

## ***Interactive comment on “Geophysical constraints on the properties of a subglacial lake in northwest Greenland” by Ross Maguire et al.***

**Anonymous Referee #2**

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### 1. General comments:

This paper reports seismic and ground-based radar measurements on a subglacial lake in northwestern Greenland. The target of the study is the subglacial lake firstly discovered in Greenland in 2013 based on airborne radar measurements. Some other radar surveys were performed at other lakes beneath the Greenland ice sheet, but this is the first ground-based lake observation in Greenland. The seismic signals enabled the authors to quantify the water depth of the lake, as well as to estimate the material underneath the lake. One dimensional thermal analysis suggested that the lake is filled with hypersaline water under a condition of well below water freezing temperature. In contrast to increasing number of studies on subglacial lakes in Antarctica, much less is reported and known about those in Greenland. The seismic data presented in this

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paper are valuable, because they provide information below ice-water surface, namely water depth and lake-bed constitution. Similar studies have been performed at some lakes in Antarctica, but this is the first case in Greenland. Numerical analysis of ice temperature is simple, but enough to provide insights into lake water composition and origin of the lake formation. Because of these reasons, I think the reported data are valuable and of great interests of the journal readers. The paper is clearly written. However, it is too concise in some parts and essential information is missing. In general, my impression is that details of method, data and analysis are not sufficiently presented as expected in a paper published in this journal. I am also concerned about the structure of the sections. I list below my concerns, which are followed by more specific comments and corrections. I hope they are considered to improve the paper.

### 2. Major concerns

(1) Presentation of methodology Some essential information is missing about the measurements and analysis used in this study. For example, radar device is described only by "a 10 MHz monopulse radar system". Information of the manufacturer, type of antenna, receiver-transmitter distance, the way of data acquisition and dragging the device (sledge?) should be described. Another example is ice temperature analysis. Only available information for this computation is "1D steady state advection-diffusion heat transfer model solved using the control volume method". How do you compute vertical strain rate? What is spatial resolution? Any influence of neglected firn layer and horizontal advection? Please describe all these details in the Method section.

(2) Presentation of data Results of the seismic and radar survey are presented in a limited way (Figs 2, 3 and 5). They are given only by plotting amplitude or power in a grey scale on a time-space domain. I wonder how the authors determine reflections at ice-water and water-bottom reflections. Fig. 2B and Fig 3A show important boundaries, but it gives me an impression that they were drawn only by visual inspection. Further, the authors discuss the phase of the seismic signals to identify the material under the ice. Nevertheless, there is no plot clearly showing such an important observation. I

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think more details, particularly plots of amplitude/power against time, are necessary to convince the readers of the interpretations and discussions.

(3) Comparison with previous studies Seismic survey on a glacial lake is new in Greenland, but available for lakes beneath the Antarctic ice sheet. Interpretation of the seismic signals should be carried out based on the knowledge obtained in Antarctica. Such studies in Antarctica include those reported in Whillans Ice Stream and Lake Ellsworth. Important previous work exists also in Devon Ice Cap in the Canadian Antarctica. Considering the proximity of the sites and possible similarity in water property, closer comparison of the thermal conditions, geographical and geological settings should be performed. Please also introduce these previous studies more in detail in the Introduction section. I would like to read what are known about water depth, lake-bed constitution, water properties in subglacial lakes in Antarctica and other regions.

(4) Construction of the sections The paper suffers from mixing of method, results and discussion in the text, particularly in the Methods section. The Methods section begins with study site, and a little of methodology of seismic and GPR measurements (2.1 Field experiment). Then, it explains a bit more about the seismic measurement and directly goes into data and interpretation (2.2 Seismic and GPR imaging). Next subsection explains the analysis of the reflection power, which is followed by interpretation of the data (2.3 Basal reflectivity). This is not usual as a journal article and not convenient for readers. Please consider reconstruction of the text. The best for readers is to explain all the methodology in the Method section, which is followed by presentation of data in detail but without interpretation in the Results section, and finally interpretation and discussion in the Discussion section. I also find the last paragraph of the Introduction section includes too much results and conclusion. I would expect this kind of summary of the study in Abstract, which is currently rather weak.

### 3. Specific comments:

Line 15-20: This abstract can be improved by incorporating the essential results of the

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measurements and conclusion described in the last paragraph of Introduction (Line 68-77).

Line 32: "Bentley et al., 2011" » Missing in the reference list (or the publication year is wrong).

Line 36-37: "airborne radio-echo sounding" » "airborne" is not a necessary condition. Snow vehicle or snow mobile are also used for surveying lakes.

