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Interactive comment on "Modelling seasonal meltwater forcing of the velocity of the Greenland Ice Sheet" *by* Conrad P. Koziol and Neil Arnold

Anonymous Referee #1

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This is a comprehensive study that models seasonal ice surface velocities at a land-terminating glacier catchment in Greenland. The work pulls together other published component studies by the authors, including a model of supraglacial meltwater pathways that drain through moulins into a subglacial hydrology model, which is coupled to an ice-flow model whose sliding parameters have been determined from an inversion using observed winter velocities. It is a challenging task to bring together many modelling and observational components and the results show some success. The paper raises many interesting points, including a comparison of results using the Weertman and Schoof sliding laws.

The differences between GPS velocities and modelled velocities highlight areas where future improvements can be made in model development. For example, it is interesting

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to see some similar challenges in Pimentel et al., Ann. Glac., 2017, e.g. difficulty in capturing early/pre-season speed-up and tendency in the model (with Schoof sliding law) for short-term speed-up events rather than more prolonged enhanced velocities.

In summary I do not have any major problems with the work and think it an interesting and valuable contribution that should be published. I list some minor issues and points of clarification that I would like to see addressed/corrected before final publication.

List of comments:

Page 1

Title: The work is on one particular catchment of the Greenland Ice Sheet, rather than the entire Ice Sheet, this is not clear in the title.

line 5: The acronym 'GrIS' is not defined

lines 8-10: Do we need further evidence to support that subglacial develop analogous to alpine glaciers and that models need distributed and channelized? This seems quite well established now in the field. Do you want this in the abstract as the key finding of this paper? At the very least 'support' and 'supports' should be changed to 'further support' and 'further supports'.

line 11: 'slow down' of what?

line 16: The acronym 'GrIS' is not defined

line 16: 'margin' should be land-terminating margin, because obviously marine terminating has other additional important influences.

Page 2

lines 12-13: Poor sentence, needs rewriting to make clearer.

lines 21-23: Presumably just talking about GrIS here.

line 30: typo "... to the drive the ..."

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line 32: I'm not quite sure what you mean by "full spectrum of supraglacial drainage pathways"

line 34: How is it similar? You don't seem to have components in the same sense as Arnold et al (1998) and Flowers & Clarke (2002)!?

Page 3

line 29: typo ". . . with with . . ."

line 30: A better reference is needed for context of Greenland melt intensity

line 31: ". . . to determine crevasse locations . . ." How? Perhaps reference later section at end of sentence.

Page 4

Figure 1: typo "loactions"

Page 5

line 5: "A threshold value of 145kPa is selected as optimal." Optimal in the sense that it provided the best match to Landsat 8 image?

line 10: "A small number of moulins . . ." could quantify percentage.

line 18 & 20: ? in citations

line 21 & throughout: "surface to bed" "surface-to-bed"

Page 6

line 6: "K_s" is "K" in equation (1) and table 1, so I think this should be "K" for hydraulic conductivity, whereas you have "K_s" to denote "sheet flux coefficient" in the table. However, this K_s does not appear in the text/equations! Hydraulic conductivity is given a value of 2 in the table, which does not match the description in the text!

line 5-7: rho_w and p_w are not defined (rho_w is defined later on line 13).

line 19 & throughout: use \max and \min in latex

line 19-20: N_0 a value is not provided in Table 1.

Page 7

line 6: Presumably “R” is a rate and is a source term from the SRLF?

line 10: You take the derivative of Eqn (9) wrt time as a term in Eqn (8). But is Eqn (9) constant!? Or is A_m a function of time?

line 12: “The englacial storage parameter . . .” is this sigma – the “englacial void fraction”!?

lines 12-17: units are missing when giving values of conductivity.

line 16: “khˆ2” should be capital K “Khˆ2”

Page 9

line 7: “. . . a small regularization constant” – so this means the zero in N_+ = max(N,0), is not actually zero!? Is this constant different from “N_0” used earlier in equation (4)? What value do you use for this regularization constant?

line 16: “. . . weighted square of the difference of squares . . .”!? This doesn’t match equation (13) so I assume this should be square of the differences, rather than difference of squares!?

line 19: please provide your chosen values for gamma_1 and gamma_2

line 18-22: How was the weighting function chosen?

line 18-22: U_obs(x,y) – are these just the 7 GPS sites? So the weighting function is 1 at these locations and zero elsewhere!? Ok, I just checked back to Section 2.1, so U_obs is the winter mean from MEaSURE. And the weights are from the provided error estimates from MEaSURE!?

line 18-22: Why isn't "U_s" also written "U_s(x,y)"?

line 18-22: It would be clearer if you explicitly said that U_s is a function of \alpha and you seek to minimize J with respect to \alpha. If I have understood correctly?

line 24: An odd/abrupt start to this subsection

line 25: There is englacial storage in the subglacial model, but water from the SRLF is not directed to this storage – correct!?

line 27 "All water entering these cells drains directly to the bed" So water is not stored in the moulins – how does this relate to Eqn (9)!?

line 29: ". . . the water is removed from the model . . ." do you actually mean the water vanishes!? Because on page 10 line 2 you say ". . . all water in crevasse fields drain to bed . . .". If I understand correctly the water in the crevassed grid cells ends up draining into a nearby moulin where it then enters the bed.

line 29: ". . . and no further routing occurs." It is instantly routed to the corresponding moulin – if I understand your next paragraph correctly!?

