Point to Point Responses

Major issue 1: "**Aims**: It is not clear exactly what the aim of the seismic data acquisition is and how it will help guide the drilling. The standard arguments for accessing subglacial lakes are outlined but the specific targets of the drilling campaign and how the seismic data will aid this are not specified. What are these data aiming to resolve and why is the most comprehensive 3-component data required to achieve this? In reality, the challenges of deep field seismic work may impede this and it would be better to know what question you are trying to address and then design a scalable experiment."

Response: Thank you for your comment. I think you've raised a very important point. I would like to respond from two perspectives:

(1) One of the main aims of this study is to help guide upcoming seismic exploration at Lake Qilin. Before any fieldwork starts, we wanted to review past seismic studies of subglacial lakes and use numerical modeling to explore how survey design and data processing choices affect imaging results. While this is motivated by the Qilin project, our broader aim is to provide insights that can apply to seismic studies of other Antarctic subglacial lakes as well.

(2) From a drilling perspective, the seismic data aims to resolve three key targets: (1) the depth of the ice–water interface, (2) the structure of the lake bottom and lake water thickness, and (3) the presence, thickness, and physical properties of any lakebed sediments. We will revise the manuscript to clarify these aims and better explain how our simulations address them.

Major issue 2: "**Known geometry**: Although designed to address an experiment across Lake Qilin, the model used bears little resemblance to known features as reported in Yan et al. (2022) (assuming this is the same lake referred to as Lake Snow Eagle therein, no location information is given in this manuscript to corroborate this). Basic feature such as ice thickness (2400m used, 3600m reported), gravity-derived water column thickness (500m used, max 200m reported), ice-lake interface geometry, lake-bed geometry, and off-lake ice base geometry, parameterized in the model bear no resemblance to the known geometry."

Response: Thank you for your comment. As mentioned in the manuscript, “To support seismic exploration at Lake Qilin and extend its applicability to other subglacial lake studies, this study develops a representative velocity model…”. Our aim was not to reproduce the exact geometry of Lake Qilin, but rather to build a generalized model that captures the key characteristics common to many subglacial lake systems.

The model parameters were selected with reference to published papers from various subglacial lakes, including Lake Vostok, Lake Ellsworth, and others (see Table 1 below). In the following responses, we will explain the rationale behind each key parameter choice, based on available data and relevant literature.

Subglacial lake name	Location	Active or not	Ice-water interface depth	Water depth	sediment
South Pole Subglacial Lake	East Antarctic	No	2857m	32±10m	Lithified sediment 150±60m
Whillans Subglacial Lake	West Antarctic	Yes	800m	8m	Soft sediment
Ellsworth Subglacial Lake	West Antarctic	No	2930～3280m	52～156m	Soft sediment >2m
Vosctok Subglacial Lake	East Antarctic	No	3700～4300m	510～1100m	Top soft Bottom consolidate 300～400m
SLD2 Subglacial Lake	East Antarctic	Yes	2250～2300m	52～82m	
CECs Subglacial Lake	West Antarctic	No	2650m	15～28m	Soft sediment 15～28m
Mercer Subglacial lake	West Antarctic	Yes	1087m	15m	Soft sediment >1.7m

Table 1. Summary of Location and Geological Features of Antarctic Subglacial Lakes

(1) The ice thickness of 2400 m was chosen as it approximately represents the average value of ice thicknesses among subglacial lakes listed in Table 1. While changes in ice thickness mainly affect seismic travel times, they do not significantly alter key wavefield characteristics such as moveout, amplitude, or phase.

(2) We selected a maximum lake depth of 500 m, primarily because a greater depth allows clearer separation of wave modes within the water column. A shallower lake would result

in overlapping wave modes, making them harder to distinguish and analyze. This depth is also realistic, as seen in Lake Vostok, where the water column reaches similar values.

(3) To ensure that the simulated wavefield primarily reflects the influence of different material properties (e.g., lake water, sediments, firn), we deliberately adopted a simplified lake geometry. This avoids complex structural effects that could obscure or complicate the interpretation of wavefield characteristics. In my view, even with such a simplified lake geometry, the model still bears some resemblance to Lake CECs.

