

The agreement between the two measurements is stated on line 587-588 (updated manuscript). Figure 5 has been updated to provide both measurements in the time/space domain and the frequency domain.

Figures

Fig 3. Consider adding scale bars to panels showing KH instabilities

We have added scale bars to all four zoomed in panels (A-D).

Fig 4.

Can you clarify how SDP extent was determined? Was the outline based on a qualitative echogram interpretation, or was it mapped from surface ice mélange expression and transposed?

The plume was identified from the elevated scattering intensity; however, the identification of the plume on the image (outline) is not based on a quantitative metric such as an intensity threshold. Here, we are simply pointing out the ability of the system to observe the plume through elevated scattering – our current efforts (outside this manuscript) are focused on SGD plume analysis. That analysis will include a combination of the time lapse imagery and acoustic data. That analysis is beyond the scope of this paper. We noted in the figure caption the plume extent was manually mapped out based on elevated scattering intensity levels.

Is it possible that ambient plume signals appear in the echogram around ~250, ~525, or ~720 m along track? Can you comment on these signatures in the main text or caption?

It is possible – particularly at 350 m along track – the return between 50 and 70 m potentially contains individual bubbles. At 525 and 720 m along track the elevated scattering in proximity to the ice face is likely from sidelobe returns of an overhanging ice face – this was determined through split-aperture processes (not discussed in detail in this manuscript). These weakly scattering regions are noted in the main body of the manuscript in the paragraph that discusses the ice face return. We have updated the manuscript to note the positions of these returns to point readers towards this phenomenon and we’ve made note in the caption as well. The scattering around 350 m is more likely to be some

form of SGD – however, there was not a clear surface expression in this area and further analysis is needed before we could be certain to identify it – however, we did include a note in the caption as to the possibility that this is also discharge.