Review of "Impact of runoff temporal distribution on ice dynamics", by de Fleurian et al.

Summary:

This paper explores how the meltwater-lubrication feedback might be impacted by varying intensity and duration of the melt season for the Greenland Ice Sheet. The authors use a coupled ice flow and basal hydrology model in an idealized domain with simplified forcing to answer this question. They test the response of the ice sheet flow rate to changes in the intensity of the melt season, changes in the duration of the melt season, and changes in the rapidity of the onset of the melt season. They find a contrasting response, such that increasing intensity of the melt season induces a net slowdown (through the development of a more efficient drainage system), while increasing duration of the melt season induces a net speedup. They also discuss differences in the ice dynamic response at different altitudes.

Overall Review:

The question of the meltwater-lubrication feedback for Greenland is a long-standing question in efforts to predict sea level rise in a warming climate. There has long been uncertainty about whether the increasing altitude extent of melting in a warming climate, which tends to increase the area of the ice base receiving surface melt input, will produce a positive feedback, or whether the increasing efficiency of the subglacial hydrological system at lower altitudes will produce a negative feedback.

This paper makes an important contribution to that literature. The ice flow and basal hydrology models that the authors employ are well suited to the problem at hand. The experimental design is well formulated, the analysis is thorough, and the presentation is sound. The biggest gap in this paper, in my opinion, is that they do not explore the question of short-term temporal variability in the melt input, although they bump up against the edge of that topic in their discussion of the importance of the rate of change of the melt forcing in the experiment that varied the onset of the melt season. However, I do not consider that an obstacle to publication. It is not the responsibility of the authors to answer every potential question about their topic. They set themselves a well-defined question (exploring the effect of changes in intensity and duration in the melt season on ice flow rates) and they designed an experimental setup that is well-suited to answering that question. The issue of short-term variability in melt input can be addressed with a bit more discussion and perhaps a call for future work. I also have numerous other comments and suggestions for this paper, but none of them rises to the level of a major issue that should impede publication.

Overall, my recommendation is to publish with minor revisions.

Detailed Comments:

L1-2: The first sentence of the abstract is a bit ambiguous. On a first reading, it sounds like you're saying that records (ie, observations) of meltwater production have a surprisingly high recurrence, but I think what you mean to say is that *record-highs* of meltwater production have a surprisingly high recurrence. Maybe change the first sentence to, "Record-highs of meltwater production…"

L11: "Furthermore…."
It would probably be better to start this sentence with "However…", since the message of this sentence is somewhat contradictory to the previous one (in the previous sentence we learn that longer melt seasons cause the glacier to speed up, but here we learn that more intense melt seasons cause the glacier to slow down, setting up a tension between "more melt" expressed through the length of the melt season and "more melt" expressed through the intensity of the melt season).

L20: "..identified in southwest Greenland that a shift in the runoff regime took place in 2003…"
Rearrange to: "...identified that a shift in the runoff regime in southwest Greenland took place in 2003…"

L21: compare → compared

L24: "the length of the melt season has been increasing" → "the length of the melt season has also been increasing"
Continuing on our theme of emphasizing the contrast between length and intensity of the melt season.

L33-34: the "e.g." should be at the beginning of the citation

L34: smaller pressure → lower pressure

L36: add a comma after "available"

L40: "will allow to drain the provided water" → "will allow the provided water to drain"

L42: "seemingly opposing results" → "seemingly opposed results"

L42-46: This entire paragraph should be one sentence, separated into clauses by the colon and a subsequent comma. The way to organize a list like this is: "There are two effects of the thing we are talking about: (i) blah blah blah, and, (ii) bleh bleh bleh." In addition, this sentence should make clear that the reason for the difference in behavior is that the high-elevation regions start from a different baseline state than the low-elevation regions, so they are on different sides of the tipping point discussed in the previous paragraph. A possible way to reword this paragraph could then be: "This threshold behaviour leads to seemingly opposed results of an increase in meltwater availability that can be observed in western Greenland: (i) at high elevations, the subglacial hydrologic system begins in an inefficient state, and thus increases in water supply will increase the subglacial water pressure and lead to faster glaciers (e.g. Zwally et al., 2002; Doyle et al., 2014), but, (ii) at lower elevations, the increased water supply will only increase the efficiency of the drainage system, leading to lower water pressure and a slower ice flow (e.g. Sundal et al., 2011; Sole et al., 2013; Tedstone et al., 2015)."

