The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-100-RC1, 2020

Interactive comment on "New insights into the drainage of inundated Arctic polygonal tundra using fundamental hydrologic principles" *by* Dylan R. Harp et al.

Anonymous Referee #1

Received and published: 23 June 2020

I appreciated the opportunity to review this paper which broadened my perspective on polygonal tundra hydrology. It was particularly refreshing to read about analytical methods in contrast to the vast majority of studies relying on numerical models.

In the paper, the authors investigate a novel analytical model which conceptualizes the hydrological drainage dynamics of inundated ice-wedge polygon centres. The study is based on a related work by Zlotnik et al. (2020) that introduces the mathematics of the model, which is, however, not published yet. In the present article, the authors use the model to investigate how the pathways and the timing of drainage from polygon centres into polygon troughs depend on the ratio between polygon radius and thaw depth in the

centre, as well as on the ratio of hydraulic conductivities in the vertical and horizontal direction of the subsurface.

The paper addresses a relevant and timely topic, since thawing of permafrost which is expected to increase with Arctic climate warming, has substantial effects on polygonal tundra hydrology and nutrient cycling. The paper provides interesting insights into the hydrology of ice-wedge polygon centres, is written mostly in a concise and understandable way, and is certainly of interest to the audience of TC.

However, before publication of the paper, I see several points which deserve improvement. Addressing these points will hopefully improve the accessibility and the reach of the paper. I also found several smaller mistakes, particularly in the figures, which can probably be fixed easily. I hope that the authors find my comments useful for further improvement of this interesting study.

General comments

- The assumptions underlying the mathematical model as well as its applicability for real-world scenarios should be explained in more detail. Overall, the described setting seems to be highly idealized and does not capture key complexities such as other hydrological drivers like precipitation and evapotranspiration, or the dynamic evolution of thaw depths in the polygon rims, all of which have substantial influences on polygon drainage. It would be helpful if the assumptions regarding these complexities would be stated clearly (e.g., in the Model overview section). In this context, the paper would also benefit from mentioning specific real-world scenarios for its application (for example, drainage following a precipitation event, drainage over the entire thaw season, or changing drainage patters with a warming climate, etc.).
- The paper lacks a comprehensive discussion of the results. While the authors interpret their findings and mention potential implications for nutrient cycling, the

applicability and the limitations of the model deserve a more detailed discussion. In this context, it would for example be interesting to relate the findings to other mathematical (analytical and/or numerical) models addressing polygonal tundra hydrology (e.g., Cresto Aleina et al. (2013)). It would further be interesting to discuss in which way the approach could be transferred to other types of ice-wedge polygons, e.g. non-inundated low-centred polygons or high-centred polygons. To my opinion, a revised version of the paper would benefit from making use of subsections in the Discussion section, which is very hard to access in its present form.

- The Introduction section of the paper would benefit from making it more concise and clearly stating the research objectives of the paper towards its end. In the present version, the introduction appears to be "meandering" around a lot of distantly-related literature, without working out clearly the addressed research gap. To my opinion this section should be revised carefully, shortened where possible, and end with stating the objectives more clearly. It should also be clearly stated in which way the paper is different from or complementary to the paper of Zlotnik et al. (2020) which is still in review.

- In the present form, the paper's conclusions are presented as a repetition of the main results in a bullet-point style. In order to improve the overall accessibility of the article, the authors should complement their Conclusions by stating the context of their findings and providing take-home messages for the readers. In the present version, it is hard to understand the paper's conclusions in isolation from the rest of the study.

Specific comments

- The paper's title might be misleading as it refers to "drainage of inundated Arctic polygonal tundra", while the paper addresses drainage pathways of inundated

ice-wedge polygon centres, and not of the entire tundra landscape.

- I might have overlooked something, but I think that the assumption on the water level in the troughs (parameter H_t) is not stated in the paper. From the context I assume that a constant value is assumed for H_t, but this choice should be justified and the value should be given somewhere. This is also a potential point for the discussion, as a dynamically changing water level in the trough would presumable influence the drainage dynamics of the centres. In this context it could also be explained, why the water level cannot drop below the surface of the centre.

- To my opinion, the Methods section would be more intuitive if it was restructured such that it first provides an overview of the mathematics of the model, an then the assumptions, parameters values and the specific settings are stated.

