Authors point-to-point responds Referee Comment #2 to egusphere-2023-132

Please find the author's responses in blue below the reviewer's comments.

Review of
Extreme melting at Greenland's largest floating ice tongue
by Zeising et al., submitted to *The Cryosphere*
The manuscript presents an analysis of a combination of measurements for detecting the local balance conditions in the grounding line region of Nioghalvfjerdsfjorden Glacier (79NG) in NE- Greenland. For this purpose the authors use pRES and ApRES and ultra-wide-band airborne radar measurements, complemented by surface elevation models, derived from TanDEM-X imagery. The geometry data are also compared to earlier seismic investigations form 1998, in order to analyse the long-term changes of the grounding zone of 79NG. They find extremely high melt rates on a local scale, but still considerable strong subglacial melting across the entire grounding zone.
The manuscript is clear and well written and presents a detailed analysis of data quality and comparison of data from different sources. Data and results are very well presented. In general, the results are based on a rigorous processing and analysis approach and provide new insight into the recent and medium term evolution of the grounding zone of 79NG. The manuscript will add important new knowledge to the scientific efforts of understanding the complex interaction of ice, ocean and climate in NE Greenland.
Apart from some minor issues, which I list further down, there is only one major question concerning the localised detection of incised channels into the underside of the glacier. The strong increase of the channel height is documented by UWB radar data between 2018 and 2021 and on a longer time scale by pronounced and locally concentrated surface lowering from SAR imagery. It was stated the measurements of Mayer et al. (2000) show no indication of subglacial channels close to the grounding line in 1998. However, the seismic measurements were performed with a 24 channel instrument, covering horizontal distances of 240 m. The single measurements were up to 2 kilometres apart and the final figure in Mayer et al. (2000) only shows an interpolated cross profile of the single shots. Therefore, it cannot be concluded that there was an absence of subglacial channels in 1998. There exists an unpublished data set of airborne radar data also from 1998 (named the "Niels Reeh data set" in e.g. Seroussi et al., 2011) which shows a much more detailed ice bottom topography in the grounding line region of 79NG. The figure shows a cross profile in the vicinity of the BB' profile, with large subglacial undulations across the entire glacier, where the deepest reaches more than 200 m.

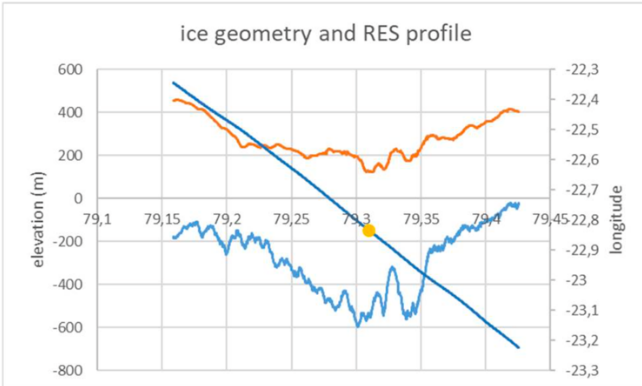

Fig.: RES cross profile in the grounding line region of 79NG from 1998. The dark blue line shows the profile location in Lat/Lon. The orange and bright blue lines show the ice geometry, while the yellow dot indicates the location of the subglacial channel identified in the recent manuscript.
Therefore, I highly recommend to consult to airborne RES data from 1998, in order to reach to sensible conclusions with regard to the temporal evolution of localised melt features.

We fully understand the concern that the seismic data do not reflect the exact geometry due to the measurement setup and we are aware that the measurement locations were separated by up to 2 km. The statement that the seismic data from Mayer et al. (2000) show no evidence of an existing channel relies primarily on one measurement located 350 m from the center of the channel, which had a width of 1 km in 2021. At this measurement location, the largest ice thickness of the across ice-flow line was found.

We agree that the ice thickness distribution based on the “Niels Reeh data set” shows a more detailed ice bottom topography. To our knowledge, this data set is an ice-thickness data set. Therefore can you please advise what the accuracy of the surface elevation data set is? Many thanks in advance.
We really appreciate that the reviewer provided the figure showing the ice geometry of this unpublished data set. Indeed, the figure shows a channel-like feature at the base, which is shifted by a few kilometers from the location of the channel in our study. Similar to the seismic data from Mayer et al (2000), the RES data show almost the largest ice thickness and the deepest draft at the location of today’s channel.

To address the concerns of the Reviewer, we will rewrite the sentence as follows: “Geophysical observations provide no evidence that this channel existed in 1998 (Mayer et al., 2000; Seroussi et al., 2011).“

Minor comments:
L. 51: I might be useful to already mention the data source of the DEMs here (e.g. from InSAR processing)

Thanks, we will add “[…] from bistatic TanDEM-X SAR interferometry […] ”.

L 52: GROCE needs a reference.

We added the link to the webpage of the project.

L. 53: either “an UWB radar”, or the “UWB radar” and adding some information.

We agree and will write "AWI’s ultra-wideband (UWB) radar".

L. 68: the spatial adjustment requires some error estimate.

We will add a sentence about the error estimate of the spatial adjustment. This is based on the standard deviation of the difference to the laser scanner data over bedrock from 2018.

