

Review of: Comment on "Exceptionally high heat flux needed to sustain the Northeast Greenland Ice Stream" by S. Smith-Johnson et al., *The Cryosphere*, 14, 841–854, 2020

Submitted to: The Cryosphere Discussions

Reviewer: Nicholas Holschuh

General Comments:

In this comment, the authors evaluate the plausibility of an extreme (970 mW/m^2) heat flux anomaly under the Northeast Greenland Ice Stream (NEGIS) by contextualizing the anomaly invoked by Smith-Johnson et al. (2020) with geologic examples elsewhere on Earth. The authors convincingly demonstrate that this value is implausible, and use that conclusion together with the modeling study by Smith-Johnson et al. to say that there must be critical processes or ice sheet characteristics missing in existing ice sheet models of NEGIS.

This comment's discussion of the reasonable bounds on geothermal flux is an incredibly valuable contribution to the literature. I think that the glaciology community has not spent enough time critically evaluating the published values for geothermal flux across both ice sheets. Back of the envelope calculations for both (a) the required volume of hydrothermal fluids and (b) geothermal gradients that would exist for these extreme heat fluxes provide a succinct description of just how extraordinary claims made in the literature can be.

While the authors of this comment provide convincing evidence that a 970 mW/m^2 heat flux anomaly does not exist under NEGIS, I do not believe that the original work by Smith-Johnson et al. proves (nor does it state) that an anomaly of that magnitude is *required* to reproduce NEGIS. What it does state is that an extreme anomaly is required to reproduce NEGIS *in their model*, which is contingent on a wide array of assumptions that underpin the specific model experiment. A different set of assumptions would have allowed NEGIS to form, even within their model framework, with lower melt-water input (see the Technical Comments below). Thus, I think some of the language in this comment regarding NEGIS as a system needs to be modified or removed. Once the language in the abstract and conclusions is softened (see the Line-Item Comments), I would be happy to recommend this comment for publication.

Technical Comments:

The material properties that describe the NEGIS system, including the transmissivity of the water system at the ice-sediment interface and the effective viscosity of the ice (most notably in the shear margins), are unknown – yet the experiment Smith-Johnson et al. designed treats the geothermal flux as the only free parameter. Thus, the question being asked in the original manuscript is not “what is the minimum GHF that could result in fast flow at NEGIS”, but rather “what is the minimum GHF that could result in fast flow at NEGIS *absent any other spatially heterogeneous boundary conditions*”. Less heat would be required if the bed were uniformly weaker, if the authors included fabric evolution or imposed viscosity transitions in the margins, or if the water transmissivity at the bed were lower. This point is made in Smith-Johnson et al., in the final two paragraphs on page 851 and the first (half) paragraph on 852.

By excluding the possibility of extreme basal melt, this comment rightfully calls into question the range of assumptions that underpin the Smith-Johnson et al. model. And ultimately, the authors may well be right, that elevated heat flux plays no role in the fast ice flow in Northeast Greenland. But there is no

evidence presented here that can exclude more nuanced explanations that are qualitatively consistent with existing mechanisms: e.g., elevated but reasonable melt rates, combined with a subglacial hydrologic system with very poor conductivity, and a weak till substrate could very well still explain the pattern of ice flow observed. It would be flawed reasoning to say that “by rejecting the Smith-Johnson model of NEGIS, we can reject the possibility that spatial heterogeneity in the geothermal flux plays a role (and potentially, critical role) in the formation of NEGIS.”

Line-Item Comments:

Page #: 1
Line #: 13-15

On line 13, you overstate the strength of the Smith-Johnson et al. conclusions. A careful read of that manuscript shows they intentionally and repeatedly acknowledge that the high melt rates are required for their model, not required for the NEGIS system, which is an important distinction. Quotes from the original paper:

By testing with four mantle plume configurations of increasing intensity (Fig. 2), we find that the GHF (GHF) needed to induce the observed upstream velocity of NEGIS in our model is $\sim 970 \text{ mW m}^{-2}$.

*This shows that GHF values of 677, 836 and 909 mW m^{-2} produce weaker ice stream signatures than observed and, **given our model set-up**, are not sufficient to induce the upstream fast flow of NEGIS.*

The experiments in Fig. 3 indicate that the elevated heat required to initiate the NEGIS in our model must be located close to EGRIP.

We acknowledge that this value may be overestimated due to uncertainties and assumptions in our model set-up, and we discuss these in the following sections.

Ultimately, the work of Smith-Johnson et al. is not enough for you to conclude that NEGIS does not require elevated geothermal flux. You can, however, conclude that the melt rates must be lower than those proscribed in Smith-Johnson et al. This could be fixed with a simple change to line 15: "Thus, fast flow at NEGIS must be possible without the extraordinary melt rates invoked in Smith-Johnson et al."

Page #: 1
Line #: 22

This quotation contains the operative words: "in our model experiment". It is important that proper emphasis is applied to that aspect of their conclusions.

Page #: 2
Line #: 50

Even the Schroeder et al. paper is not a direct observation (and has values pinned to values from an ice sheet model), so this could easily be another example where glaciological modeling overestimates the geothermal flux!

Page #: 3
Line #: 87-89

The first sentence is perfect -- this should be the key takeaway message of the comment. In addition, the following few sentences (through line 94) do a good job of motivating why the point made above is important.

Page #: 3
Line #: 95-99

This section, mirroring the abstract, overstates the strength of the conclusions in Smith-Johnson et al. Modifying the language to capture the nuance of the original paper is important. Maybe something along the lines of:

"Given that the extraordinary heat flux invoked in Smith-Johnson et al. (2020) cannot exist at NEGIS, there must exist some other weakness in the NEGIS system that enables fast flow that is not captured by their model. While we cannot rule out a supporting role for geothermal flux at NEGIS, the flux required to produce extreme basal melt invoked by Fahnestock et al., and Smith-Johnson et al. is geologically implausible, leaving open many questions about the dynamics of the NEGIS system.