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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Tsunamis unleashed by rapidly warming Arctic degrade coastal landscapes and communities – case study of Nuugaatsiaq, western Greenland" *by* Mateusz C. Strzelecki and Marek W. Jaskólski

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General comment: This paper highlights an important and hitherto largely discounted risk for small, remote, coastal communities in fjord environments of eastern Arctic Canada, Greenland, and other regions. The authors are to be congratulated for their initiative in documenting the effects of the 2017 tsunami on the community of Nuugaatsiaq, including the persistence of impacts over two years post-event. Until now we have had little basis for adjusting planning and development strategies in communities such as Pond Inlet, Nunavut, where much development has occurred on high ground

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but some parts of the community closer to the shore may be at risk from nearby slope failure (in this case across Eclipse Sound on the south coast of Bylot Island). This detailed account of effects in a comparable though smaller community across Baffin Bay may bring home the urgency of attention to tsunamigenic landslide risks. The authors provide a good account of the tsunami event (largely from prior published sources) and valuable observations on erosional and depositional effects in Nuugaatsiaq, 32 km down-fjord from the landslide trigger. It is fortunate that the community was not located closer. They also provide an interesting data-set on the loss or displacement of buildings in the settlement and on debris persisting in the community at the time of their July 2019 visit. In Table 1, they also document a range of other impacts, including socio-economic impacts of evacuation and dispersal to other communities, and the ongoing risk which precludes a return to Nuugaatsiaq. These are valuable and original contributions, but I do have some remaining concerns about the paper.

General review points: Scientific significance: The paper is highly valuable in providing detailed documentation of tsunami impacts in a remote Arctic community, which subsequently had to be abandoned. It documents the down-fjord human settlement impacts of a very large rock-avalanche generated, fjord-confined megatsunami.

Scientific quality: Good but lacking in some respects, as outlined below.

Presentation quality: Good, but some missing references and some figures are too small to make out and, in some cases, not clearly located.

Title: I'm not sure that the landslide which triggered this tsunami event was clearly associated with rapid regional warming. It appears to have been a case of an earthquake generated fault rupture leading to gravitational collapse, possibly related to debuttressing with glacial retreat. I understand the argument that warming may contribute to more rapid glacial retreat (debuttressing additional fjord walls) and may trigger slides or slumps in ice-rich permafrost soils, but I'm slightly uncomfortable with the current title.

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Abstract: This is too short and insubstantial. Should report major findings, including impacts on buildings and other infrastructure, and some of the social and economic impacts in Table 1, provided the supporting data are provided. It should also report the comparison drawn between effects at Nuugaatsiaq and other similar events in Greenland.

Organization: The paper would benefit from addition of a short section in the Introduction on the geological, topographic, and bathymetric setting, the environmental conditions to which the coast, landscape, and infrastructure pre-tsunami were adjusted (tides, waves, winds, storms, permafrost), and the pre-disaster characteristics of the community (history, population, age structure, social and economic conditions). Further, in section 3.1 it would be helpful to provide more detail on the wave behaviour on arrival in Nuugaatsiaq – approach direction, runup, backwash, overwash in the saddle, possible refraction/diffraction around the point, and inundation limits. The authors might also consider reorganization of the landscape impacts results section (3.2) into two or three sections such as 3.2.1 Wave runup and drainage; 3.2.2 Erosional effects, 3.2.3 Deposits.

Missing details: The most serious deficiency in my view is the lack of elevation data in relation to tsunami effects and deposits. I appreciate that this may not be readily available, particularly as they were not permitted to fly vertical photography over the settlement. However, I would be surprised if some community topographic mapping had not been undertaken in the past. Elevation data should be available through ArcticDEM (see, e.g., https://bluewaters.ncsa.illinois.edu/liferay-content/document-library/18symposium-slides/porter.pdf, slide 37/40, which also shows runup estimates). This is key contextual data which present hypotheses for testing against the observations reported in this paper. In addition, the analysis of shore-zone and backshore slope effects would benefit from an understanding of the pre-existing morphology, slope angles, surficial geology, and nearshore bathymetry (if available). For example, were the backshore slopes fully vegetated or already subject to some slope failure? Is there

any sand in the beaches and/or nearshore? If not, this would support the apparent absence of extensive sand deposits resulting from the tsunami. What was the source of the boulders scattered across the wash zone? Were they all iceberg-rafted, or were some derived from the shore zone?

