Reviewer comments on "Persistent, Extensive Channelized Drainage Modeled Beneath Thwaites Glacier, West Antarctica"

General comments

This paper supports the existence of stable subglacial channels beneath Thwaites Glacier, and suggests that existing observations are incompatible with a distributed-only drainage system. The authors generate an ensemble of simulation results by sweeping through plausible parameter values, and then filter out results that are incompatible with both observed data as well as a number of physical constraints.

The configuration of the subglacial drainage system has consequences for drainage efficiency (and water pressures), submarine melting, and basal friction. Understanding each of these processes is vital if we are to understand the future evolution of Thwaites Glacier. This makes the work presented in the paper particularly important.

We thank the reviewer for their thorough review and for providing useful suggestions for improving the manuscript. We have addressed all their concerns and have provided additional material and clarification about our choice of comparison criteria between observed specularity content and our model output.

A key part of this paper is the discussion of a methodology used to select data- compatible parameter values and subsequently drainage configurations. Generally, I think the method employed is sensible, but my general comments are on the consequences of some of the decisions made in this method.

How much of the observed behaviour is imposed (compared to emerging from the results) by the matching criteria? For example, criterion 1 (Line 212) compares zones, thus introducing a "special" line in between the lower and upper specular zones (zones 2 and 3) at the transition zone of Schroeder et al. 2013. Given that zone classification is discrete, it seems like any zone transition is likely to mark/impose a transition in the mode of drainage. Have some of the conclusions (such as the transition between drainage modes) been imposed based on the choice of selection criteria?

The goal of our comparison is to determine which model runs simulate the pattern of specularity content observed by Schroeder et al. (2013), which is used to infer channelization near the terminus and is not by itself proof of a drainage style transition. For the comparison, we define four zones based on the presence or absence of observed specularity content that data-compatible runs should be able to reproduce. Of these four zones, only the border between Zone 2 (specular) and Zone 1 (non-specular) could represent a change in dominant drainage style; however, it is not clear why this occurs if only relying on observed specularity content. The transition to the non-specular Zone 1 could occur for a variety of reasons, including: 1) widespread convex channels refracting radar energy across the entire glacier width (as hypothesized by Schroeder et al., 2013), 2) a few discrete channels removing water from the surrounding distributed system (as supported by our modeling), or 3) a distributed system that is below capacity due to supercooling or other reasons. Therefore, our comparison criteria do not pre-determine a model outcome, but allows us to test which drainage configuration(s) can explain the pattern of observed specularity content. Please refer to our response to RC1, comment #3, for additional information about why we chose our two comparison criteria, and how they work in tandem to select for data-compatible model runs.

To give another example, if the specularity is a strong indicator of channelisation, then some of the observations in the selected runs will necessarily match with the specularity; namely, the extent of the channels. This is not a criticism of the criteria or methodology, but rather I think it would be good to distinguish the observations that can be directly inferred using the imposed data and criteria from those that emerge by incorporating the model. For the latter, I think insight about the nature of the channels (i.e. the number and size of channels) and the set of parameters values compatible with the observations demonstrate the benefit of using this methodology to interpret observations.

The reviewer points to an important distinction between what the observations and model each indicate about subglacial drainage beneath Thwaites Glacier. Low specularity does not necessarily indicate channelization, but this is a hypothesis that our modeling seeks to test. As mentioned above, low specularity indicates a subglacial drainage system that is below capacity for any number of reasons, and our modeling is designed to determine the reason for the low specularity near the terminus. By themselves, the only conclusion that can be drawn independently from the specularity observations is the pooling of water in regions of high specularity content. Beyond this, the model must be used to test hypotheses of drainage configurations, discharge, water pressure, etc. (more detail given in response to above paragraph). Please see section 3.1.1 for a description of which model parameters yielded runs that were compatible with observations.

To finish, I wonder how a less-discrete compatibility criteria would compare to this method. For example, if you were to use the L2 error between the normalised S and R_{wt} fields. I imagine that this would resemble criteria 2, but would not require choosing critical thresholds. I am not suggesting the authors include this at all in their paper, I am just making a general comment.

This is an interesting suggestion for a comparison method, although physical complications could create unreliable comparisons in regions of low specularity and low R_{wt}. High specularity content and high R_{wt} both unequivocally represent broad, flat areas of pooled water, yet the two are governed by independent processes and likely do not covary when their values are low. This makes comparison of the two difficult, and an L2 error unlikely to work as a comparison method. Comparisons between the two should instead rely on spatial point patterns (such as our binary masks) that map where specularity content and R_{wt} are high. Unfortunately, this method does require choosing critical thresholds of what is considered "high" for each quantity. We address this problem by creating a population of masks for each variable, each using a different critical threshold within a reasonable range, and comparing all 66 combinations of specularity content and R_{wt} masks. Data-compatible runs only have to match one mask combination, which makes our comparison less sensitive to our choices of critical thresholds. A more in-depth discussion of this comparison method can be found in our response to RC1.

