Reply on RC2.

We thank the reviewer for their positive and constructive comments on this manuscript. In the response below, we address the comments made by Reviewer 2 (Kiya Riverman) and explain the changes we have made to the manuscript. Reviewer comments are in black, and our responses are in red.

This paper presents a novel and compelling dataset describing bedforms of the initiation of the NE Greenland Ice Stream (NEGIS). Studies of this ice stream are impactful because of the unique geometry and flow style of the ice stream: it extends deep within the interior of the Greenland Ice Sheet, and rapid flow initiates from a singular point, with flow widening downglacier. Interestingly, NEGIS does not flow within a bed trough — the locations of its shear margins are set by some process other than topographic forcing. This means that there is the potential for the ice stream to widen or shrink on rapid timescales. There has been a history of publications discussing the role of the bed in controlling the location and geometry of this ice stream using seismic and radar surveying. However, since those publications were released, radar surveying techniques have improved to now allow for much a much higher resolution look at the shape of the bed. What this enables is now a very compelling test of many of the hypotheses laid by prior work. With a more complete view of the bed of NEGIS, we can better understand how its subglacial geology and hydrology control its flow. The new radar dataset shows a streamlined bed with a variety of interesting features worthy of discussion. The dataset itself is well worthy of publications in TC, though I have some concerns about how the interpretation of the features is placed within the context of existing literature from the same field site.

As it stands, the paper draws strong conclusions from only one geophysical dataset instead of positioning itself as an excellent hypothesis test (our validation) of theories about controls on NEGIS that were developed with other geophysical data sets. The manuscript would be improved by incorporating the results of prior geophysical surveying (radar, common offset and common midpoint active seismic surveying) to strengthen the interpretations made here. With the incorporation of prior surveying into the analysis presented here, the paper will be a robust contribution to the literature on this important ice stream.

The radar survey of Christianson et al (2014) includes processed basal reflection strength within the survey area suggesting regions of wetter and drier bed, which could be used to support your hypothesis. The same radar survey was processed to focus on internal stratigraphy in Keisling et al (2014) which drew the conclusion that NEGIS has been a persistent feature across the Holocene and that modern flow is accommodated by a slippery bed. The active-source common offset survey of Riverman et al (2019a) identifies bed material across the ice stream (as seen in their Figure 2). These results alone, if incorporated into the existing manuscript, would strengthen the interpretation of bed materials across the ice stream. The seismic AVO work of Christianson et al (2014) could also be better incorporated.

We thank the reviewer for their constructive comments and have outlined our responses below.

199 What other evidence exists that these are large channels? These are LARGE channels — it would be somewhat of a surprise to find the sufficient volume of water necessary to carve them this far into the accumulation zone. Do the channels follow hydropotential lows? Or topographic lows? Whether or not the reflect subglacial water drainage or proglacial water

drainage might be able to be determined from their relative positioning across the wider landscape.

To determine if these channels follow hydropotential or topographic lows, we would need hydrological modelling, which we think is outside the scope of this paper since the focus is mainly on MSGLs. In addition, the calculation of hydropotential routing would not be optimal with the DEM in its current configuration, due to the upwarping swath edge artefacts described in Section 2.1. However, this would be an interesting follow-up for future work.

The role of subglacial meltwater will also be discussed in more detail in Section 4.2, as detailed in the response to Reviewer 1.

201 Prior radar and seismic work across the shear margins at this location has identified these as shear margin moraines and discussed formation hypotheses — that work should probably be discussed here (Riverman et al 2019a). How does this new dataset either support or reject the formation hypotheses put forward in that paper (that ice 'drops' its subglacial sediments as it enters the ice stream and effective pressures drop).

We agree that this work should be discussed here, and will refer to the previously identified bedforms in more detail in this paragraph. Since these data were not available online, it was difficult to ascertain whether the ridges we observe here were exactly the same bedforms that are described in Riverman et al. (2019). Whether this dataset supports or rejects the formational hypotheses proposed is unclear, and we would say that this would also be a potential for future follow-up work.