Socio-economic impacts: The analysis of building losses and displacement is an important part of the socio-economic impact, including the relative performance of various foundation types. However, Table 1 provides an extensive list of social and economic impacts of the event that receive no attention whatsoever in the text. These represent a variety of impacts, some of which may be based on data and some of which may be more hypothetical or based on hearsay. It is difficult to assess the validity of this list without further details. At the same time, if the analysis of socioeconomic impacts is limited to infrastructure impacts, this should be more explicit on line 41.

Specific scientific comments: Line23: Delete “Even as Arctic tsunamis are often presented in media coverage as a part of polar myths” and begin sentence “Their increasing frequency . . .” Line 41: As noted above, this promises “insights into . . . socioeconomic impacts” but it is not until we study Table 1 that we discover the community is abandoned and the survivors are dispersed to two other communities. Lines 49-50: “The largest boulders and litter lines were marked with a handheld GPS” – To me this raises the expectation that these data will be shown and used to demarcate a runup limit (or at least a zone of known runup), preferably in relation to topography, for which you need elevation data (see above). Line 50: Re “careful survey of vegetation cover change” – The paper reports a lush growth of grasses obscuring some tundra blocks, boulders, and debris. It is unclear whether this vegetation is different in composition or productivity from what formed the vegetation cover prior to the event or if it differs from the cover beyond the runup limit. Can the authors report species (line 82) and further details? Lines 89-90: “. . . vegetation cover (grasses) was covered by a relatively thin layer of tsunami deposits” – Delete ‘relatively’ – it is not meaningful. What type of deposits? - composition, thickness, location(s). Line 90: Salt patches “covering

the exposed or inundated grounds" – I'm unsure what this means – occurs on non-inundated surfaces as well? Lines 93-94: Re "... some pars of the grass cover were [compressed] by fragments of icebergs washed [onshore, or also by the waves" - as is common in wave overwash of vegetated dunes on exposed coasts. Lines 107-122: Are there any recognizable differences between areas of wave overflow (into harbour) and area of wave uprush, followed by drainage? Line 111: I assume this is referring to modification by snowmelt runoff, but the text "modified by snow-melt flow tsunami deposits accumulations" is confusing and meaningless. Line 112: Here and elsewhere, you reference "the lowland" – I assume this is the low part of the peninsula ridge and might be best described as the "saddle" through which the waves washover over into the west harbour. This is a recognized landscape term. Line 118: "... at the border" – meaning? Line 128: You state that damage to 26 buildings was documented. What percentage of all buildings in the community does this represent? Were some undamaged? Does it include all damaged buildings? Line 130: Not clear what is meant by "point foundations" – Is this what we call block foundations in Canada? Simple piles of wooden blocks and wedges supporting the sills. Or something else? Lines 160-162: What about Qullisssat? Abandoned for other reasons? Line 165: We need, at least briefly, results and discussion pertaining to other social and economic impacts listed in Table 1, or otherwise they stand as unsubstantiated statements. Line 179: Change "are going to be" to "are likely to be" Line 190: Change "are going to be" to "are projected to be" Lines 196-197: First conclusion bullet – Change to "... directly impacted an Arctic inhabited settlement and forced it evacuation." Lines 205-207: Reference to explanation "by the local morphology and geology ..." – This is why we need more details on the study site in the introduction. Line 208: Re "mapped tsunami deposits" – These need to be shown on the map. Lines 213-214: Delete final clause "and are analogous to ... Yukon" – This is highly debatable. General query: No reference anywhere to permafrost or frozen ground. Is this area permafrost-free? General query: Most far-travelled boulders seem to be ascribed to ice-rafting. Large waves can transport large boulders tens to hundreds of metres across relatively smooth surfaces (such

as a grassed slope or saddle), so I would not be surprised if some boulders were deposited by the waves (after all they toppled the front-end loader). References line 241, Chao et al: 2018 here but 2017 on line 61. References lines 254-256: State of the Arctic Coast 2010 was published in 2011. Figure 1: Please plot elevations and runup limits on this or similar map. Figure 2: Would appreciate locations of a, b, c. Figure 3: Please provide locations. These figures are too small to be easily comprehended. Figure 4: It is unclear whether some yellow buildings mark the displaced position of red buildings. The legend describes red buildings as destroyed, so if some were moved, they should have another colour representing original locations of displaced buildings. Also, on this map or Figure 1c or another, please plot mapped deposits in relation to runup limits. Figure 5: Good to have locations for all these figures. They are very small but legible.

Editorial comments: These are numerous and could be provided to the authors most easily in a Word or rtf document. Note several missing references: Bessette-Kirton et al. 2017; Clinton et al. 2017; Gibbs et al. 2019. I can provide some additional references re tsunami hazards in Baffin Island if desired.

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