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Supplement of

Possible biases in scaling-based estimates of glacier change: a case study in the Himalaya

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Supplementary figures

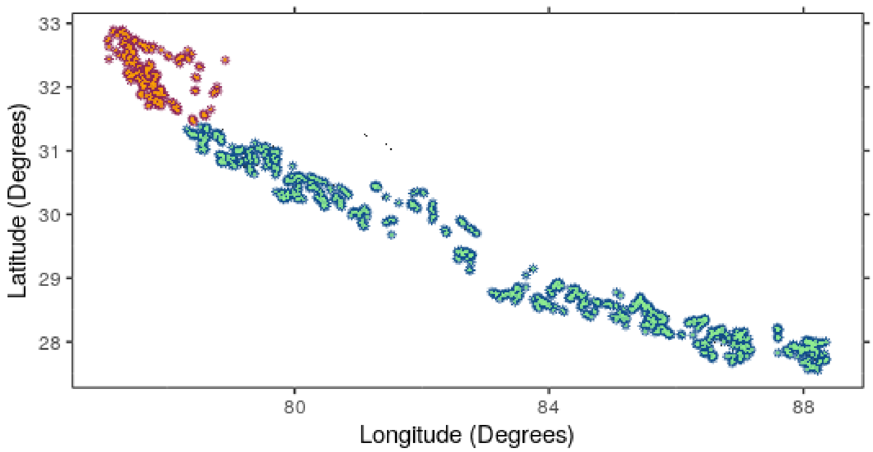

Figure S1: The locations of the 703 simulated glaciers from Ganga basin, the Central Himalaya (green symbols), and the 164 simulated glaciers in the western Himalaya (orange symbols) are shown.