L. 80: I do not understand this sentence. What do you presume in the hardware?

Thanks for finding this. I think this was a typo and should be “pre-summed”. We will additionally improve the wording and will use “pre-stacked” instead.

L. 85: The processing steps change the ground resolution, which should be discussed here.

We will add a sentence about the resolution of the ground resolution after SAR focusing.

L. 90: Accuracy of the laser measurements?

The vertical accuracy of the laser scanner DEM is 0.1 m. We will add this to the sentence.

L. 105: The off-nadir reflections depend on the location of the instrument. This could be demonstrated in more detail here.

We will add the following sentences to demonstrate this:
“The steeper the basal gradient between the nadir ice base and the location of the off-nadir reflection increases on average, the earlier the off-nadir reflection occurs. Thus, if an off-nadir reflection appears before the nadir basal return depends on the location of the measurement relative to the surrounding basal slopes and their gradients.”

L. 135: This is unclear to me. Does that apply generally to single-repeat pRES measurements, or is this a special case?

In general, single-repeated measurements do allow melt rate measurements. However, the water-saturated surface influences the signal for deeper layers in a way that only low correlation values can be found, which prevents the strain-rate analysis and consequently the melt rate analysis.

L. 167: You state that you are able to estimate the ΔR_n, why are you underestimating the melt rate then?

To make this clearer, we will rewrite this sentence as follows:

"The largest ΔR_ε^n was found to be 2.7 m for $\Delta t = 1$ a at ApRES2b. In case the change in ice thickness is based on an off-nadir basal reflection, the correction with the nadir range shift due to ice deformation underestimates the melt rate by ≤ 2.7 m a^{-1}."

L. 180: citation format needs change

Thanks! We have changed the citation format.

L. 188: The inaccuracy of signal propagation speed does not depend on the melt rate. If you would like to state that the uncertainties in the propagation speed result in similar inaccuracies as about 1% of the melt rate do, this should be reformulated.

Thanks! We will reformulate this sentence as follows:
"A further uncertainty arises from the inaccuracy of the signal propagation speed in the ice resulting in an inaccuracy of the melt rate of ~1% (Fujita et al., 2000)."

L. 195/196: To which width does the region of surface lowering reduce in which distance?

The width decreases to 500 m within 5 km distance. We will add this to the sentence. Thanks!

L. 201: In which distance free floating occurs and what are the criteria for "free flotation"?

The ice is freely floating between 4 and 5 km from the grounding line (depending on the location). This is shown by the lower flexure limit in Fig. 1. The lower flexure limit is based on interferometry which showed that the ice is freely moving up and down with the tides downstream of this limit. We will add this sentence as follows:
"Five kilometers downstream of the grounding line behind the lower flexure limit where the ice is freely floating (Fig. 1c), […]."
Additionally, we will explain the origin of the upper and lower flexure limit in the caption of Fig. 1.

L. 222: The Lagrangian perspective also tells only one side of the story. Only the combination completes the information.

Yes, we agree. We will add this to the sentence:
"However, because the ice is flowing, considering the Lagrangian perspective in addition to the Eulerian is necessary for a full understanding of the process that causes these changes."

L. 222: I would be good state again that the profiles are taken from Fig. 1

Thanks, we will do so.

L. 260: The 42% thinning are restricted to a narrow region, compared to the 79NG total extent. This should be mentioned here.

We agree that this sentence was not well expressed. We will rewrite this sentence following your suggestion:

"[...] reveals a thinning by 42 % in a narrow region 5 km from the grounding line and an ice base that became channelized, especially in the vicinity of the grounding line."

L. 270/271: This is true for significant changes in general, but applies also for warmer temperatures and therefore enhanced melt rates.

Indeed! This is why we wrote 'due to the warming of the ocean and atmosphere.'

L. 281: As long as the pinning points exist at the front, seasonal changes cannot be expected.

Yes, that is correct. We decided that it would make sense to delete this sentence.

L. 307/308: The low melt rates upstream of the grounding line and outside the large channels depend on what? Is there a patchy grounding line, or do you expect a distributed drainage system, if you refer to low water columns?

We think the wording of the sentence was misleading. We expect low melt rates outside of channels to occur (1) upstream of the grounding line and (2) downstream where a low water column exists.
We expect that the subglacial water is drained via the channels and therefore don't expect water outside the channels upstream of the grounding line. Downstream the grounding line, a low water column thickness might exist at some areas where we observed low melt rates.
We will rewrite these sentences as follows:
"This results in an upstream shift in the melt pattern compared to the outside of the channel:
(i) Upstream the grounding line and downstream where a low water column exists, higher melt rates occur inside the channel than outside.
(ii) In the vicinity of the grounding line, where the ice is in contact with warm ocean currents, lower melt rates occur in the channel than outside."

Seroussi, H., Morlighem, M., Rignot, E., Larour, E., Aubry, D., Ben Dhia, H., & Kristensen, S. S. (2011). Ice flux divergence anomalies on 79north Glacier, Greenland. Geophysical Research Letters, 38(9).