

Dear Ben and co-authors,

Thank you for this interesting study. I think the question you address is important, and the high-elevation meteorological observations provide a very rare opportunity to learn about the complex processes at play. I also agree with the general premise that temperature-index models can exhibit excessive sensitivity to temperature changes, particularly in environments where temperature is a poor proxy for the energy available for melt. This is a well-known limitation of temperature-index approaches, and your study provides an interesting illustration of it.

My main concern is with the interpretation of the results, particularly the statements in the abstract (L8–11) and conclusions (L392–397) suggesting that existing global glacier models may overestimate future glacier *recession*. While this might well be the case, I don't think this conclusion can be drawn from the experiments presented alone.

1. Calibration of global glacier models

The TI models in this study are calibrated to reproduce COSIPY's simulated ablation at a single point, at 6464 m elevation. As you acknowledge in L207–212, this requires unusually high melt factors to compensate for radiation-driven ablation at very low temperatures.

However, this is not how global glacier models are calibrated. Many use glacier-wide observational constraints, including geodetic mass balance, to calibrate empirical mass-balance models that operate across the entire elevation range of a glacier. The glacier-wide calibration problem is often underconstrained, with substantial parameter equifinality (e.g. Rounce et al., 2020, Schuster et al., 2023). Different combinations of temperature corrections, precipitation factors and melt factors can reproduce similar glacier-wide mass balances while producing very different local mass balances, particularly at extreme elevations.

Furthermore, many large-scale TI models operate at daily or, more commonly, monthly resolution, with formulations and calibrations adapted accordingly. Applying an hourly TI model at 6464 m, where temperatures rarely exceed the melt threshold, and calibrating it to reproduce substantial radiation-driven ablation is a rather particular experiment. It is not clear how representative this is of the models used for global projections.

To illustrate how differently global models can behave at these elevations, I ran two standard OGGM mass-balance models at the Khumbu study elevation, using the publicly available, globally calibrated OGGM glacier directories. The results are shown in the figure below ([code](#)). Both models simulate some melt at 6464 m, but exhibit lower temperature sensitivity than the TI model used in this study, although they remain substantially more sensitive than COSIPY. At another Himalayan glacier picked more or less at random (Baltoro), the same approach produces no melt at all at this elevation under present-day conditions. In other words, depending on their calibration and climate bias correction, global models may simulate anything from substantial melt to no melt at all at these elevations.