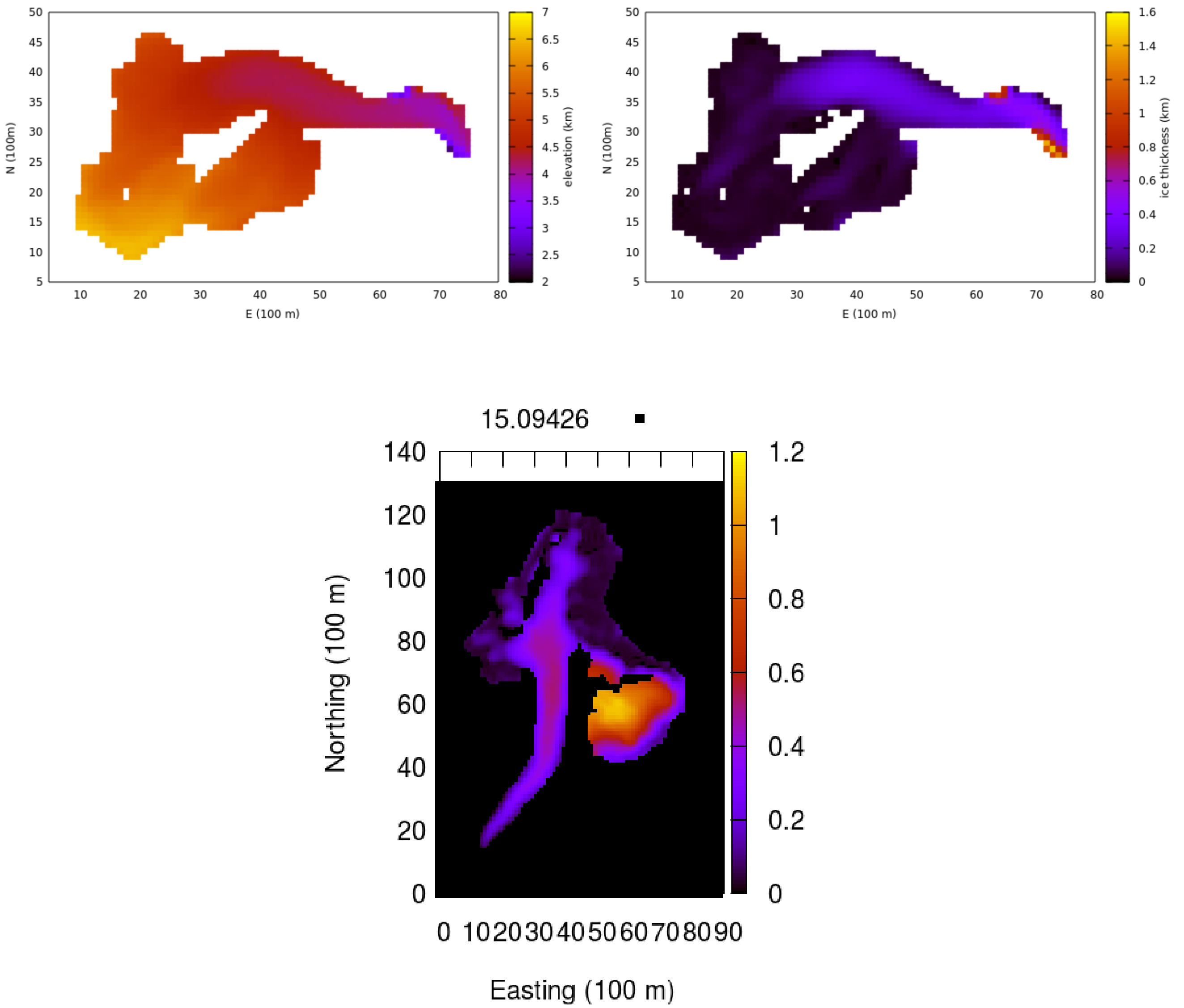

Figure S2: Top: The bedrock (left) and modeled ice thickness (right) for the glacier RGI-ID 15.04060, where noisy/steep bedrock led to a violation ice-conservation. Similar problem was encountered on two other glaciers, RGI-ID 15.05142 and RGI-ID 15.09803. See main text for more discussions.

Bottom: Glacier RGI-ID 15.09426 has a debris-covered left tributary that was truncated due to mapping errors. This led to an unrealistic pile up of ice in the modeled steady state (color scale: ice thickness in km). This glacier was not included in our study.