- It might be helpful for readers to also state the full (dynamic) equation of the mathematical model in the Methods or in the appendix, which in the current version of the paper only contains the steady-state case.

- In lines 327 ff. the authors discuss the implications of drainage dynamics for the melting of the top of ice wedges. These explanations should be extended and put into relation to other aspects influencing the degradation of ice wedges (e.g., hydrologic regime of the troughs (Nitzbon et al. 2019), the geometry of the troughs (Abolt et al. 2020))

- Fig. 1: The inlet shows a polygon with hexagonal symmetry, while the mathematical model assumes a radial symmetry. This might confuse readers and the inlet should hence be adopted to reflect the mathematical model.

- The second panel in Fig. 2 and the second panel in Fig. 3 show the same cases. However, the reported numbers for the volume accessed by the flow deviate slightly (10.2% vs. 10.6%). Only one number can be correct. The same applies to the reported numbers in the fourth panel of Fig. 3 and the second panel of Fig. 4 (49.1% vs. 43.5%). Please check which value is correct and report consistent numbers.

- In Fig. 5 and Fig. 8 it is hard to associated the colours displayed in the plot with those of the colourbar. The figure could be improved by using a continuous colour range in the plot and indicate isolines with numbers (similar to the labelled isolines in Fig. 2 to 4). It might also be worth considering to indicate the specific parameter combinations shown in Fig. 2,3,4,6,7 in the "global" Figures 5 and 8 with markers.
- The depletion times shown in the upper panel of Fig. 6 (case $K_r/K_z = 1$) do not match with the respective numbers for this case in the upper panel of Fig. 7. I suppose that the upper panel of Fig. 6 actually shows the case $K_r/K_z = 100$.
- The authors might consider combining Fig. 6 and 7 into one Figure or decide to not show Fig. 6 at all, as its information are also contained in Fig. 7. I also do not understand why the lines plotted in Fig. 7 do not use the same colour-coding as those shown in Fig. 6.
- If I understand correctly, the parameter κ characterizes the hydraulic conductance of the rim, with higher values meaning an improved conductance of the rim. However, at some points (including Fig. 1) the parameter is referred to as the flow "resistance", which I find confusing (or I misunderstood the parameter). A consistent and intuitive terminology for this parameter should be used.
- The default value chosen for κ should be mentioned and justified in the Methods section.
- The paper contains a reference to a Bachelor's thesis by Oehme (2019) which is wrongly stated as a Ph.D. thesis in the References list. The work by Oheme

(2019) is based on the numerical model by Nitzbon et al. (2019) published in TC, which might be an appropriate reference.

Technical corrections

- All panels of the Figures should be labelled with letters according to the journal standard (a,b,...), and these should be used in the main text for references to the Figures.
- Fig. 2: The precision of the decimal numbers on the left axes (e.g. $0.828L$) is higher than the respective values in Fig. 3, 4, etc. If there is no reason for this, this should be made consistent between the figure.
- The unit is missing in the y-axis label of Fig. 7.
- Units should be provided in the format required by TC.
- For the enumeration of boundary conditions in the text of Appendix A1, the authors should not use (1), (2), etc. as this might be confused with the numbering of the equations in the main text.
- Remove "TBD..." from the Author contributions statement. Contributions of EJ are not stated there either.
- Fig. 9: Should be K_z and not Kz in the label.
- Lines 224 and 225: Should be "upper right" and "lower right" instead of "ùpper left" and "upper right".

References

Cresto Aleina, F., Brovkin, V., Muster, S., Boike, J., Kutzbach, L., Sachs, T., Zuyev, S. (2013). A stochastic model for the polygonal tundra based on Poisson–Voronoi diagrams. Earth Syst. Dynam., 4(2), 187–198. https://doi.org/10.5194/esd-4-187-2013

Abolt, C. J., Young, M. H., Atchley, A. L., Harp, D. R., Coon, E. T. (2020). Feedbacks Between Surface Deformation and Permafrost Degradation in Ice Wedge Polygons, Arctic Coastal Plain, Alaska. Journal of Geophysical Research: Earth Surface, 125(3), e2019JF005349. https://doi.org/10.1029/2019JF005349

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2020-100, 2020.