The Cryosphere Discuss., 7, C715–C719, 2013
www.the-cryosphere-discuss.net/7/C715/2013/

The Cryosphere Discussions
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Interactive comment on "Influence of high-order mechanics on simulation of glacier response to climate change: insights from Haig Glacier, Canadian Rocky Mountains" *by* S. Adhikari and S. J. Marshall

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Received and published: 2 June 2013

To M. Pelto:
We thank you for your positive reviews. We will carefully consider all of your comments when we get the opportunity to revise the manuscript. For now, we provide point-by-point response to your concerns as follows:

1. *1713-8: It is worth noting that glaciers lacking a consistent accumulation zone will not survive even the current climate (Pelto 2010; 2011). Five out of ten years*

with no accumulation zone, AAR of 0, fits this description.

It is true that glaciers lacking a consistent accumulation zone may not survive even the current climate (e.g., Pleto, 2010). Using 3D dynamical models, we found the same and highlighted in the conclusions [see conclusion #2 on page 1730]. We will provide relevant citations here.

2. *1713.9: An average AAR of 0.14 indicates a very negative mean annual mass balance (Ba) for Haig Glacier 2000-2012. A reference should be made to the mass balance of Peyto Glacier, the nearest glacier with a long term record that had negative mass balances each year from 2001 to 2011, with an average of -730 mm/a from 2000-2011.*

   Thanks for this. We will insert a sentence to provide an outlook about the balance state of Haig Glacier in the context of other glaciers in the region.

3. *1718-18: For both the PS and SD model briefly state what was the motivation for using each model? Is it for a differential diagnosis of the importance of the various stresses?*

   FS, PS and SD models deal with unique mechanism of deformational flow [see equation (8) or Figure 5]. As stated on page 1718 [lines 4–6], together these models provide an intuitive tool for studying the mechanics of glaciers. Considering these three models, the key objective of this research is to isolate and evaluate the importance of high-order mechanics (e.g., lateral and longitudinal stress gradients) on simulation of Haig Glacier response to climate change [see the manuscript title]. This objective has been clearly stated in several places in the paper [e.g., page 1709; lines 15–18], including the abstract [page 1708; lines 2–8] and conclusions [page 1729; lines 14–18]. So, we don't think anything additional should be mentioned here.

4. *1722-12: Is there a quantitative measure of the velocity fit for each model from Figure 6g that can be provided?*

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We have provided the mean (over the glacier interior) [page 1723; lines 2–3] and maximum surface velocities [page 1722; lines 11,18,23] obtained from individual 3D models. However, we have not provided any statistical comparison with the measured data. We will include some statistics regarding the average misfits between the modelled and measured velocities. Thanks for this.

5. *1725-7: Given that the glacier has had no accumulation zone in 5 of the last 10 years is this an appropriate description and why would you expect the glacier to survive current climate?*

   Sorry that we did not quite get this question – may be wrong pointer? Anyway, the main objective of this paper is not just to evaluate the fate of Haig Glacier in an ongoing climate warming. Through model comparison, we also wanted to evaluate the influence of high-order mechanics on variety of glacier evolution scenarios, including the cases where glacier advances. This has been clarified in several places in the manuscript [see our response #3]. So, the analysis under hypothetical "no-change" or "glacier-advance" climatic scenarios (although glacier has already lacked a consistent AAR) should not be viewed as out-of-place experiments. Model comparison for both retreat and advance scenarios is useful to generalize the conclusions regarding the importance (or not) of high-order mechanics for other glacier applications.

6. *1728-4: The over deepened basin should develop a small lake, which would impact glacier retreat. Even small lakes have been observed to enhance the retreat of glacier termini through increased ablation and when the ice is very thin breakup. If a lake does not form in the depression, why not?*

   During the latter stage of glacier retreat, it might be possible to form a small pond due to the presence of bed overdeepening although current observations suggest that Haig Glacier drains efficiently [page 1715; lines 13–17]. Because the main objective of this paper was to evaluate the influence of high-order me-

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chanics, rather than providing accurate predictions of the fate of Haig Glacier, we overlooked the possibility of future lake formation on purpose. We will now consider providing a brief discussion about the possibility of lake development and its potential effects on speeding up the future retreats of Haig Glacier.

7. *1728-9: Figure 1 indicates peak mass balance near the divide. Given the eastward shift of the divide this indicates significant thinning of the accumulation zone, which would not occur if this was still an accumulation zone, given the slow dynamic response here. Pelto (2010) and Paul et al (2004) both note that thinning and retreat at the head of the glacier is a sign of glacier disintegration and loss.*

   This is certainly true. We will cover this when we discuss the current balance state of Haig Glacier [see our response #1].

8. *1728-22: The output of Figure 12 for the areal extent and thickness of the glacier in 2050 are quite similar indicating the robustness of the output. Figure 9 documents the velocity for the different models for an advance scenario. It would be useful to see the velocity distribution at the 2050 time step for the modeled glacier in Figure 12.*

   Yes, we can provide velocity plots, but we doubt these will be useful. As mentioned on pages 1708 [lines 10–11] and 1730 [line 14], flow speeds are very low in glacier retreat scenarios: velocities on the order of a couple of meters per year at 2025, and even less than a meter per year at 2050.

9. *1730-2: Reference to Bolch et al (2010) would place Haig Glacier in the context of other glaciers in the region during this approximate period.*

   OK. We will consider Bolch et al. (2010) when we elaborate a bit on the current balance state of Haig Glacier in the context of other glaciers in the region [see our response #1].

10. *1730-12: Is it worth contrasting the results here to those of Marshall et al (2011), which used a more heavily mass balance less dynamic model approach?*

    Conclusion presented here is that role of high-order mechanics is minimal during the retreats of Haig Glacier. This cannot be directly related to or compared with works presented in Marshall et al. (2011), simply because they do not provide explicit projections for Haig Glacier.

Interactive comment on The Cryosphere Discuss., 7, 1707, 2013.