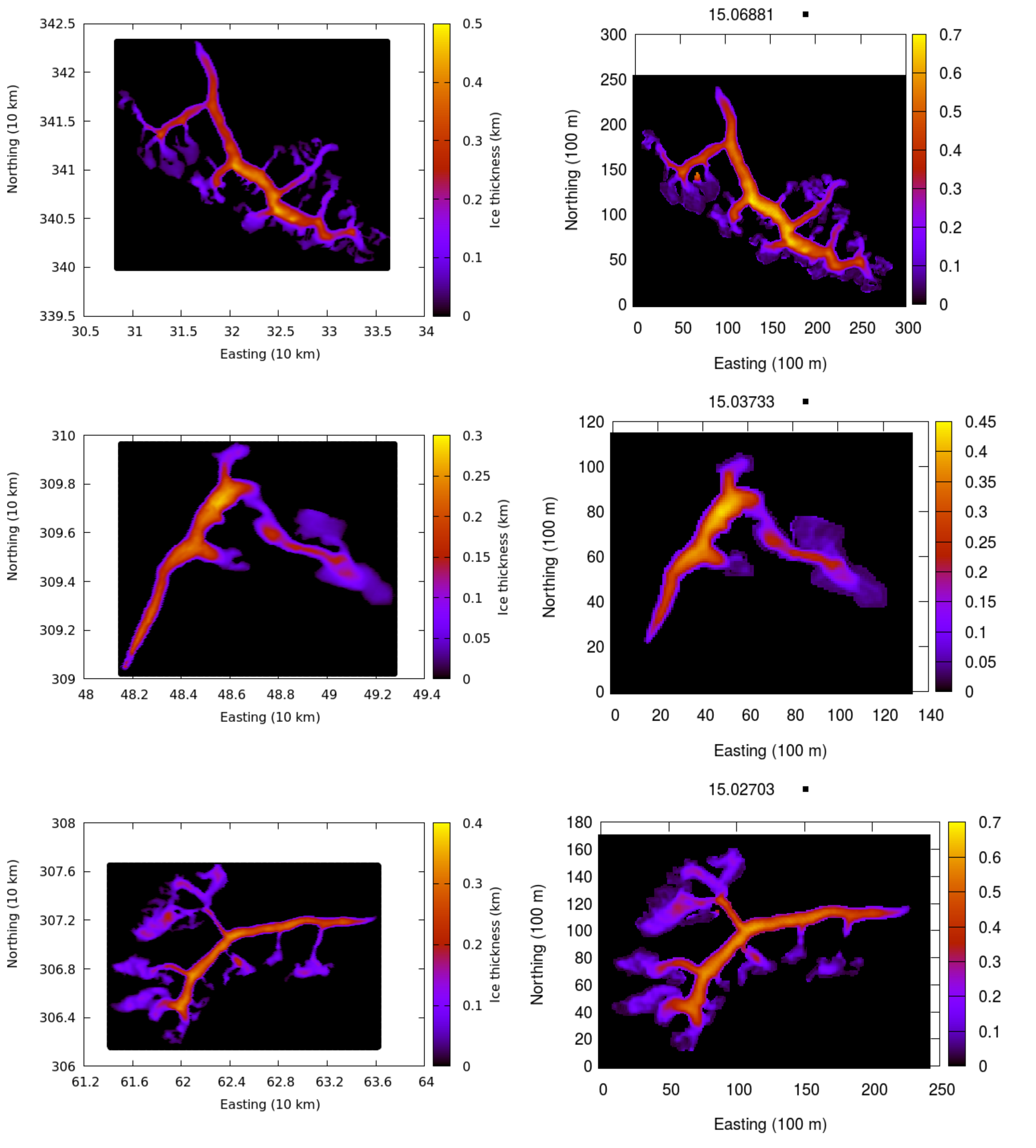

Figure S3: Ice thickness maps of Gangotri (top row), Khumbu (middle row), and Zemu (bottom row) glaciers. The maps on the left shows estimates of glacier thickness according to Kraaijenbrink et al. (2017). Those on the right are corresponding steady states simulated by the SIA model in this study. The color scale denotes ice thickness in km and varies between plots.