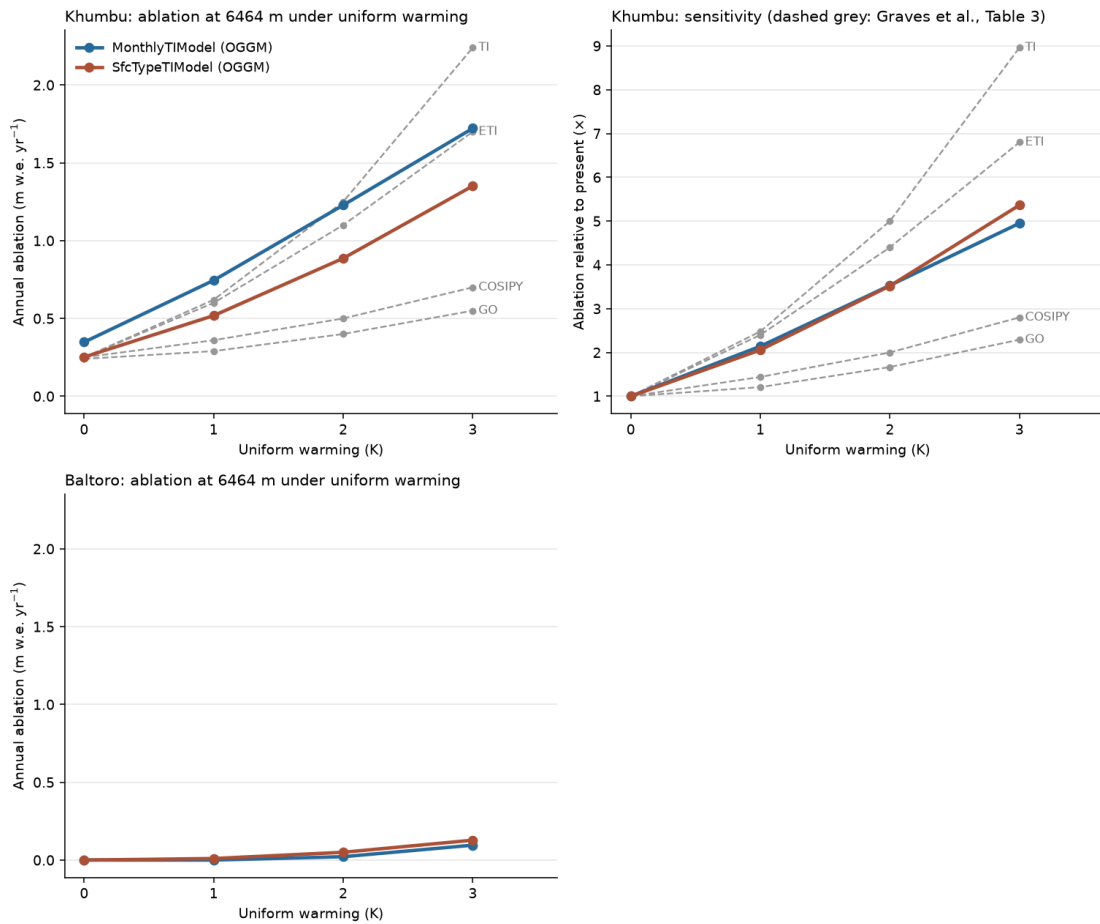


Figure: Sensitivity of ablation to uniform warming at 6464 m a.s.l. (the Camp II elevation) on Khumbu Glacier (top) and Baltoro Glacier (bottom). The results come from two OGGM mass-balance models: the monthly temperature-index model (MonthlyTImodel, blue) and its surface-type variant with separate snow, firn and ice melt factors (SfcTypeTImodel, red). Both use RGI7 outlines (Khumbu RGI2000-v7.0-G-15-08331, Baltoro RGI2000-v7.0-G-14-11612) and monthly ERA5 forcing for 2000–2025. Model parameters (melt factor, temperature bias, precipitation factor) are calibrated for each glacier as a whole to its 2000–2020 geodetic mass balance, not at this elevation. A uniform +1, +2 and +3 K is added to the temperature series, with everything else unchanged.

This illustrates how strongly the results depend on calibration and model formulation, and why the behaviour of a locally calibrated TI model cannot be extrapolated directly to existing global glacier projections. The reverse is equally true, of course: global glacier models should *not* be used to make quantitative claims about mass balance at a single point, especially without uncertainty ranges provided.

Given that several global glacier models are open source and readily available, I think it would have been useful, and relatively straightforward, to examine their actual behaviour at the study elevation before drawing conclusions about their projections.

2. Temperature perturbations and climate sensitivity

The synthetic warming experiments (L161–168) are useful for comparing model responses to imposed temperature changes, but I wonder whether they constitute an entirely like-for-like comparison in terms of climate-change sensitivity.

Temperature-index models deliberately use air temperature as a proxy for several meteorological processes controlling melt. In this sense, changing temperature is effectively how these models represent climate change. Energy-balance models, however, explicitly resolve these processes, and a physically consistent warmer climate would also involve changes in other meteorological variables, including shortwave radiation and humidity.

There is literature on the importance of these covariations for glacier surface energy balance (e.g. Prinz et al., 2016; Khadka et al., 2024). I think this deserves more consideration when interpreting the differences between model responses.

In other words, the TI models in Figs. 7–9 are being used in roughly the same way as they would be in a climate-change projection, whereas the SEB models are subjected to a more restricted perturbation experiment. As you acknowledge yourselves (L161–168), these experiments are not realistic climate-change scenarios. I think this distinction matters when using the results to draw conclusions about future glacier projections.

3. Ablation isn't glacier recession

The abstract (L8–11) suggests that global projections may overestimate future glacier *recession*, while the conclusions (L395–397) extend the results to glacier mass loss. However, your study only investigates surface ablation at one point. Glacier-wide mass balance also depends on accumulation, and glacier recession involves changes in glacier geometry and dynamics.

Because of equifinality (again!), the calibration of large-scale glacier models can accommodate quite different combinations of melt factors, temperature corrections and precipitation factors. The resulting accumulation estimates can vary substantially between models. For example, OGGM computes an average annual accumulation of 2.85 m w.e. yr⁻¹ at 6464 m on Khumbu and 1.65 m w.e. yr⁻¹ at the same elevation on Baltoro. I have no particular reason to trust these point-scale estimates from OGGM at all. Other global models, with different precipitation inputs and calibration strategies, could produce substantially different values.

In short, neither the sign nor the magnitude of the error in glacier-wide mass balance can be inferred from your study's experiments. I would therefore recommend sticking to the term *ablation* in the abstract and conclusions, as this is what you are evaluating.

4. Figure 1

I find the choice to show and discuss glacier area above 5400 m in Figure 1 and the introduction (L33–38) somewhat misleading. The experiments are conducted at 6464 m, and conditions at 5400 m can be very different, with substantial summer melt in many regions of HMA. For example, Mölg et al. (2012) report several metres of melt over a single summer season at around 5400 m, in an environment where temperature-index modelling can work reasonably well.

The figure seems to suggest that a large fraction of Himalayan glacier area is potentially affected by the limitations demonstrated here, although neither the spatial extent of these limitations nor their implications for glacier-wide mass balance have been established. I think the figure, at least as currently used in the manuscript, risks overstating the relevance of this particular point-scale experiment - at the very least, I'd suggest to add the elevation of this study's experiment to the plot as it would give the necessary context and add an additional information.

The nearby Mera Glacier (Khadka et al., 2024) could provide an excellent test case to investigate whether the behaviour observed at 6464 m also applies at around 5400 m, at least in this part of the Himalayas.

5. Conclusions

I am very sympathetic to the effort to encourage the community to move away from temperature-index models, and studies such as yours are important in providing evidence and observational data from otherwise poorly monitored regions. However, I would recommend to distinguish more carefully between the demonstrated differences in point-scale model sensitivity, the limitations of temperature-index models in general, and the much broader claims about existing global glacier projections.

On a personal level, I am very keen on getting a robust answer to the question of whether our global models are too pessimistic about future glacier change. They might well be, although I can also think of several reasons why they might be too optimistic! But I am not convinced that the experiments presented here allow us to answer that question with such confidence.

I hope these comments are helpful and look forward to the discussion.

Best wishes,

Fabien Maussion

References

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