Review of Seismic Acquisition, Modelling, and Data Analysis of Antarctic subglacial lakes by Kai Lu and Yuqing Chen

Alex Brisbourne, BAS, 13/06/2025

Lu and Chen create a model of a subglacial lake and generate synthetic seismic data to help design a field campaign and data processing workflow to guide the drilling of subglacial Lake Qilin. The processing flow is then applied to existing data from Thwaites Glacier. Although there is value in this type of study, this manuscript does not achieve this goal. There are a number of significant issues with the methodology that merit the study of little value and most of the conclusions are simply reporting the basic principles of reflection seismology. As such, the article is not suitable for publication.

Some of the major and minor issues are outlined below although neither list is exhaustive.

Major issues

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.

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.

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.

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.

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.

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.

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.

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.

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.

Referencing: 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?)

Minor issues (not an exhaustive list)

L63 – Yan 2020 refers to Robin and Rothlisberger for 3800 m/s. The original publications should be referenced instead.

L65 – assume ice base and lake bed flat but not according to Yan et al. 2022

L66 – 5200m/s is from Greenland, and not the original reference. What is the local geology likely to be? What densities are used? Why use geology of Greenland in Antarctica?

L76 (paragraph from) – Is this description necessary? It is presenting basic reflection seismology principles.

L87 – jump from Fig2 to Fig 11 in the text

L116 – Hollman (2021) is not a suitable reference for firn.

L131/Fig 5 – Why is the upper 20m at constant velocity in the firn?

L140 – a small reflection coefficient at firn-ice interface is mentioned. This is probably a result of the parameterisation of the firn velocity as in reality there is no firn-ice interface to generate multiples, just a continuous velocity gradient.

L154 – It is not acceptable to exclude the firn layer as this impacts raypath geometry significantly.

L362 – where is the surface ghost phenomenon attributed to geology (reference required)? Surface ghost is a well known phenomenon and reported often.

L405 – need a reference for this multiples claim

Fig 21/22 – figure captions don’t relate to the figures