Reviewer 3:

We would like to thank Reviewer 3 (dr. Leysinger Vieli) for her comments. Since the reviewer sent a lengthy letter hereby we will orient ourselves on her general and specific comments. We will take into account all of the technical comments that do not require discussing (without specifically addressing them in this reply), while the rest (i.e., the concern on the sliding parameters and grid resolution) are already covered in general and specific comments.

<u>General and specific comments:</u>

First, as it is the case with the first two reviewers, we feel that we need to better stress the novelty of our paper. Here, we will summarize our guiding idea and the main conclusion, but for detailed reading we refer the reviewer to our response to Reviewer 1.

Models based on the SIA capture most of the broad characteristics of valley glaciers, and therefore may be a good candidate for the numerical experiments in which future behavior of a valley glacier is studied. In these type of experiments, careful calibration with a historical record is a necessity. Since such experiments are computer-time costly, models based on SIA are good candidates to test the results of a full-Stokes model.

In this paper, we investigate whether these ideas hold. We compare runs performed with an SIA model with runs of a full-Stokes model (FSM based on the Elmer/Ice code). We focus on the response of bulk glacier characteristics (length and volume) to different climatic forcings. Although there are studies examining general differences between SIA and FSM based on a single forcing function and a simple glacier bed profile (e.g., Pattyn, 2002 and Leysinger Vieli and Gudmundsson, 2004), a study that systematically builds up the complexity of the defined problem by applying several configurations of climatic forcing and glacier bed characteristics has not been performed up to our knowledge. Additionally, we derive and test an equation (Equation 1 in the paper) that allows users of Elmer/Ice code to study glaciers in 2D simulations when glacier width is included. This equation is of great importance because Elmer/Ice code does not have a developed solver that accounts for changing glacier width in 2D set-up.

As the reviewer's comments are mainly focused on the technical details of the study, we would like to emphasize one more time the main point of the paper: that the used FSM model shows consistent lag in climate simulations, an important message we try to transfer. This raises a question if a sophisticated ice-flow model, such as the one based on Elmer/Ice code, is capable of correctly simulating a response time of a real mountain glacier or is a simple model based on SIA more suitable for climate simulations (as we stated in the discussion section).

Second, as the main weakness the reviewer claims that we adjust our SIA model by "some parameters to produce the same initial geometry but the effect of this adjustment has not been discussed and accounted for". As it can be seen from the reviewers' further comments, we believe she speaks of the sliding parameters. Allow us to clear up this misunderstanding. Both models use the Weertman-type of sliding law. To study mountain glaciers, sliding has to be included (Leysinger Vieli and Gudmundsson, 2004 on the other hand exclude any basal motion, and they can only speculate how its inclusion would reflect on their results). In SIA, the sliding law is not modelled explicitly, but its bulk effect is absorbed in the sliding parameter that is included in the equation for sliding velocity (Equation 2 in the paper). The values suggested by Budd at al. (1979) are 1800 * 10^{-15} Pa^{-3} m^2 yr^{-1} for sliding and 0.06 * 10^{-15} Pa^{-3} yr^{-1} for deformation. These values are empirical constants and can be subject to some adjustments (Greuel, 1992). In FSM, the sliding law is presented through basal shear stress (Equation 4 in the paper) that is defined as a non-linear function of a basal (i.e., sliding) velocity and a sliding parameter. Elmer/Ice code manual *does not define* the sliding parameter but *only suggests* the possible value of 0.03 MPa $m^{-1/3}$ $yr^{1/3}$.

We need the specific model set-ups (e.g., initial state, boundary conditions and sliding law, time step and grid set-up) to be identical to make a realistic comparison between the simulations performed using different models. This means that the sliding parameters, although differently implemented in our models, must be as comparable as possible. Since Elmer/Ice code manual *does not define* the sliding parameter, we performed series of experiments to test different values for sliding (i.e., we performed large number of experiments using both SIA and FSM to obtain the correct values for sliding). Our experiments led us to conclusion that using the parameters defined in Table 1 of the paper we will obtain steady state length and volume that are equal in the two models for the three glaciers.

We wanted to test the realism of our defined sliding parameters (i.e., if the sliding parameters of the two models can be compared to each other). Thus, we hypothesized that sliding velocities in FSM and SIA are equal, and we derived an equation (Equation 5 in the paper) which shows that sliding parameter in FSM can be derived from the sliding parameter in SIA. Please note that the sliding parameters derived using this mathematical formulation differ by about 20% from the ones presented in Table 1. Nonetheless, the defined equation can serve as a guidance to readers how to correctly choose their sliding parameter when using Elmer/Ice code.

The reviewer further states: “At the front the basal velocity in FSM and the sliding velocity in SIA are not the same due to not accounting for the change in thickness in the FSM model. This effect is seen in basal shear stress as well as in the force balance components.” This is not correct because the reviewer’s conclusion is based on a misinterpretation of Equation 5. If we assume to have a no-slip basal condition in FSM, the peaks are still present (please see the attached Figure 1). In this figure, we plot steady state basal shear stress and horizontal ice velocity simulated using FSM for a no-slip boundary condition (red), a model set-up with high sliding coefficient (blue) and a model set-up with the sliding coefficient presented in the paper (green). We can see that high peaks at the glacier head remain in all set-ups. This means that the choice of sliding parameter does not influence the presence of this instability. What causes the instabilities is already discussed in the paper at P.9, L.29-34.

