Author response to reviewer comments, round 2

In the following we respond to the reviewers comments on our manuscript. L. Arenson's comments were more technical whereas C. Kinnards comments needed some elaboration. Thank you very much for the attentive revision and we hope we incorporated the comments satisfactorily.

Note for notation in our response below: In blue our response to the reviewers comments and italics marks the text as it has been changed to in the revised paper.

1 Response to Comments Review 2 L. Arenson (Referee 1)

R1.1	- Page 13, line 2: "below" instead of "underneath" changed
R1.2	- Page 15, line 19: "Twelve" instead of "12". Note: Don't start a sentence with a numeric value. changed
R1.3	- Page 18, line 8 & 9. Please check and reword this new sentence. Changed to: *The flow-law exponent n has been found to increase with ice content (Arenson et al., 2002, Arenson and Springman, 2005) and rockglacier creep is mostly dominated by relatively thin shear layers with reduced viscosity (Hoelzle et al., 2002, Haeberli et al., 2006, Buchli et al., 2013)*
R1.4	- Whole document: "Timescale", "time scale" or "time-scale"? changed
R1.5	- Whole document: "adjustment times", " 'adjustment time-scale' " or " 'adjustment times' "? changed to adjustment timescale
R1.6	- Page 23, line 4: "longevity"or "permanence" instead of "endurance" changed to longevity
R1.6	- Caption Figure 5: "geometry" instead of "geomoetry" changed
R1.7	- Figure 6 to 8 & 10 to 11: In the Figure use the proper Murtèl spelling with the accent. changed

R1.8	- Figure 6e: x-Axis label is cut changed
R1.9	- Caption Figure 8: Space between number and unit changed
R1.10	- Caption Figure 8: “introduced. The lines” instead of “introduced The lines” changed
R1.11	- Figure 10: There is a grey box that should be deleted. Kind regards and good luck with further research.

2 Response to Comments in Author Response C. Kinnard (Referee 2)

I attached a few comments to the authors regarding some points that were adressed only partially in my opinion (effect of ignoring side drag on 'A' parameters and related sensitivity experiments).

The discussion of the influence of debris/ice fraction on the rheology and hence temperature sensitivity of rock glaciers should be discussed with a bit more details than just a couple of reference, as was suggested by both reviewers. The impact of moisture variations as the ice/debris fraction changes could have impacts on the rheology not considered in this model. I do not expect the authors to change their results and still consider their study very relevant, but the authors could strenghten the discussion about their 'model limitations and implications for rock glacier temperature sensitivity'...

We added the following paragraph to the manuscript elaborating on the role of moisture and water. We also mention that we neglect the role unfrozen water/moisture and its impacts in the section ‘model setup’. Therefore we think that a comprehensive discussion of its role is more confusing than helpful for the purpose of our simple model approach.

This becomes increasingly more complex as an expected warming will not only influence the rheological properties of the ice itself but also change the ratio of ice and debris by reducing the volumetric ice content. A new ice/debris proportion will alter the viscosity of the rockglacier in a spatially heterogeneous manner because melting effects have been shown to be spatially diverse (Arenson and Springman, 2005 and Monnier and Kinnard, 2016). The direct impact of moisture variations due to precipitation events has been shown to impact rockglacier rheology on a short term down to a few days (Wirz et al., 2015), whereas the impact of a changing ice/water proportion is assumed to show its consequences on the long-term.

Nevertheless, due to the fact that the creep is dominated near the base within our model and that we have calibrated our model parameters to observed geometry and velocities, we do not expect the general dynamical behaviour and involved timescales to be substantially different for other rheological parameter choices.

We also implemented the following references:

Monnier, S. and Kinnard, C.: Interrogating the time and processes of development of the Las Liebres rock glacier, central Chilean Andes, using a numerical flow model, Earth Surf. Process. Landforms, 41, 1884–1893, doi:10.1002/esp.3956, 2016.

Wirz, V., Gruber, S., Purves, R. S., Beutel, J., Gärtner-Roer, I., Gubler, S., and Vieli, A.: Short-term velocity variations of three rock glaciers and their relationship with meteorological conditions, Earth Surf. Dynam. Discuss., 3, 459–514, doi:10.5194/esurfd-3-459-2015, 2015.

Arenson, L. U. and Springman, S. M.: Mathematical descriptions for the behaviour of ice-rich frozen soils at temperatures close to 0 °C, Canadian Geotechnical Journal, 42, 431–442, doi:10.1139/t04-109, 2005.

R2.1	Page 2: is this -0.02? Check final manuscript Changed to -0.02
R2.2	Page 3: -0.02? Changed
R2.3	Page 5: As far as I see you only derived A from inversion of equation 6 and did not calculate f_A (results in table 3). This is actually confusing in the manuscript: you introduce f_A in equation 6 but is does not re-appear afterward? I disagree that ignoring side drag would have no effect. Since its effect is presently captured in the A parameter, ignoring side drag gives you lower A values than if you introduce a shape parameter. This is because side drag lowers the total stress from the rock glacier column, and hence your inverted A values must be lower. Lower A values will impact you sensitivity experiments... We agree that explicitly including side drag (by introducing a form factor) would change the inverted A value specifically the scaling factor $\cdot f_A$. Nevertheless, such a form factor would only act as a scaling factor, that is kept constant over time, and which is already implicitly included in our A. Therefore, all the modelling results and sensitivities would be exactly the

	same.
R2.4	Page 5: ... which is calibrated on surface displacements. changed
R2.5	Page 6: attenuate..? changed
R2.6	Page 6: reduce the ice contribution (or fraction) to the total material influx. Changed to: *Therefore we keep the material input from the rockwall constant but reduce the ice contribution to the total material influx.*