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Interactive comment on "Numerical simulations of Gurenhekou Glacier on the Tibetan Plateau using a full-Stokes ice dynamical model" *by* L. Zhao et al.

Anonymous Referee #2

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Review comments on "Numerical simulations of Gurenhekou Glacier on the Tibetan Plateau using a full-Stokes ice dynamical model" by L. Zhao and others.

General comments

This paper presents numerical modeling of a small valley glacier in a Tibetan mountain range. The aim of the study is to forecast the evolution of the glacier for the next 50 years under warming temperature conditions. The model consists of ice flow and mass balance models. The ice flow model is so called full-Stokes model, which is able to compute glacier flow under a complex stress regime by taking higher order stress terms into account. The mass balance is given as a function of elevation and ELA, in which

ELA is parameterized to the changes in summer mean temperature. The mass balance model is based on field measurements and a previous modeling work performed on a nearby glacier. Model experiments were carried out to compute ice velocity and temperature for the current glacier geometry, and to simulate three-dimensional geometry change under two different warming scenarios. Computed changes in ice velocity and surface elevation from 2008 to 2057 are shown in Figure 8 and 9, and changes in area and volume are given in Table 1. As a conclusion of the experiments, the authors state that "this small glacier will probably disappear in a century, and significant numbers of glaciers will be lost in the region (page 146, line 15–19)".

This study is interesting to the glacier research community because data and information are lacking in Tibetan glaciers. The numerical model (Elmer/Ice) has already been applied to many glaciers in previous studies, and thus the experiments are technically sound. Nevertheless, modeling is based on poorly grounded mass balance parameterization. Moreover, the results are not very well analyzed nor discussed, which results in speculative and qualitative conclusions. Important field data are not presented in the paper and many of important citations are in Chinese. Thus, I suggest the author to present and carefully analyze available data for this glacier, before setting up a model for numerical experiments. Please see below for my major concerns on the manuscript, and more detailed comments and suggestions.

Specific comments

(1) Full Stokes flow model The authors claim "The steep and rugged geometry requires use of such a flow model to simulate the dynamical evolution of the glacier (page 146, line 5–6)". However, the slope of the glacier is never mentioned and bedrock elevations are smoothly interpolated from only several ice-radar profiles. The glacier geometry is relatively simple and no-sliding condition is assumed. As it is expected from the low temperature conditions, computed ice velocity is very slow (less than 2 m a-1). Is full Stokes model really needed to simulate this glacier? It is nothing wrong to use a flow model with higher complexity, but it does not assure the significance of this modeling

work.

(2) Mass balance model Assuming that ice dynamics does not much for the evolution of this glacier, the results of the experiments is highly dependent on the mass balance model. Unfortunately, the mass balance given by Equations (2)–(4) is not convincing. The model result showed thickening of the glacier in the upper reaches, which indicates something wrong with the prescribed mass balance. The authors take three different mass balance gradients based on mass balance modeling reported for nearby Xibu Glacier (Caidong and Sorteberg, 2010). According to this previous work, the mass balance of Xibu Glacier is characterized by steep gradients in the ablation zone and a much smaller gradient in the accumulation zone (Figure 6 and 7 in Caidong and Sorteberg, 2010). Such a mass balance distribution is commonly observed in the field and often assumed in numerical models. Contrasting to such mass balance profile, this study uses a very steep mass balance gradient in the accumulation zone (Figure 3). The modeled mass balance falls within the range of field data. However, the field data show large variations and nothing is explained about the data in this paper. Moreover, the ELA is parameterized to summer mean temperature with a linear coefficient of 79 m K-1 (Equation (4)), whereas the value reported for Xibu Glacier is 140$\pm$125 m K-1 (Caidong and Sorteberg, 2010). These numbers are so different and uncertainty is expected to be large. This coefficient was determined from the field data, but again no details are given in the text. Because the model output is totally dependent on the mass balance equations, the authors should derive the equations more carefully and convince the readers with field data and relevant information.

(3) Analysis and discussion The modeling results are not very well analyzed and discussed. Because of large uncertainties in the input data, the results have to be evaluated more carefully. One example is the computed retreat and area reduction rates. These numbers are highly dependent on the bed geometries near the margins, where no ice-radar data are available. However, there is no error bar given to the results. The rapid retreat at the northeastern terminus was explained by thinner ice there, but ice-

radar measurements were not performed in that part of the glacier (Figure 2). Another problem is very limited analysis and discussion on three dimensional glacier geometry change. One of the important advantages of the model is its capability to handle three-dimensional geometry. For example, it appears that the uppermost part of the glacier is detached from the main ice body after 50 years (Figure 9b). Is this realistic? Or is this an artifact as the result of ice thickening in this region (Figure 10)? More detailed analysis of the glacier geometry change, e.g. flowline analysis, ice volume change as a function of time, contour maps, improves the significance of the study.

(4) Presentation Plots are colorful, but not very well prepared for presentation on a paper. For example, surface and bedrock contour maps are more useful than Figure 4. Flow vectors can be superimposed on the velocity contour map (Figure 5). It is hard to compare two diagrams with different color codes (e.g. Figure 8 left and right). Glacier margins near the terminus can be enlarged to show the details of the glacier retreat (Figure 9). As compared to the previous paper presented by the coauthors (Zwinger and Moore, 2009), there is a lot of things to do to improve the presentation.