In summary, the authors present a sensible methodology for making inference from some observed data (in conjunction with other physical constraints). As a consequence, they suggest that there may be significant channelisation beneath Thwaites Glacier. The existence of stable channels beneath Thwaites will have significant impact on the future of the glacier.

Overall I thought this paper was well written, and the conclusions well reasoned.

Specific comments

1) *Given the importance of correlation as a measure of similarity I think it is important to say exactly how the correlation between masks of R_{wt} and S is calculated.*

Correlation is computed using:

$$r = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\left(\sum_m \sum_n (A_{mn} - \bar{A})^2\right)\left(\sum_m \sum_n (B_{mn} - \bar{B})^2\right)}}$$

Where A and B are the specularity and R_{wt} masks, respectively, and the overbar denotes an average. This equation can be added into the manuscript.

2) *In 3.1.1 you state how many runs remained after eliminating unsteady runs that don't satisfy criteria 1 and 2. However, for the remainder of the paper you only use runs data compatible runs, which also have sufficient water pressure. Did this additional criteria eliminate any of the 20/14 steady state runs that satisfy the comparison criteria? If so, it would be interesting to state here how many of your runs in total were data compatible. If not, is this condition (water pressure) at all necessary to include?*

No data-compatible runs had water pressures below 90%, so this criterion can be removed from this section.

3) *Section 2.4 was a bit unclear. It wasn't until the start of 3.1.1 that I knew how the criteria were applied. I think the second half of 2.4 should be re-thought to clarify the methodology. Particularly because I think the methodology is key to this paper. I think it is important to highlight that for each simulation there is 66 specularity—R_{wt} combinations to compare and that if one of these combinations satisfy the criteria then the simulation is deemed realistic. I think Lines 226 and 227 say what needs to be said at the end of 2.4 (rather than line 215 which is too vague).*

We acknowledge this section is unclear and will move lines 226–227 up to section 2.4 to increase clarity.

4) *Did the specularity—R_{wt} combinations suggest any particular, consistent values of critical S or R_{wt} ? Presumable S^{crt} is an important parameter by which we can interpret specularity results?*

All 66 combinations of S and R_{wt} thresholds yielded successful comparisons for some sets of parameters, although which combinations yielded successful matches varied with conductivity and roughness parameters. Across all runs, comparisons were more successful with higher R_{wt} thresholds, with critical R_{wt} values of 0.99 or 1.0 accounting for 60% of all matches. Conversely, match success rate was not sensitive to the choice of specularity threshold, and each threshold value was responsible for 7–10% of successful matches.

Technical corrections

In equation 6: is $\mathbf{q_c}$ *a scalar value? If so, it would be clearer if it was not in bold. And if so, how is it calculated? Discharge is a vector so it isn't clear what the "discharge in the distributed system within a distance* l_c*" means. Presumable there it involves some integration of a dot product taken with respect to a direction. (If it is a vector, the absolute value of a vector should probably be clarified to mean the* L_2 *norm of the vector.) As it stands, more information about* $\mathbf{q_c}$ *is required to understand equation (6).*

The authors agree q_c should be treated as a scalar, as it is only defined in one dimension. In responding to this comment, we also noticed a typo in the original equation. Equation 6 should read:

$$\Xi = \left|Q \frac{\partial \phi}{\partial s}\right| + \left|l_c q_c \frac{\partial \phi}{\partial s}\right|$$

This will be changed in the next version of the manuscript.

Line 117 : surfface -> surface

This will be fixed in a subsequent draft of the manuscript

Figure 2 is first referenced on line 206. The caption for Figure 2 refers to FSS (flux steady- state) before this abbreviation is introduced in the text. It is not until line 228 that that FSS is defined to mean flux steady-state. Maybe just say flux steady-state rather than FSS in the caption of figure 2?

This will be fixed in a subsequent draft of the manuscript.

REFERENCES:

Schroeder, D. M., Blankenship, D. D., and Young, D. A.: Evidence for a water system transition beneath Thwaites Glacier, West Antarctica., Proceedings of the National Academy of Sciences of the United States of America, 110, 12225–8, https://doi.org/10.1073/pnas.1302828110, 2013