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Interactive comment on "Consequences of permafrost degradation for Arctic infrastructure – bridging the model gap between regional and engineering scales" *by* Thomas Schneider von Deimling et al.

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General comments.

The context of this study is to analyze consequences of permafrost degradation on Arctic infrastructure using a model and an approach which attempts to bridge the gap between small and large scales and processes. This is useful because most global scale/land surface models cannot resolve the detail typically required for small-scale systems, such as the case of infrastructure impacts considered here. The study suggests a Process-based Tiling Model approach to bridge this gap, which attempts to capture sufficient detail but which also can be scaled up to larger LSM-scale with rela-

tive ease. The study uses measurements from a road site in northern Alaska, and involves model-based analysis of the impact the road has on permafrost thaw undergoing climate warming. The study combines methodological development with site-specific analysis in the form of a case study.

This study is very relevant and should be of value for readers of TC, especially those interested in improving representation of LSMs for arctic processes. My main concern is that the PTM approach/Cryogrid is only evaluated against itself. If one of the objectives of the study is to present methodology development of the PTM approach, then a more robust evaluation and validation would be useful. Currently, different Cryogrid models are configured which are meant to correspond to simpler versus more complex conceptualization of processes, as well as finer versus coarser spatial resolution of the road-bank-tundra system. This is certainly of value and such comparisons are useful. However, since the evaluations are only conducted within the framework of the Cryogrid model, there is no external validation of the approach against other/independent models, for example models which account for higher resolutions and additional physical processes relevant at the small (100-m) scale.

Hence, a validation of the approach in the strict sense is currently lacking. This makes it difficult to place the actual performance, robustness and accuracy of the Cryogrid/PTM approach in a broader context. An evaluation/validation against a geotechnical model/GTM, or other similar fine-scale process model, would make the contribution stronger. This is important, because some process relevant at the small scale are not accounted for. These generally include consideration of later heat flux, both advective and conductive (2D), and possibly subsurface lateral flow of water (Darcy's law is mentioned, but not clear if flow can occur both in the vertical and transverse direction, as 2D flow), as well as mechanical soil deformations potentially leading to ground subsidence, which typically occur during freeze-thaw cycles. Such processes impact heat distribution in the ground. Also, only a 2D transect of the subsurface is considered, but flow and heat flux in the transverse direction (3D model) could also be relevant. Of course the ambition of the PTM approach is to avoid accounting for detailed processes/representations. Therefore, it would benefit readers to know precisely how accurate the PTM approach actually is, by comparison against a model or models which account for them. This would then more robustly support the PTM approach in being sufficiently adequate for "bridging the gap" to LSM scales.

Also, some of the details of the implementation of the model could be clarified. For example, the ponding feature in the model needs clarification, please see comments below. This is especially important considering its impact on results, for example Fig 5. Also, the implementation of effective thermal conductivity could be clarified, specifically if/how the dynamic phase state of water, as ice or liquid, filling the pore space is accounted for in the subsurface, or if only a static thermal conductivity of the different materials (shown in Table 2) is considered.

Further, the presentation would benefit from an explanation of what the advantage of the approach is compared to using, for example, a GTM at the small scale which is forced/driven by boundary conditions obtained from an LSM? This is essentially what is being done in this study. Hence, infrastructure impacts could, at least in principle, be modeled that way by combining large and small scales using different models, and hence without bypassing fine-scale processes and their effects. Perhaps this is the intention of the discussion in Section 4; if so, that section could use clarification, please see comment below.

Specific comments.

L 106-107: There are other lateral processes which also impact permafrost change and thaw, especially subsurface lateral processes such as flow of water and associated advected heat flux, both for 2D and 3D model representations.

L 110: It is not entirely clear what a "conservative assessment" means in the context of "permafrost thaw impacts". If models are conservative in their assessments of the impacts of permafrost thaw, then one would assume they are over-estimating thaw

rates. Perhaps this part could be rephrased/clarified.

L 129-130: There are several other studies on modelling polygonal tundra dynamics, please consider citing.

L 180-190: Are there any other PTM models other than Cryogrid, if so please consider citing.

L 245: Vulnerable case, ponding – please explain/clarify exactly how ponding is represented in the model and what effects it has. Does this impact the SEB? Enable infiltration of water from the surface, as a source? Does it impact thermal properties, is effective thermal conductivity considered at the surface-subsurface interface? etc.

Section 2. Model setup, boundary conditions. Would be useful to mention here that the model depth is 1000 m (if this indeed is the case), this is "hidden away" in Appendix A3. The reason being a thin model domain of only approx 10 m (as Fig 3 and 4 depict) would most likely incur boundary effects from the base boundary condition.

Section 3/Figures 4,5: It would also be nice to see/visualize the boundary conditions which are used to drive the model, if possible, for example the forcing/driving conditions at the surface. This can help understand and interpret the results shown in these figures.

Section 4. The model and approach used in this paper is very nice and clearly relevant, but the purpose of this section is not so clear. It would be far more informative and convincing to actually demonstrate the strategy for the different applications suggested here. For example, can a demonstration of a model linking to LSMs beyond the 100-m scale modeled here be made? Also, the discussion on suggested analysis for risk assessment from line 350 onwards would have more substance if a demonstration could be made.

Fig 4: Consider making a note that the vertical extent (elevation) of the model domain is not depicted here, could refer to Appendix A3. Also in Fig 3, the extent of the model in the vertical direction is depicted only as around 10 m, but according to A3 is 1000 m.

Fig 6: Please improve clarity, font sizes and legends are relatively small.

Table 2: Hydraulic properties are not described; what is the hydraulic conductivity or permeability, and porosity, of the different materials used? Typically, there is great variability and hence uncertainty in hydraulic conductivity and this greatly impacts water flow.

Table 2: Do the thermal conductivities refer to dry porous media? How is effective thermal conductivity, accounting for phase state of water-ice in the porous media, calculated?

Table 3: Is there a 'conservative' setting for the HighRes model setup? Please clarify.

Fig A2: What do the model ranges, min to max, with median, refer to here? What is changed between the "Cryogrid model runs" to get the ranges of results? Please clarify.

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