(5) Main conclusions The author states in the abstract that "These changes imply that this small glacier will probably disappear in a century" and "significant numbers of glaciers will be lost in the region during the 21st century". Because these statements are very influential, I suggest the author to carefully backup them by data and text. As far as understand, the bases of this statement is the mean rates of volume loss computed for the next 50 years (1.03% and 1.46% for the two temperature scenarios). This is for the next 50 years and no experiments were performed further in the future. The results are highly dependent on the sensitivity of ELA on the temperature change (Equation (4)). Warming by 5 degrees raises ELA by 400 m, which is well above the current highest altitude of the glacier (Figure 3). However, glacier may survive under the 2 degrees warming scenario, because expected shift in ELA (160 m) is still below the glacier top. The authors argue that "The glacier is typical in many respects of many small galaciers in the Nyainqentanglha region". On the other hand, they also write

"only about 40 out of 960 glaciers are larger than 1 km2 (this glacier is 1.4 km2)" and "it is not clear if Gurenhekou glacier is really representative in its area loss rate." I hope the main conclusions are more logically derived and moderately described in the text.

Other comments

page 146, line 16: . . . Tibetan glaciers are not particularly sensitive to climate warming, . . .

» Please explain why. Otherwise, better not in the abstract.

page 147, line 6: . . . loose . . .

» lose?

page 147, line 7–8: However, little work has been done . . .

I think the sentence is odd.

page 147, line 15: significant aspect ratio

What do you mean?

page 147, line 18–19: . . . accumulation rates are relatively high . . .

Is it high in Tibetan Plateau?

page 147, line 28: Gurenhekou glacier

Please be consistent "glacier" or "Glacier".

page 148, line 4: southeast

» southwest?

page 148, line 6-8: The region is of special interest . . .

Please provide citations.

page 148, line 9: strikingly regular in shape

What do you mean?

page 148, line 20: 140 m along a traverse line and . . .

What do you mean?

page 148, line 24: surface mass balance (SMB)

Please use the abbreviation in the rest of the paper once you define it.

page 150, line 8–9: We can test this hypothesis . . .

I wonder how you test the mass balance model with surface elevation change. Do you neglect the ice dynamics?

page 151, line 1–4:

This is very important part of the modeling. Please consider to show the temperature and mass balance data and plot the temperature dependence of the mass balance.

page 151, line 11-13: Surface and bed geometry

Please provide contour maps of the surface and bed. Because surface and bed elevation data are sparse, discussion is needed on the quality of the DEMs derived by interpolations.

page 151, line 13-20: Finite element mesh

Please show the mesh. What are the element type and resolutions? Because Elmer/Ice is widely used for glacier modeling, please introduce previous works carried out with the same code.

page 152, line 12: gravity acceleration

» gravitational acceleration?

page 152, line 12: ice density

What is the influence of firn in the accumulation zone?

page 152, line 17: effective strain tensor

» effective strain rate?

page 152, line 20: heat capacity and conductivity

Please provide citation.

page 153, line 3: the upper interface is. . .

» the upper interface are . . .

page 153, line 18-20: The first is diagnostic simulation . . .

I do not understand the latter half of this sentence. Isn't it computation of velocity and temperature for a given glacier geometry? Is mass balance relevant, here?

page 154, line 4: Gao et al., 2012

» 2010?

page 154, line 15: Lhasa station

Please consider to present the data.

page 154, line 23: fixed point iteration scheme

What is this iteration for? Please clarify.

page 155, line 4-5: We find . . .

Please provide some statistical numbers, e.g. maximum deviation, standard deviation, . . .

page 155, line 8: steady state solution

I'm still wondering what is done in the diagnostic experiment. Did you evolve the glacier surface until it reaches a steady state?

page 155, line 23-26: Using topographic maps, . . .

Please consider to show the data on the glacier retreat in the past. Explain more details if you analyzed the topographic maps and aerial photos.

page 156, line 1: acceleration

» retreat?

page 156, line 5: area reduction rate

Reduction rate should be positive when the area decreases.

page 157, line 3-19:

I agree that glacier growth above the level of the surrounding mountain ridge is unlikely. Even if this sensitivity test shows its effect is insignificant, such a result gives me an impression that something is wrong with the mass balance model.

page 158, line 5-13:

I found that this discussion is very weak. Because of the parameterization of the mass balance to the temperature, one can easily expect a greater ice loss under a greater warming rate. This paragraph shows nothing more than this. To extrapolate the results to 100 years in the future, more careful analyses are needed on the glacier area and volume changes. For example, on which bases you assume a constant volume reduction rate for the next 100 years?

page 158, line 20-21: Hence if our results are representative . . .

This is an important assumption that modeling results on this relatively large Gurenhekou Glacier (1.4 km2) represent all other smaller glaciers in the region. This assumption has to be supported by data. Otherwise, the statement "95% of glaciers in the range would disappear" is misleading.

page 158, line 28: . . . increased rate . . .

» increased area loss rate?

page 159, line 12-13: it is likely that southerly facing glaciers will accelerate . . .

» Please explain why.

page 159, line 3-26:

These are interesting and important discussions. The climate variability has to be analyzed to assess the representability of Gurenhekou Glacier. It would be interesting if this model is used to investigate the effect of these changes expected in the future, i.e. changes in temperature and/or precipitation, albedo, debris cover. . .

References

Caidong, C. and Sorteberg, A.: Modelled mass balance of Xibu glacier, Tibetan Plateau: sensitivity to climate change, J. Glaciol., 56, 235–248, 2010.

Zwinger, T. and Moore, J. C.: Diagnostic and prognostic simulations with a full Stokes model accounting for superimposed ice of Midtre Love′nbreen, Svalbard, The Cryosphere, 3, 217– 229

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