

Our responses to the review comments are in this document, where the Reviewer's comments are shown in *blue italic text*, our responses are shown in plain black text, quoted text from the original manuscript are shown in *black italic text*, and any changes to the manuscript are shown in **bold black text**.

Review: Increasing precipitation due to climate change could partially offset the impact of warming on glacier loss in the monsoon-influenced Himalaya until 2100 CE

Summary

This study focuses on Khumbu Glacier in the Everest region of Nepal and how changes in temperature and precipitation affect its evolution until 2100 for two different emission scenarios. For this, the study relies on downscaling meteorological inputs from RCMs using AWS data, forcing a distributed energy-balance model with these inputs, and finally forcing a glacier evolution model with its outputs. They found that an increase in precipitation can offset some of the expected glacier loss for intermediate future scenarios (RCP4.5). This effect could not be observed for high-emission scenarios (RCP8.5), as the larger temperature increase compared to intermediate scenarios leads to a higher fraction of liquid rather than solid precipitation.

General Comments

In the introduction, at several places you talk about the detached debris-covered tongue (e.g. L81ff and L119) . Could this be merged in one place to make it easier for the reader to follow and reduce repetition?

The Introduction has been slightly rearranged to contain all the information about the detached glacier tongue in the third paragraph.

2.1 Glacier model experimental design: It is not clear to me from this section how COSIPY and iSOSIA work together and at which stage of the setup each model is used. It would be helpful to explain the individual inputs and outputs of the two models and clearly state how the two models are used during spin-up, the transition until 2015, and the future projection (e.g., what setup of COSIPY was used as input to iSOSIA at the different stages, or was an input different from COSIPY used to drive iSOSIA at some stages?). In its current form, I am not able to follow the model setup.

Section 2.1 had been edited to make this clearer. The second paragraph that describes the spin-up simulation now starts with the following sentence:

“The spin-up simulation from the ice-free model domain to represent the late Holocene glacier was forced using a simple approximation of mass balance.”

The third paragraph that describes the present day simulations now starts from this sentence, when the year represented has been added:

“The late Holocene simulation was forced to present-day (2015 CE) conditions using three surface mass balances (one from each RCM) calculated using the Coupled Snowpack and Ice-surface Energy and Mass Balance model in Python (COSIPY v1.3) (Sauter et al., 2020).”

The fourth paragraph is now separated from the previous text and starts with this sentence where COSIPY forcing is mentioned explicitly:

“We used the output from the present-day simulation with the 2095–2100 CE mass balance **calculated using COSIPY to force the model to 2100 CE for a period of 80 years.”**

Specific Remarks

L22: What do you mean by “precipitation is not often represented in glacier projections”? At a minimum, glacier models use temperature and precipitation for making predictions into the future.

The line in question does not simplify to precipitation and instead reads:

“However, the impact of changes in precipitation amount and distribution on future glacier change remains uncertain because **these variables is not often represented in glacier model projections.”**

Which we feel is sufficiently clear in stating that changes in precipitation amount and distribution, rather than only amount or fixed values are investigated here. We have updated the sentence to make clear that amount and distribution are both variables in our study.

L81–L98: What is the connection of this section to the research question (maybe defining the area of interest, only the active glacier)?

Yes, which is important because simulations of the entire (active + stagnant) glacier as represented by the RGI outline will overestimate present-day ice volume. This is discussed in Section 4.4.

L158: Can the complete ice-free model domain be displayed in Figure 1c?

The hydrological catchment has been added to Fig. 1C.

L160: What other meteorological forcing parameters were used for defining the starting point? You describe only ELA and an atmospheric lapse rate, but how was, for example, accumulation rate defined? And which COSIPY model configuration was used for this? Or is another mb model used? It is not clear which mass-balance forcing is used for the spin-up.

For the spin up simulation, we used a simple elevation-dependent description of mass balance, which was the same as in Rowan et al. (2015) but not completely described in the previous version. The following sentence has been added:

“Accumulation above the ELA was calculated as a function of elevation 0.2 m m^{-1} up to a maximum of $2.0 \text{ m w.e. a}^{-1}$ and ablation was calculated as a function of elevation 0.5 m m^{-1} up to a maximum of $2.0 \text{ m w.e. a}^{-1}$.”

L168–L171: Where do you discuss the results of this? Which observations did you use? How did you select NOAA RCM quantitatively?

The results of this assessment are shown in Fig. 3 and discussed in Section 3.4.

L171–L174: How exactly did you define the ice-free topography? In L159 you state that you used ice thickness from Farinotti et al. (2019), but here you state you add the dynamically detached debris-covered tongue to the model domain as a static topographic feature. Do you only add the tongue as a static feature after 2015? Please explain in more detail which ice-free topography you are using.

The Reviewer is correct about the ice-free topography for the spin-up simulation. The text here has been updated to read:

“We simulated only the active section of the glacier beyond 2015 CE and added the dynamically detached debris-covered tongue simulated at the present day to the model domain as a static topographic feature for the future simulations. The volume of the detached tongue was calculated by using the simulated present-day velocity field to separate the simulated present-day ice volume where velocities declined below 10 m a^{-1} .”

L175–L176: Does this mean you use a 5-year mean mass balance (2015–2020 and 2095–2100) for forcing, or do you repeat those 5 years cyclically for 200 years and 80 years, respectively?

The former is correct. To make this clear, the text “for 200/80 years” has been removed.