Page 10

line 11: "veronoi" "Veronoi"

Figure 3: It may be helpful to somehow illustrate the crevasses (crevasse field). You could possibly use hatched grid cells, like in Figure 6. I suppose this is implemented in a finite difference grid, so the curved lines of the internal catchment would actually be straight edged.

Page 11

line 8: "The effective pressures at the end of the . . . simulation . . ." Presumably they've stabilized by then?

line 10: "coefficients." State the coefficients, i.e. "coefficients, mu_a and mu_b."

line 10: "... the basal water pressures, ... form inputs ..." how are the basal water pressures used? Initial conditions of the subglacial summer simulations!?

line 16: "A parameter search ...". I'm not sure what you are getting at with this sentence.

line 18: "... sensitivity analysis (not shown)." Section 3.3!?

Page 12

Section 3.1: What percentage of your lakes hydrofracture? I don't think you provide this value, but you should. How does it compare to observations, in particular the recent study by Cooley & Christoffersen (2017) could be relevant to determine if this is consistent with observations?

Figure 5: This is a very poor figure and needs changing or removing. In the words of John Turkey: "There is no data that can be displayed in a pie chart, that cannot be displayed better in some other type of chart."

Page 13

Figure 6: I think a different colour scale would be better. The colours for moulin, crevasse and lake hydrofracture need to stand out from the background colour scale, as do the hatch marks which also get a bit lost. If I understand correctly the total area of the red circles should be ~double that of the blue circles (based on fig 5), which appears to be the case. Can you also include the GPS sites on this figure? I'm interested to see how close the sites are to the supraglacial input locations.

Section 3.2: What exactly are you calibrating in the model – which parameters are being varied to best match the duration and magnitude of speedup events? The results shown in this section are the end result after the calibration (e.g. fig 7 & 8)!? But then that is no different from the 2012 results in section 3.3 (e.g. fig 9)!?

line 11 & elsewhere: "RACMO2" or "RACMO2.3" (from page 3 line 26)

Page 14

Figure 7: could label on which of the automatic weather stations is displayed (e.g. AWS5 is shown in (b) etc.). The same for Fig 8 & 9.

Page 16

line 24 & elsewhere: It is standard to separate out multiple units using $\,$ in latex, e.g. $\mathrm{m}\,\mathrm{yr}^{-1}$.

Page 17

line 7-8: “In this section, . . .” This sentence is poor and needs restructuring.

line 16-17: “The impact . . . where the water . . . was not input to the base.” Where was the water put instead? Removed? Drained to the bed less suddenly!? Your sentence appears incomplete, or another sentence to explain is needed.

line 18: “The impact . . . was negligible.” This surprises me. So velocities at the drainage locations (or just downstream) are unaffected by rapid water input!? Or are you just referring to velocities at the GPS sites (which may not be close to the drainage input locations)?

line 20: “. . . calibration runs, . . .” here I take “calibration runs” to mean the baseline runs after calibration (i.e. Figs 7 & 8).

Page 18

line 6-7: “. . . elevated velocities . . .” I don’t see this in figure 9(a) – two slight blips perhaps!?

line 24-25: “. . . dependent on melt input.” But there appears to be no or little surface runoff at this time (day 238-242)!?

Page 21

Figure 11: Vertical axis should say “velocity”. The figure may be better if the horizontal

axis had a scale as well, e.g. distance from terminus/ice-margin or elevation. Could you also have a vertical dashed line on the graph indicating the equilibrium line.

line 12: “qualitatively” presumably the maximum extent of channelization can be quantified.

line 16-22: What year where the tracers injected?

Page 23

Figure 13: Are the 3 red dots all L1? These moulin injection sites do not appear to be moulin locations in your model!? I’m comparing to Figure 6!?

Page 24

lines 1-2: “. . . there is a brief period . . .” Is there? Is this right at the end, after day 250? It’s hardly worth mentioning is it!?

Figure 14: A sheet-dominated to channel-dominated drainage “switch” seems only to occur with the 2011x4 results. This is a significant difference with the other simulations and worth discussing in the text. Although, the “switch” does not seem to noticeably effect the ice velocities.

Page 25

line 3: typo “computational imposed limitations” computationally!?

line 3: typo “. . . choice ice sheet . . .” “. . . choice of ice sheet . . .”

lines 9-10: “. . . likely to lead to stresses assumed negligible . . .” needs rewording

line 13-14: “The atmospheric pressure . . .” I’m not sure what exactly you mean by this sentence can you explain further. Is this something that can be easily checked?

line 15: units

line 15: typo “Similarly to the study . . .” “Similar to the study . . .”

Page 26

line 16: “The parameter values . . . in Banwell . . .” state their values to help comparison.

lines 27-28: “The initial rapid delivery . . . of water to the bed . . . are not observed to have an effect in [on!?] modelled velocities.” Is this just at the GPS sites or everywhere, even close to the drainage locations!?

Page 27

line 6: “. . . a good match . . .” good might be too strong, perhaps “reasonable”.

line 11: “higher order” “higher-order”

line 29: “. . . in line with observations by Hoffman . . .” in line with “findings”!?

Page 29

line 24: “GriS” “GrIS”

Page 33

line 31: “Proceedings of a workshop held at Seattle . . .” seems vague, I’m not sure how the journal will view this type of reference.

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