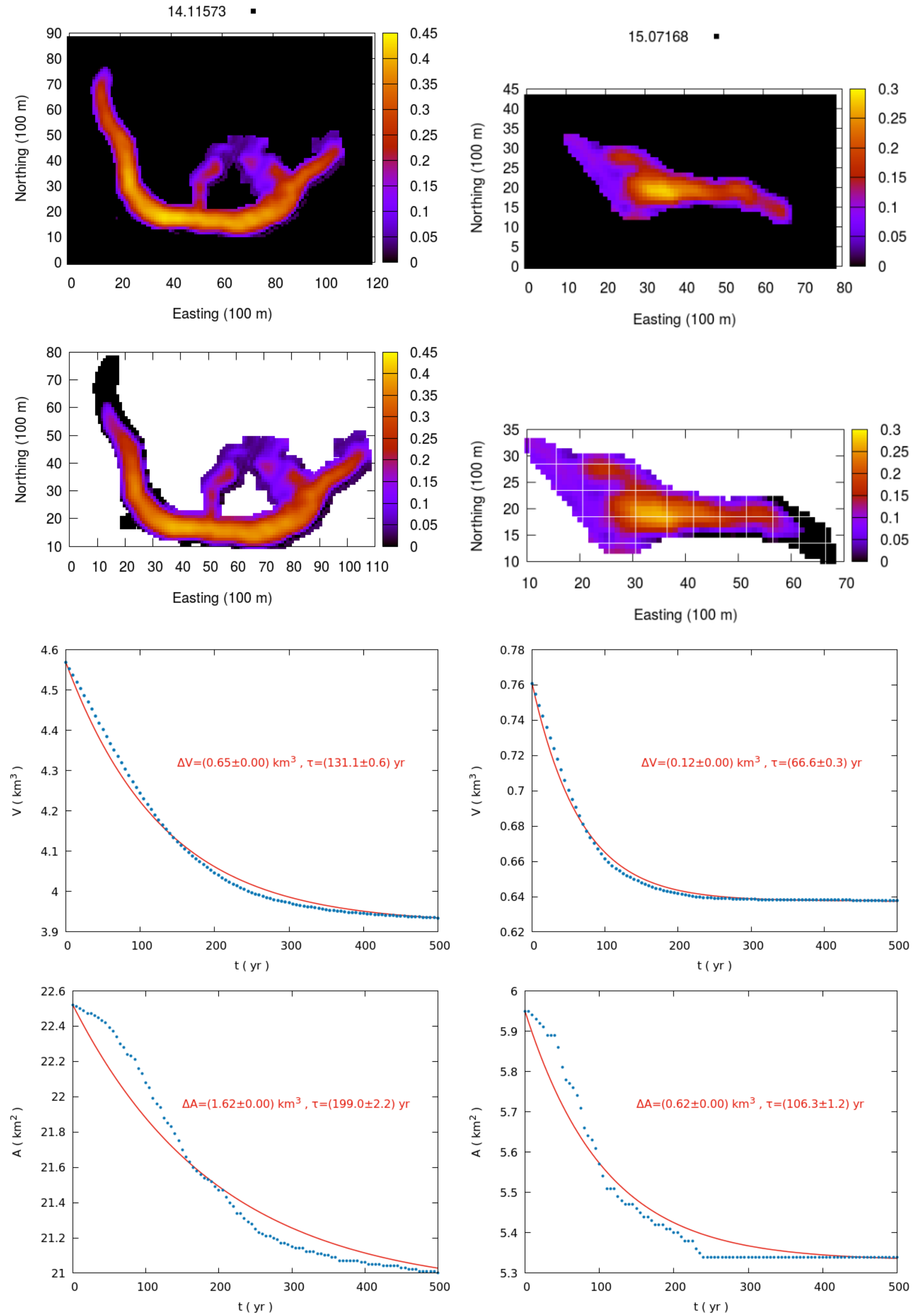

Figure S4: The ice thickness maps of the initial steady states (first row) and transient states at t=500 years (2nd row), and the evolution of volume (3rd row)and area (4th row) are shown for two arbitrary glaciers RGI-ID 14.11573 and RGI-ID 15.07168. The color scale in the top two rows denote ice-thickness in km. Red solid lines in the volume and area plots show the corresponding best-fit exponential decay. The best-fit linear-response parameters are also given. See text for more details.