L180: How did you define dry, moderate, and wet quantitatively? How large are the actual differences?

A reference has been added here to Figure 2D where these values are shown.

L188: Why are you discussing lapse rates here? What exactly did you use them for (what simulation did you perform with different lapse rates)? Can you introduce where the lapse rates are used (in the COSIPY simulation?) and what other variables are used by COSIPY at this point (in Figure 2a it states COSIPY uses 9 climate variables)? Please make clear at each point in the text whether you are discussing COSIPY or iSOSIA.

Lapse rate is one of the COSIPY variables, and we agree that this text was misplaced. It has been moved to Section 2.5 where the COSIPY perturbations are described.

L191–L207: This reads as a discussion about the influence of avalanches rather than an explanation of the glacier model experimental design. It feels out of place here. I also do not understand from this section how avalanche contributions are accounted for in the model chain (only in COSIPY, only in iSOSIA, or in both?).

This paragraph was added here in response to previous Reviewer comments, and highlights that avalanching is treated in iSOSIA (not in COSIPY) and that this is described in detail in Section 2.6. As such, we have left this text unchanged apart from adding “in iSOSIA” here to clarify where the avalanche calculation occurred.

L349: “and and”

Fixed.

L364–368: Where are the results of this sensitivity study, or the values used in the end? Ah, it is in section 3.1. Maybe add a reference here.

Done.

L373: At which temporal resolution are you forcing COSIPY?

As stated in the following line, the time step in COSIPY was hourly.

L381–383: How was COSIPY used within iSOSIA exactly? Did you provide the resulting mass-balance maps to iSOSIA?

This is described in detail in the following section, in second paragraph of Section 2.6, and we prefer not to duplicate here to avoid confusion.

L385: Which spatial grid is iSOSIA using? The same as COSIPY?

Yes. We have added the sentence here:

“The model domain topography was the same in iSOSIA as that used in COSIPY.”

L400–L401: What do you mean by “no change in forcing applied between time steps”?

That the forcing was constant across the periods described. This has been clarified in the text:

“...with no change in forcing applied between these two periods”

L401–L402: Do you mean you are not including elevation-change feedbacks within COSIPY?

The changes in the glacier surface simulated in iSOSIA are not returned to COSIPY. We feel that this is accurately described in the text as written.

L427: Why is there no reference to Fig. 8? It looks like in Fig. 8 you conducted some sensitivity experiments regarding h_0 , but I cannot find any link to this in the text.

Figure 8 is referenced from Section 3.4 and Section 4.5.

L527: Just by looking at EB7910 in Fig. 5, it does not look like the energy available for melt (Q_{melt} , red line) and the sensible heat flux (Q_{sens} , yellow line) are perfectly correlated ($r=1$).

We agree, and have modified the text to read:

“At the South Col (EB7910) the energy available for melt correlated **most closely with the sensible heat flux (Fig. 5).”**

L547: You could use MAAT here.

Done

L572: With which metrics did you assess that NOAA provides the best starting point?

The model-data comparison is shown in Fig. 3, but this was not referenced here and it was not explicitly stated in the figure caption that this is a comparison with the NOAA result. This has been updated.

L588–L594: What is the maximum velocity in this study? As I understand it, the 220 $m a^{-1}$ are observed and the 118 $m a^{-1}$ are from a previous study.

This has been added:

“Simulated present-day glacier velocities (Fig. 9) reached a maximum of 248 $m a^{-1}$ and”

L611ff: In Fig. 2e you separate precipitation between monsoon and non-monsoon, but here you talk about summer and winter precipitation.

This has been corrected to use consistent monsoon/non-monsoon terminology.

L712: From where do you take the observed accumulation rates and distribution, and why are those not included in Fig. 1d?

These are shown in Fig. 1D, although the accumulation rates are estimated rather than observed. We are not aware of any observations of accumulation rate for this region. The text has been updated to correct this point:

“and improved the agreement between simulated and **estimated** accumulation rates and distribution (Fig. 1D).”

L821: Rounce et al. (2023) starts its simulations in the year 2000.

This has been corrected.

L1222: Fig. 1c: No satellite image, as stated in the caption.

We are not clear what is meant by this point; the background image in Fig. 1C is a satellite image of the glacier. To avoid confusion, the caption has been updated to “**Map** of...”

L1222: Fig. 1d: Why do you not show ELA for RCP8.5? Is it above crest height?

The ELA under RCP is above the maximum elevation of the glacier surface, and is difficult to estimate precisely because avalanching has a strong impact of the distribution of snow. For such a small glacier in high-relief terrain, ELA becomes less meaningful as a mass balance metric and we do not present a value here.

L1266–L1267: How are you extracting the present-day ice surface elevation from Farinotti et al. (2019)? As far as I know, it is a dataset of ice thickness, which is valid at the RGI outline date. How do you obtain the 2015 surface elevation from this? Is the corresponding outline date 2015 in RGI?

The Farinotti et al. (2019) ice thickness is subtracted from the DEM to estimate the subglacial topography. The DEM is then resampled to give the model domain. The geophysical data used to constrain the ice thickness estimate dates from 2000 and 1978 surveys, and the glacier surface changes dramatically from year-to-year (King et al., 2020) and Fig. 3D-E. As such, the subglacial topography is an estimate of the glacier bed at the present day, but is not accurate for any particular year, and the year assigned here represents the model time step rather than that for the topography.