The reviewer misses the discussion on the effect of different sliding parameters on our results. In Section 4.1 we already present a good indication of the influence of changing sliding parameters on our results. There we explain the influence of sliding parameter on the ice velocity and basal shear stress (paper P.9, L18-24). We do not discuss this influence on the instabilities seen on figures for the basal shear stress, since we could not find any connection. Nonetheless, in order to improve the paper following the reviewer's comment, we will elaborate the discussion in the revised paper.

Third, the reviewer is puzzled about the dependence of our results on the structured grid definition and grid resolution. In the present type of experiments, it is necessary that the grid is equally defined in both models. We do not believe that in detail comparison can be done if the grids are of different resolution or if the grid in FSM is adjustable at the glacier front. Since in these experiments we simulate glacier length (and volume) evolution, it is only natural that some of the results will be limited to one-to-two grid points, but more important is *the difference in response times* between our models (a result that the reviewer does not comment). To give better insight to the reviewers' question, we will investigate how the glacier time evolution under different climatic conditions changes when we use a higher grid resolution.

Fourth, the reviewer asks for more elaboration on the goal of the experiments with a varying glacier width. Please note that the glacier width, as defined in Equation 8, is defined for a large number of mountain glaciers that have a wide accumulation basin and a narrow tongue. Therefore, we do not see anything disputable in our formulation. As we already stated at the beginning of this letter we perform the experiments described in Section 4.2-4.4 of the paper to test an equation (Equation 1 in the paper) that allows users of Elmer/Ice code to study glaciers in 2D simulations when glacier width is included. Also, we extend our analysis by including more complicated bed profiles since many mountain glaciers have a bed with a reversed bed slope or ice-fall over a certain distance along the flow line.

Finally, throughout her letter, the reviewer points to too many differences in the model set-up between our study and the one from Leysinger Vieli and Gudmundsson (2004) to make a direct comparison. She states: "For the comparisons with Leysinger Vieli and Gudmundsson (2004) it is not clear what the observed differences mean …", and "The model set-up is e.g., not the same as the one used by Leysinger Vieli and Gudmundsson (2004) but the results are much compared with each other…". In order to address the reviewer's concern, we will no longer make in depth comparison of our results to Leysinger Vieli and Gudmundsson (2004) in the revised manuscript.

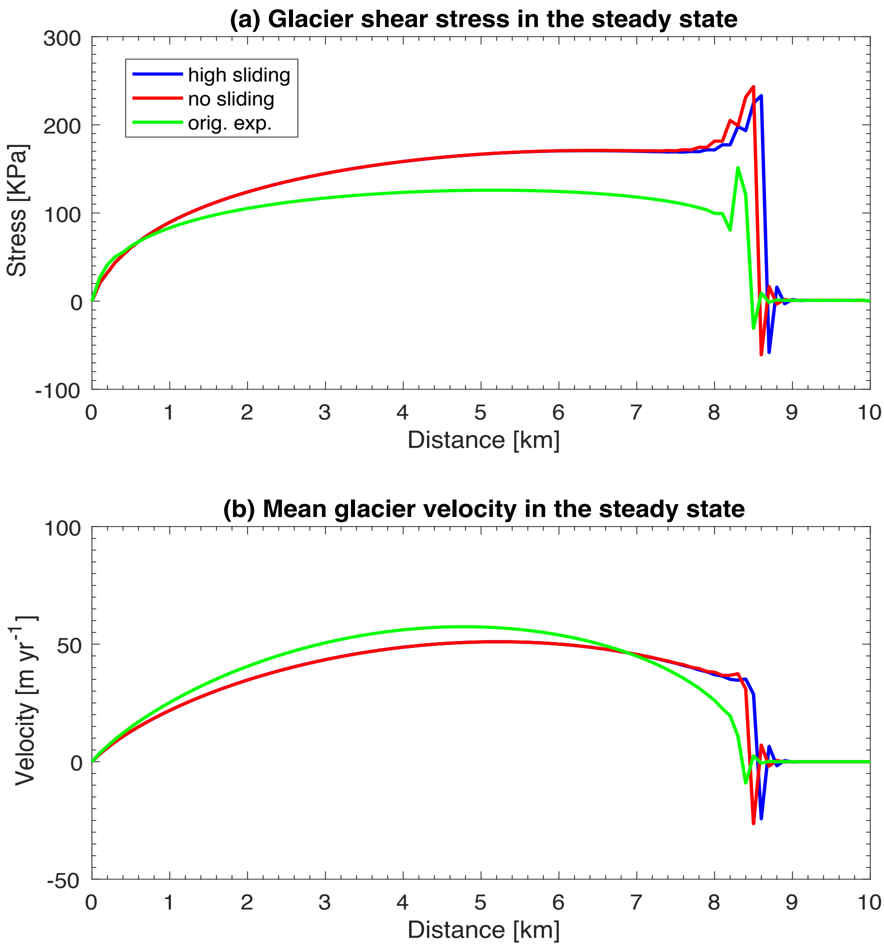

Figure 1. (a) Basal shear stress and (b) horizontal ice velocity simulated using FSM. Green line represents the result from the paper, red line is the simulation with no-slip condition and blue line is the simulation with high sliding.