We now realize that the introduction may have unintentionally overemphasized Lake Qilin, while failing to clearly explain the rationale behind designing a generalized reference subglacial lake model. This lack of clarity may have caused confusion about the model's intent, and we will address this issue in the revised version.

Major issue3: "**Attenuation**: Attenuation will have a significant impact on the amplitudes, especially of the multiples. This must be considered, otherwise all that is being evaluated is traveltimes. Noise is also a consideration."

Response: This is a great point—thank you for bringing it up. Because the firn layer is loosely structured, it may cause noticeable attenuation in the shallow subsurface. What's not entirely clear yet is how this attenuation might affect the wavefield characteristics and what it means for later processing and imaging. How to estimate the Q value? Both questions will be addressed through dedicated simulations and discussions in the revised paper.

Major issue4:"Bed topography away from the lake: Yan et al. (2022) present the ice base geometry from radar that indicates that the lake sits in a deep subglacial valley with 3D topography. The steep sides of the valley away from the lake will impact seismic survey capability by introducing off-axis reflectors that will produce complex interfering arrivals and also reduce the long-offset acquisition capability that is discussed in the acquisition methods section. By using absorbing boundaries at exactly the lake perimeter, these potential issues are not addressed. Only by using the off-lake geometry with a model that reaches beyond the limits of the lake can the true achievable fold be determined."

Response: Indeed, seismic data acquired along any 2D survey line inherently contain 3D information, and it is well understood that off-axis reflections caused by 3D subsurface structures can interfere with 2D processing results. However, as we noted earlier, the aim of this study is not to explore the effects of lake geometry or complex topography on the wavefield. Rather, our focus is to isolate and understand the wavefield characteristics resulting from different subsurface material properties—such as water, sediment, and firn. Introducing realistic 3D topography would obscure this aim by adding additional complexity unrelated to material contrasts. We acknowledge that such geometric effects are important and plan to address them in future works.

Major issue5: "**Source**: What is the perfect surface source that doesn't produce a ghost? Why and how 20Hz? Most cryosphere studies tend to be closer to 100 Hz."

Response: Any seismic source will produce a source-side ghost if it's placed at some depth below the surface—it has nothing to do with the type of source, but rather with how deep it is buried. In our simulation, we used a lower dominant frequency (20 Hz) mainly to reduce computational cost. Higher-frequency wavelets require much finer grids to avoid dispersion during finite-difference modeling. That said, the dominant frequency (20 Hz vs. 100 Hz) doesn't really change the key features of the wavefield, so this choice doesn't affect our conclusions.

Major issue6: "Test data: It is not clear why the authors chose to use data from Thwaites glacier that are not over a subglacial lake when published data from Lake Ellsworth and Lake CECs, for example, are available."

Response: We apologize for not using subglacial lake data in our field test. At the time of writing, we were unaware of any publicly available seismic datasets from subglacial lakes. The Thwaites Glacier dataset was the only Antarctic seismic data we had access to, so it was used for demonstration purposes.Since then, we have searched for open-access Antarctic subglacial lake seismic data and successfully downloaded the dataset for Lake CECs. Regarding Lake Ellsworth, we found only elevation data (ice surface, ice base, and lake bed) online, but not the original seismic records. We contacted the BAS Polar Data Centre

(PDCServiceDesk@bas.ac.uk) to request access to the raw data, but have not received a response to date.If you are able to share the Ellsworth seismic data with us, we would be extremely grateful. Regardless, we will replace the Thwaites Glacier dataset with subglacial lake data in the revised version of the manuscript.

Major issue7: “**Logistics and field demands**: the discussion of field methods of data acquisition does not consider any logistical implications in terms of field practicalities, shipping weights and volumes, personnel requirements, implications of weather truncating working time etc. The assessment of the three methods does not bear any resemblance to the reality on the ground in what can be challenging conditions. This reads very much like a desk-based exercise that has not considered the realities. It does not take a modelling study to demonstrate that higher fold leads to better data.”

