Replies to referee comments on:

Snow accumulation, albedo and melt patterns following road construction on permafrost, Inuvik-Tuktoyaktuk Highway, Canada

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RC: Referee's Comment, AR: Authors' Response, ☐ Manuscript Text

Referee #2

The manuscript is really well written, the figures are of high quality and the topic is interesting and well presented. The methodology is sound and the selected data sources are appropriate for the analysis. This manuscript has the potential to be a good contribution to the literature.

My main comment to the authors would be that the novelty of the work could be improved/highlighted more. Many of the points made in the discussion are well established in previous studies (as pointed out by the authors). However, I do believe that that this manuscript has many unique parts that just could be highlighted a bit more. The following points are suggestions of how this paper could be improved and the full potential of this study could be unlocked. It may not be necessary to do all of these, but including some may improve the uniqueness of this study.

Response to referee #2

We thank you for taking the time to review our manuscript and for providing helpful and constructive feedback on our work. We are confident that our revised manuscript has significantly improved due to your suggestions and look forward to its possible publication in the TC. Please find our responses and relevant changes based on your comments below (referee comment in gray italic and authors response in normal font).

RC: *A unique feature of this study is the high resolution DEM and the derived high resolution snow depth data. I believe it would be a great addition if this would be discussed more, especially analysed in from a spatial point of view. The authors limit themselves with sticking to selected transects.*

AR: We totally agree with the reviewer that we should give more attention to this high resolution DEM, we have revised our manuscript and included it in the abstract and in the conclusion. Regarding the concern about selected transects, we want to clarify that our chosen transects, spaced at 1 m intervals, actually cover the entire highway section for which we have data. We acknowledge the need for improved clarity in our manuscript and have addressed this in the revision:

Abstract:

> ~~We~~With a new, high resolution snow depth raster, we quantified the snow accumulation at road segments in the Trail Valley Creek area using digital elevation model differencing.

Methods:

We created 140 m long transects (n = 4026) perpendicular to the road every 1 m over the ITH centerline using GRASS GIS . This ensured comprehensive coverage of the entire section of highway from which we have data. Subsequently, we extracted the snow depth values.

Conclusion:

With a new, high resolution snow depth raster, ~~O~~our study confirms that the presence of the road significantly affects snow accumulation, resulting in [...]

RC: In the introduction the authors highlight the snow accumulation leading to water ponding and the importance of this to vegetation (and permafrost conditions). This is neglected in the analysis of the data and the discussion. The authors also introduce the NDWI within the method section. It would be relatively easy to expand the study to include an analysis of water ponding after snow melt along the highway.

AR: In the introduction, we highlighted the significance of snow accumulation leading to water ponding and its relevance for permafrost degradation. We looked into this topic in detail before we decided not to include this part in our presented study. As part of the first author's master's thesis (Hammar, 2022), the NDWI was initially used to analyze the ponds along the highway. However, she observed a common occurrence of negative NDWI values in the small ponds, contrary to the expected positive values for water bodies. This behavior of water pixels in the visible spectrum is typical in high-latitude regions, characterized by a low sun zenith angle and shallow water bodies that facilitate phenomena such as sun glint, turbidity, and lake bottom reflectance (Muster et al., 2013). Consequently, we concluded that the NDWI may not be suitable for delineating water bodies along the highway, especially given that the highway is relatively new, and the ponds may not yet be large enough to be captured at the spatial resolution of the satellite imagery. Nevertheless, we acknowledge the importance of studying water ponding after snowmelt along the highway. We believe that the use of the NIR band alone could be a possible way to delineate ponds. However, developing a reliable and accurate method for this purpose is beyond the scope of our current study. Another option may be higher resolution airborne datasets. This topic remains of interest to us and we intend to explore it in future research.

RC: It would be interesting to include a spatial analysis of the albedo. Maybe for selected dates. If no analysis, maybe at least a map.

AR: Thank you for your suggestion. Since our primary focus in this study was the road, we have presented a spatial analysis over several distances from the road in Figure 5. For every distance we calculated the average snow albedo in order to reduce other effects such as vegetation. We believe that this method provides more valuable information than an albedo map for our specific research objectives.

RC: The relatively recent creation of the highway allows remote sensing analysis prior to the existence of the infrastructure. The analysis of snow patterns prior and post the existence of the highway is very interesting, what about things like ponding and NDVI in the area of the highway. This is also (partially) mentioned in the introduction but not further explored in the paper.

AR: Although we initially studied NDWI and NDVI changes after road construction, we decided not to include this work in the current study. We did not succeed to quantify ponding due to the small pond sizes and the pond reflection characteristics. Regarding the analysis of NDVI we have two major reasons not to include it in our current study:

First, the limitation stems from the availability of Sentinel-2 data going back only to 2015, which coincides with the construction period of the road. Therefore, the high resolution of Sentinel-2 images is not available for the pre-construction period. Landsat, on the other hand, has a lower spatial resolution of only 30 m, which is too coarse to capture areas close to the road as mixed pixels including parts of the gravel road need to be excluded. However, we recognize the potential utility of Landsat data in the long term, especially as the road ages and the vegetation damage caused by construction recovers.

Second, NDVI values as a measure of vegetation biomass measured next to a gravel road may be misleading. Road dust leads

to reduced summer NDVI values due to the dust blocking the spectral characteristics of the underlying vegetation (Ackerman and Finlay, 2019). Given the findings and cautions raised in Ackerman and Finlay (2019), we decided not to include our NDVI analysis in the current study.

Still, we agree that vegetation change and water ponding following road construction are very interesting topics that could be studied in the future, potentially utilizing other high-resolution datasets for a more comprehensive examination.

Minor points:

RC: Where was the wind data measured. Please include the source in the source in the caption.

AR: We included the data source in the caption of the revised manuscript:

> (c) shows the predominant wind direction ~~for the Trail Valley Creek study site (October 2018 – April 2019).~~ for the Trail Valley October 2018 – April 2019 (climate identifier: 220N005, current station operator: Environment and Climate Change Canada - Meteorological Service of Canada) (Environment and Climate Change Canada, 2023).

RC: Line 374. "We detected earlier snowmelt at distances up to 600 m from the road depending on the observation date, which is greater than in previous studies". Bergstedt et al. (2022) (cited by the authors) report a distance of up to 5 km.

AR: You are correct, Bergstedt et al. (2022) report an effect of a road on snowmelt up to 5 km distance. We corrected our statement in the revised version of our paper:

> We detected earlier snowmelt at distances up to 600 m from the road depending on the observation date, which is ~~greater than in previous studies~~ a greater distance than in the study by Benson et al., 1975.

A: Additional comments from the authors

In the editor's initial decision, we were recommended to double check the location of the treeline in Figure 1, which appeared to be too far north in relation to the TVC research station. The definition and precise location of the treeline varies strongly across different scientific publications and studies. For the Mackenzie Delta region in particular, a large number of studies displays different tree lines (Eaton et al., 2001; Raynolds et al., 2019; Brandt, 2009; Burn and Kokelj, 2009; Palmer et al., 2012; Fraser et al., 2014; O'Neill et al., 2023). An important study by Antonova et al. (2019) estimates tree height and forest properties using TanDEM-X data in small forest patches located at the northern edge of the treeline zone in the Canadian Arctic, specifically including TVC. In this study, the term "treeline zone" is utilized to refer to the transition area between boreal forest and tundra, implying that the change is not abrupt, and a gradient of tree densities and heights can be observed within this zone. Therefore, in the revised version of our manuscript we refer to the region as "treeline zone".

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