L47: no need for the comma after "observations"

L48: forgot the space in "subglacial drainage"

L53: "has the recent study" → "as the recent study"

L60: replace the semicolon separating the citations with "and"

L61: "We will first give an overview of the component of the model which are specific to this study"
Is there only one component of the model that is specific to this study? If so, then the sentence should read, "...the component of the model that is…" If not, then it should read, "...the components of the model which are…"

L61-62: It's a bit weird to have two sentences start with "we first…" You can only do one thing first! Maybe start the second sentence, "We then present the results…"

Eqn1: Good choice of sliding law! It is much better to have a plastic or pseudo-plastic bed for this sort of study than a Weertman or Budd law.

L75-80: I assume that "n" represents the rheological exponent for ice, but you should still specify the meaning of all variables used in your equations.

L86-88: The explanation of the meaning of eqn. 2 is a little unclear. You start the explanation saying, "This equation involves…" but then only discuss the first term; then you say, "The other term represents…" but it was not clear that the previous sentence was only discussing the first term. Also, you should mention that the first term only includes melting due to viscous dissipation within the hydrological system, not other heat sources and sinks. Maybe rephrase as: "The first term in this equation represents the growth of the efficient system by the melting of ice walls through the heat generated by dissipation, where...[list variable meanings here]. The second term represents the closing of the efficient system by ice creep, where...[variable definitions]."

General model description: Equation 2 only includes melt from viscous dissipation within the hydrological system, not from any other source. Nor does equation 2 include a mass conservation for the water system. However, we can infer that additional melt sources are possible because surface melt input is routed to the bed, and presumably mass conservation is handled through the inefficient part of the double continuum model. I understand that these issues are addressed in the cited references, but it would be good to include a bit more information in this paper as well. In particular, I would like to know what other sources of melt input are considered: in addition to viscous dissipation in the water system and surface melt draining to the bed, does the model also consider melt from shear heating as the ice slides over the base? What about melt from geothermal heating? I think that including slightly more information about how the model works would help this part of the paper.

L93-101: This seems like a reasonable coupling architecture.

L105: You should probably mention here that you chose a flat bed at z=465 m instead of a bed at z=0 m in order to facilitate comparisons with southwestern Greenland. Otherwise, this number seems a bit random.

L161: "...test if the perturbation lead to…" → "...test if the perturbation leads to…"

L163: If the probability that the medians are different is 1%, doesn't that mean that the confidence level is 99%?

Figure 2: Panels a-c represent the spatial mean over the whole domain, right? The text (L166) implies that that is what you are showing, but it would be helpful to state that in the caption as well.

L196-197: "Even higher up on the glacier the effective pressure is driven by downstream activity as there is no runoff at these elevations."
Question: do you include a background level of subglacial melt input to the hydrological system, so that there is actually a small source of water high up on the glacier? Or is water flowing upstream to get into these regions? Because if water is indeed flowing upstream, then that seems a little unrealistic. This is where my previous request for more information about the model becomes relevant.

L214-215: "Since we chose to keep the runoff constant for this set of simulations, changes in the length of the melt season simultaneously impact the melt intensity."

Maybe it would be better to phrase this as, “For this set of simulations, we wish to investigate the affect of changes in the melt season length, independent of changes in the integrated melt volume, so we vary the melt intensity inversely with the melt season length.” Rephrasing it this way puts the emphasis on the reasoning behind your experimental choice.
While you are, of course, free to devise any experimental design you wish for an idealized model, it might also be worth pointing out that these sorts of compensating changes (where melt season length and intensity trade off with one another to keep the integrated melt roughly constant) are not likely to happen in reality. In reality, it is more likely that a warming climate will produce increases of both the intensity and the duration of the melt season. However, this set of experiments does nicely compliment the experiments shown in section 3.3, allowing you to separate out the effect of melt season length while keeping integrated melt constant.

L229-230: “While the reference simulation was only showing...” → “While the reference simulation only showed...”

L230: “...there is a quite large acceleration…” → “...there is quite a large acceleration…”

L239: “This contrasts with the short melt season…”
Do you mean that it contrasts with the long season, since the previous sentence was discussing the short season?

L247: “contrasted” → “contrasting”

L269-270: Rephrase this sentence in the active voice. Maybe something like, “In order to discriminate between the effects of melt season intensity and length, we release the requirement that the runoff must be equal in all simulations.”