222-230 This section oversimplifies the conclusions of Christianson et al (2014). That paper finds a drape of subglacial till broadly across the entire region. Those sediments become dilatant within the fastest flowing section of the ice stream - but this is a result of fast ice flow (not the cause for fast ice flow). Christianson argues that the positioning of NEGIS is a more complicated hydrologic feedback — effectively, water is broadly present across the region, but routing of water to the shear margins (because of the hydropotential low set by the ice surface troughs) causes water to collect in the shear margins. This dries the region adjacent to the shear margins, slowing ice incorporation into the shear margins. Those ideas were then further supported by Riverman et al 2019a and 2019b, which performed detailed hydropotential analysis and meltwater routing modeling across the region and found that water indeed should be routed to the shear margins. Does this new dataset support this hypothesis for what sets the shear margin location of NEGIS?

Here we intend to make the comparison that the conclusions from the Christianson et al (2014) only infer subglacial till, whereas the swath data now allows us to visualise a much wider area of the subglacial bed and therefore we can infer the presence of bedrock outcrops. Therefore, we would rephrase the last sentence as follows:

"The observations from Christianson et al. (2014) infer that an underlying layer of dilatant till might explain the presence of the ice stream in this location and its lack of a major subglacial trough, but our observations of a mixed bed landform assemblage would suggest that the characteristics of the bed are perhaps more heterogenous than previously recognised."

We will also add a paragraph in Section 4.2 discussing the role of subglacial meltwater and its potential contribution to MSGL formation (detailed in the response to Reviewer 1), although we would not draw conclusions from this dataset regarding the location of the NEGIS shear margin.

245 Some of the main conclusions presented in this manuscript are that MSGLs can form at slower flowspeeds than previously thought — is it possible that they could even form at flow speeds down to 10-25 m/yr?

Given that no MSGLs are present outside of the shear margins, where the flow speeds are between 10-25 m yr^{-1}, we would assume that this would not be this case. If it were, then presumably MSGLs would be much more prevalent across deglaciated landscapes.

246 If the shear margin moraine forms through sediment rain-out during ice incorporation into the ice stream, then perhaps this could occur quickly, and this margin too could be a more transient feature.

This is a good point, although this is difficult to constrain from our data. Since the north-western shear margin has been observed in the radargrams to have shifted in Jansen et al. (2024), and no such jump is evident on the south-eastern side, we would think that it is more likely that the north-western margin is a transient feature in comparison to the south-eastern.

275-280 I found it difficult to track the logic through this section. I would expand on these arguments so that they are more clearly made. Specifically, how would we have observed higher shear strain rates within the margins at some point in the past? In the paleo record in some way?

We would add this clarification into this paragraph at ~line 277 to better explain the logic:

"The folds in the isochrone observed at the NEGIS onset in Jansen et al. (2024) are consistent with folding due to convergent ice flow (e.g. similar to Petermann Glacier), which are then sheared where they are intersected by the shear margins, causing them to rotate and tighten. The timing of this intersection of the folds by the shear margin is constrained to 2 ka by both the offset of ~55-75 km of the fold hinges (as they are advected with ice flow over ~2000 years) as well as the cessation of fold amplification at 2 ka. When the shear margins localised in their current location, the ice stream was decoupled from the interior of the ice sheet, as the rotation of the orientation of the ice crystal basal planes lead to mechanical weakening in the shear margins (Gerber et al., 2023), which in turn facilitates localised deformation and which, at that point in time, enabled the faster flow observed at present. Higher velocities would have produced higher shear strain within the margins, which has not been observed in the analysis of the fold amplitudes in Jansen et al. (2024).

Figure 5 this figure reflects the sum of so much work — I could spend hour staring at it! No notes, just impressed.

Thank you for this kind comment.

Again, this work is impressive for its generation of a truly novel dataset that has the potential to really change the way we think about NEGIS. I apologize for being so 'you should better incorporate my work into this work' in this review — I usually try to avoid that! I also see that the seismic works I'm suggesting be incorporated here are not readily available online, which likely limited any efforts you would have made in that space. Dang! I am happy to provide any/all of the Penn State seismic surveying effort and processed results. Please do not hesitate to be in touch, riverman@up.edu

Citations for works mentioned above

Christianson 2014: Dilatant till facilitates ice-stream flow… EPSL

Riverman 2019a: Wet subglacial bedforms of the NE Greenland Ice stream shear margins. Annals of Glaciology

Riverman 2019b: Enhanced firn densification in high-accumulation shear margins of the NE Greenland Ice Stream… JGR Earth Surface

Keisling et al 2014: Basal conditions and ice dynamics inferred from radar stratigraphy… Annals of Glaciology

--Kiya Riverman