Response: Thank you for pointing this out. We fully agree that factors such as shipping weights and volumes, personnel requirements, and weather-related constraints are critical in real Antarctic seismic fieldwork. However, these aspects are inherently difficult to quantify and compare systematically. Therefore, in the revised version, we plan to include a summary of existing Antarctic seismic acquisition practices, focusing on a more objective description of the logistical characteristics of each method (e.g., equipment setup, personnel requirements, duration). This should provide a clearer context for readers without over-interpreting our modeling results.

In addition, our aim was not to demonstrate that higher fold necessarily leads to better imaging—this is already well understood. Rather, our goal was to use simulations to illustrate the differences in theoretical fold, illumination coverage, and imaging quality among three commonly used seismic acquisition systems in Antarctic settings.

In the revised manuscript, we plan to streamline the discussion of seismic acquisition system configurations and place greater emphasis on simulations and analysis related to the firn layer and subglacial sediments—such as how to estimate sediment thickness and infer physical properties. We believe this shift in focus will offer more meaningful insights and enhance the scientific value of the paper.

Major issue8: "Seismic velocities and densities: The values selected for the representative velocities seem very far from the reality. The firn velocity profile has a constant velocity to 20m. The bedrock velocity is from Greenland. The sediment is assumed 3750 m/s (what sediment could this be?) whereas it is more likely to be ~2000 m/s in a low energy depositional environment (compare to deep ocean for example). Densities are also required but never mentioned."

Response: Thank you very much for pointing this out. You are absolutely right that the seismic velocity within the upper ~20 meters of the firn layer is not constant—we acknowledge this was an oversight on our part, and we will correct it in the revised manuscript. As for the bedrock velocity of 5200 m/s and the sedimentary layer velocity of 3750 m/s, these values were taken from Table 1 of a published study on the South Pole subglacial lake (Seismic detection of a subglacial lake near the South Pole, Antarctica). A velocity of 3750 m/s typically corresponds to lithified or well-compacted sedimentary material, while values closer to 2000 m/s are more representative of soft or unconsolidated sediments. In the revised version, we will conduct a more comprehensive review of reported Antarctic bedrock and sediment velocities, and clearly state the sources and rationale behind the velocity values we adopt in the model.

Major issue9: "Model testing: There is no value in testing the sediment layer model without a firn layer as due to the strong seismic velocity gradient in the firn the raypaths are modified (steepened) which has significant impact on incidence angles at the ice base."

Response: Thank you for this important point. The strong velocity gradient within the firn indeed steepens the raypaths and affects the incidence angles at the ice–bed interface. In the revised version, we will update the model to include a depth-dependent firn layer, so that the influence of firn on seismic wave propagation—especially its impact on raypath geometry and reflection characteristics—can be appropriately captured.

Major issue10: There are two papers on subglacial lake Ellsworth and one on Lake CECs that bear closer resemblance to lake Qilin than the Thwaites example used. No previous studies (Lake CECs, Ellsworth, Vostok) are not presented or discussed in any detail, especially relating to the seismic investigations. Further referencing is also inadequate (e.g. L16 – where does the 670 lake number come from for example?)

Response: Thank you for your thoughtful comment. We used the Thwaites Glacier dataset in our real-data analysis because, at the time, we were unaware of any publicly available seismic datasets from Antarctic subglacial lakes. We acknowledge that this limited the relevance of our case study, and we will address this in the revised manuscript. We are now conducting a more comprehensive review of subglacial lakes that have been investigated through seismic surveys or drilling. Examples such as Lake CECs, Lake Ellsworth, and Lake Vostok will be explicitly discussed and properly referenced in the revised version.

The figure of "670 subglacial lakes" is taken from the paper "Subglacial lakes and their changing role in a warming climate". We will carefully check and update all citations to ensure they are accurate, complete, and properly traceable in the revised manuscript.

Minor issues: Thank you very much for highlighting the minor issues in our manuscript. These detailed suggestions are valuable for improving the overall clarity, consistency, and presentation of the paper. While we will not provide point-by-point responses to each minor comment here, we will carefully revise the manuscript to address all of them.As you rightly noted, the list may not be exhaustive, so we will also take this opportunity to thoroughly review the entire manuscript to ensure it meets the highest standards of accuracy and quality.