L283-284: “However, the extreme values for the longer melt seasons tend to show more important acceleration events happening at the end of the melt season.”
What do you mean by “extreme values”? Are you referring to individual ensemble members as opposed to the ensemble median for each simulation? If so, maybe consider rephrasing to, “However, while the median summer velocity is similar for all simulations, individual ensemble members with large acceleration events late in the melt season are more common in the longer melt season.”

L290: “Comparing the simulations with different intensities yields more significant differences between simulations”
Actually, by comparing tables 4 and 5, it looks like the simulations with different intensities actually have *fewer* significant differences, but those differences are larger in amplitude. Maybe it would be best to replace “more significant differences” with “larger differences”, to avoid confusion between ‘significant’ meaning ‘big or important’ and ‘significant’ meaning statistical significance.

L349: “We see on Table 6…” → “We see in Table 6...”

L357: “...is might have…” → “...might have….”

L363: “...is some discrepancies…” → “...are some discrepancies…”

Section 3.5: Shortcomings

This section looks like it would go better in the discussion than in the results. In addition, while you discussed the lack of spatial heterogeneity in meltwater injection in your model, you have not mentioned the lack of temporal heterogeneity. As you mentioned immediately before this

section, there is a body of work suggesting that the rate of change of subglacial water input may be more important than the actual volume of input. In that case, high-frequency temporal variability in the meltwater input (from both the daily cycle and from synoptic weather variability) might play an important role in governing the response of the subglacial hydrological system. In a warming climate, we would expect not only an increase in melt season intensity and duration, but also an increase in synoptic melt variability, including an increase in short-duration melt extremes like the examples cited as motivation in the introduction of this paper.

Overall, it is fine that you have chosen the particular experimental design that you did, as your experiments are well suited to answering the question of length vs intensity of the melt season. However, when we move from these simplified idealized setups and start to think about the implications of your results for the future evolution of the Greenland Ice Sheet, the largest missing piece of the puzzle is, in my opinion, the lack of short-term temporal variability in your melt input. I think that it is important to discuss the potential role of short-term melt variability in the discussion section.

L397-411: Discussion of recharge rates.

This discussion touches on the issue I mentioned above, the importance of the rate of change of melt input. However, the importance of the rate of change means that not only is the onset of the melt season important, but so is synoptic temporal variability throughout the melt season. This would be a good place to include a few sentences about short-term temporal variability. Furthermore, as a matter of presentation it might be good to emphasize this topic by giving it its own paragraph. The first paragraph of the discussion section is too long anyway, so consider adding a paragraph break somewhere around lines 395-400.

L409-411: "This large impact of the slope of the temperature rise at the begining of the melt season is problematic to provide estimates of the impact of the lubrication feedback as this parameter is highly variable and complex to characterise in the existing dataset."
This sentence is difficult to parse. Consider rephrasing to, "This large impact of the slope of the temperature rise at the beginning of the melt season is problematic for efforts to estimate the lubrication feedback, because this parameter is highly variable and complex to characterize in the existing dataset." I would also add that the large impact of the slope of the temperature rise at the beginning of the melt season also reinforces the argument I made above that variability in melt rate during the melt season may also have a big influence on the hydrological and ice dynamic response.

L412-412: "In our model, the observed mean velocities are mainly driven by the lower regions of the glaciers where the velocities are significantly higher."
Hmmm….Does this mean that you might have more representative metrics of ice dynamics if you computed relative speed-up instead of absolute speed-up? Would it be too much work to add relative speed-up to your analysis?

L423-427: "However, it is not expected that the current evolution in climate would only alter the length of the melt season in Greenland and our model shows that the impact of lengthening the melt season is actually only one third of the acceleration that we observe when we reduce the temperature by a comparable amount. This shows that at least in our model, the effect of the intensity of the melt season is more marked than its length."
However, when you *increased* the temperature by a comparable amount, you saw no significant change in the mean annual velocity of the glacier (Table 5). The response to melt season intensity was asymmetric. Since we expect both intensity and length of the melt season to increase in a warming climate, this suggests that your model actually supports the opposite conclusion: in a warming climate, the speedup caused by an increase in melt season length is likely to outweigh the (statistically insignificant) slowdown caused by an increase in melt season intensity.

L427: “as larger implications” → “has larger implications”