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Interactive comment on "Rockglaciers on the run – Understanding rockglacier landform evolution and recent changes from numerical flow modeling" *by* Johann Müller et al.

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General comments

I really enjoyed reading this manuscript. The authors begin by analyzing and presenting field evidence for recent topographic changes observed on two rock glaciers in the Alps, which show thinning in their accumulation area over the last decade, and then go on to build a simple conceptual model of rock glacier dynamics to test the sensitivity of rock glacier dynamics to changes in temperature and debris-ice accumulation rate. The model sensitivity results are compared with observations and the authors conclude that changes in rock glacier temperature and material (debris and ice) influx are not sufficient to explain the observed thinning rates - hence internal ice melting must also

contribute to thinning. This is a classical and very elegant approach to scientific testing and I congratulate the authors for this nice work. I also concur with the other reviewer - that you have been careful in not over-interpreting your model, which does includes simplifications. However some of my specific comments will suggest discussing more thoroughly the possible implication of these simplifications on the results.

I have mainly minor comments which are addressed below and small technical corrections annotated in the uploaded manuscript.

Specific comments

Terminology

- rock glacier VS rockglacier: I believe the former is correct.

DEM differencing accuracy

P.5 L20: "The limitations concerning processing, uncertainties and application are presented in Kääb and Vollmer (2000), Roer et al. (2005c), Roer and Nyenhuis (2007) and Müller et al. (2014b), and applied in this assessment."

-My first question when looking at the DEM difference field in Figure 2 is what is the error on dZ/dt? In other words what is the detection limit? If this information has indeed been produced before you should at least state it, in the text or in the figure caption, for the benefit of the reader.

- My other question is why not presenting the average dZ/dT for the whole rock glacier surface as well? This should give you the total (or average) rock glacier mass-balance, assuming that the data is precise enough: if it is negative then internal ice melting has been larger than mass influx (sediments + ice). You present contrasting results (p6, L10) on the 'main lobes' where DEM differences and survey data do not give consistent results. The difference may be due to sampling errors in the survey data (22 points if I recall), or else DEM errors which are not presented.

Rheology of ice-debris mixture and the shallow ice approximation

- The viscosity (or the softness parameter A) depends on temperature, but also on fabric, and moisture content. The later is particularly true for 'warm' rock glaciers , i.e. close to their melting point. For 'warm' ice increasing debris concentration may in fact decrease the viscosity by favouring higher moisture content at ice-debris interfaces, up to a critical debris concentration past which inter-particle frictional strength increases the viscosity (see reference below and other works cited in them). I do not expect that you include the sensitivity to moisture in your model, but that this aspect be included in the literature review on rock glacier rheology, and discussed with respect to its implication for the sensitivity of the softness parameter to temperature as climate warms. An excellent review of the rheology of debris-ice mixture is also given by Moore (2014), which you should refer to in your introduction and discussion.

Moore PL. 2014. Deformation of debris−ice mixtures. Review of Geophysics 52: 435-467.

Monnier, S., & Kinnard, C. (2016). Interrogating the time and processes of development of the Las Liebres rock glacier, central Chilean Andes, using a numerical flow model. Earth Surface Processes and Landforms.

Rock glacier mass-balance

(p.8 L25) : The rock glacier density is kept constant in space and time in your model, you should state it clearly in the model definition. This means that (i) no internal ice melting can take place, and (ii) that variations in active-layer thickness, which in rock glacier is often blocky and dry, are not considered. Hence in your model experiment the rock glacier is allowed to grow downslope indefinitely over time. In reality as the rock glacier front flows downslope/down-valley warmer temperature there should increase internal ice melting, i.e. the active layer should deepen, which could have a stabilizing effect on flow by increasing the frictional resistance. This is in my opinion the most important oversimplification of the model: you consider mass influx (debris+ice with a

fixed fraction) but mass outflux is not permitted. See Konrad and Humphrey (2000) for an example of prescribed mass balance profile on rock glaciers (debris-covered glacier in their case). The active layer will isolate the internal ice from the atmosphere but climate warming on decadal to centennial scales will change the active-layer thickness. This point should be emphasized and the implications discussed. Including mass loss could be a nice addition for follow-up work.

Konrad, S. K., & Humphrey, N. F. (2000). Steady-state flow model of debris-covered glaciers (rock glaciers). IAHS PUBLICATION, 255-266.

Sallow ice approximation and side friction in a parabolic cross-valley profile

P.10 L8: you use the shallow ice approximation which implies a slab of infinite width, i.e. without friction effects, yet you parameterise the rock glacier bed with a parabolic cross-valley profile of finite width. Consider using a side drag parameterisation (shape factor, see e.g. Cuffey and Paterson, 2010, and use in Monnier and Kinnard, 2016). If you do not include it, discuss why not and possible effects of ignoring side friction: the driving dress can be reduced by 10-25% depending on the cross-profile shape (this if the shape factor approach is valid).

Combined sediment and temperature sensitivity experiments (section 5.2.3.)

(p15 L7, and Figure 10): Why did you choose to present the model run with a decrease of material input to 40% of the original value? I may have missed it: is it because this particular combination fits the observation better in some way? It is not clear and could be better presented. Do you have a basis to assume that there has been a 60% decrease in mass influx to the rock glacier in the past?

Section 6.2.3 Adjustment times

I found this section somewhat confusing, especially with regards to the analogy with glacier response times definitions (p20 L21), and the section deserves some clarification.

i) Your adjustment time scale is based on the kinematic wave speed (cf equation 12) . This is the time taken for the topographic perturbation to travel to the front, and is faster than the ice velocity.

ii) Your diffusion timescale (cf equation 14) is the time taken for the topographic perturbation to diffuse over the whole landform, and is longer than the adjustment time.

My impression is that your adjustment time (kinematic wave) is more akin to the reaction time that you mentioned for glaciers, i.e. the time it takes for the front to respond to a mass-balance perturbation, while your diffusion time scale is in turn more akin to the volumetric time scale, i.e. the time taken for (most of) the landform to adjust to a new mass-balance state. You say the reverse. I may get this wrong, but you may want to clarify better theses concepts and the analogies to glaciers. The fact that the terminology of response times in the glaciology literature is somewhat confused certainly does not help... See discussion in Hooke (Principles of Glacier Mechanics, 2005, p.375) for example for the different definitions.

P.7 L6 : "Surface features (e.g. slope, substrate) as well as velocity fields are further used to delimit the different subsystems."

- Which velocity fields? If you refer to previously published data insert the proper reference.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/tc-2016-35/tc-2016-35-RC2-supplement.pdf

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