Line 51: "approximately 40% of ..." » This is not consistent with 124 out of 400 as described in Line 40.

Line 68-77: I think this is too much for Introduction. Please consider moving the essential results in Abstract.

Line 81: Please provide coordinates and elevation of the lake.

Line 82: Can you indicate the 980 km<sup>2</sup> drainage basin on Figure 1B?

Line 86: "24 40 Hz" » Hyphen is missing.

Line 96: "longitudinal seismic reflection image" » Here and other places, the authors use "longitudinal" and "across", which are not clear to explain settings. Here, for example, "seismic reflection image along the survey route" is better if I understand it correctly.

Line 107-108: "An additional reflection with opposite polarity of R1" is not clearly shown by Fig. 2B. Also not clear why you think "which is consistent with a lake bottom reflection".

Line 110: What do you mean by "across the seismic section"?

Line 111-112: Uncertainty due to wave velocity is evaluated, but I wonder if there is additional uncertainty due to signal peak determination. How do you define the reflection boundaries in Figure 2B?

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Line 116: "across the majority of the transect" » "across" is confusing.

Line 117-118: "lake is slightly deeper" » Do you mean "ice is slightly thicker"?

Line 118: Please define "transect distance".

Line 126: "A\_R1 and A\_R2" » The variable "A" should be in italic?

Line 160: "IMBIE Team Report" » The author name is inconsistent with the reference list.

Line 160: Can you provide an estimate of "net storage capacity of all of Greenland's subglacial lakes"?

Line 180: How do you know the surface temperature in the region?

Line 181-182: "the basal temperature ... be well below the pressure dependent melting point" » Why do you think so?

Line 185: "1D steady state advection-diffusion heat transfer model" » Please describe more details with equations to be solved.

Line 190: "When advection is ignored" » I understand that you ignore vertical ice motion. It is confusing because you also neglect horizontal advection of ice. Ice flow is small near the divide and downglacier advection of cold ice does not influence the conclusion about basal temperature below melting point, but mentioning the horizontal ice flow helps the readers.

Line 199: Do you have estimate of the salinity from the computed basal temperature? Can you discuss your results with the study at Devon Ice Cap?

Line 199-200: "ice surrounding the lake would be frozen" » Do you think the hypersaline condition is limited with in the lake area? Such condition may extend to the surrounding area and cause basal melting outside of the lake.

Line 210-219: I agree that continuous supply of surface meltwater to the bed is not likely

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because meltwater production is limited in this elevation range. Near the study site, a Japanese research group has been running an automatic weather station (e.g. Aoki et al., 2014), performed in-situ snow observations and ice core studies (e.g. Niwano et al., 2015; Kurosaki et al., 2020). I suggest the author to discuss water availability in the region based on the climatic conditions and the previous studies.

- Aoki, T. et al. (2014). Field activities of the "Snow Impurity and Glacial Microbe effects on abrupt warming in the Arctic" (SIGMA) Project in Greenland in 2011-2013. *Bulletin of Glaciological Research*. 32. 3-20. 10.5331/bgr.32.3. - Niwano, M. et al. (2015). Numerical simulation of extreme snowmelt observed at the SIGMA-A site, northwest Greenland, during summer 2012. *The Cryosphere*. 9. 2015. 10.5194/tc-9-971-2015. - Kurosaki, Y. et al. (2020). Reconstruction of Sea Ice Concentration in Northern Baffin Bay Using Deuterium Excess in a Coastal Ice Core From the Northwestern Greenland Ice Sheet. *Journal of Geophysical Research: Atmospheres*. 125. 10.1029/2019JD031668.

Line 235: "cryoconcentration" » Is this a right word to explain lake formation due to "latent heat from freezing".

Line 235-239: It is odd to read this conclusion within the same paragraph explaining "Latent heat from freezing". Please consider to change the paragraph, or merge these sentences with the next paragraph.

Line 266: "Peters et al., 2013" » Missing in the reference list (or the publication year is wrong).

Line 272: "hydropotential modeling" » "hydropotential analysis"?

Figure 1c: Please label the ends of the GPR and seismic survey profiles (e.g. "X" and "Y") so that you can use the labels on Figures 2 and 3.

Figure 6B: There is something wrong with the line colors. I would expect warmer temperature for the higher geothermal heat flux.

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Figure S2B: The vertical axis label "Ice Sheet Velocity" is odd. It's seismic wave velocity, right?

Figure S4: Please enlarge the study site and consider drawing contour lines. Otherwise, the color scale map does not tell a lot about the hydraulic potential distributions around the lake.

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