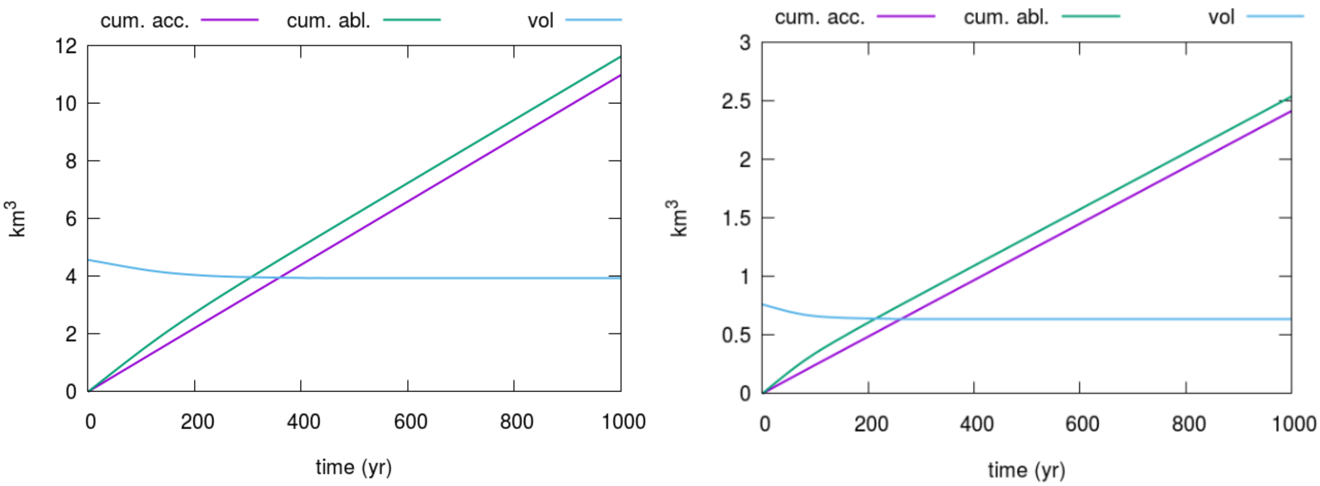

Figure S5: The time series of cumulative accumulation (purple line), cumulative ablation (green line), and total ice in the domain (blue line) after the step-change in ELA on the two glaciers shown in the previous figure: RGI-ID 14.11573 (left), and RGI-ID 15.07168 (right). We have confirmed that the cumulative accumulation minus the cumulative ablation equals the change in stored ice up to an accuracy of 1 parts in 10^9 at any time t.

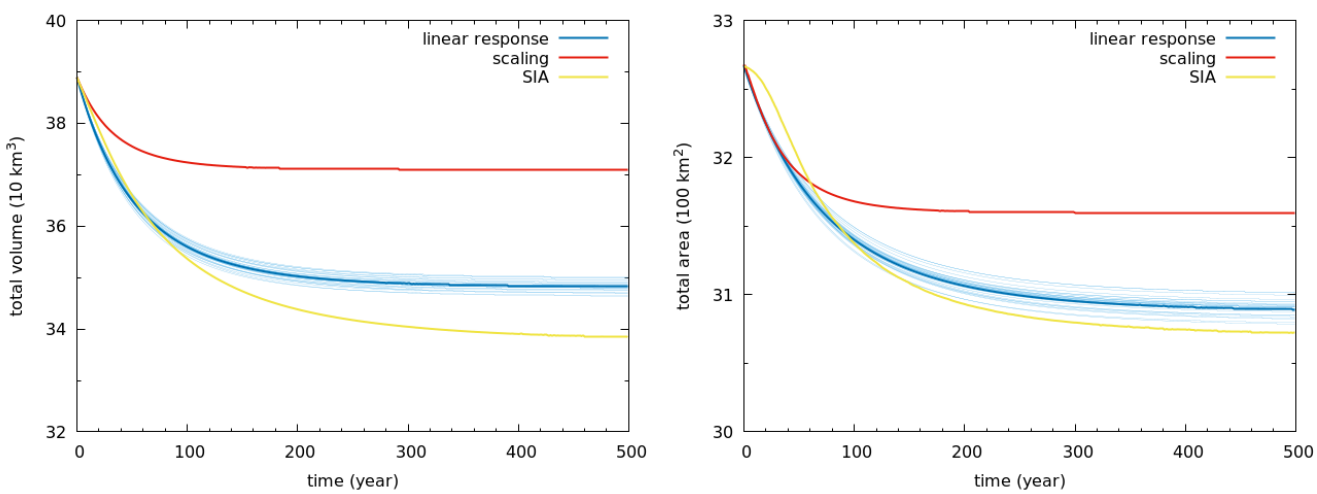

Figure S6: A comparison of the predicted changes in the total volume and area for the central Himalayan glaciers where there was less than 20% volume and area change by 500 years. As expected, for this set of glaciers the match between the SIA and linear-response models is even better than that shown in main fig. 4. See main test for more discussions.

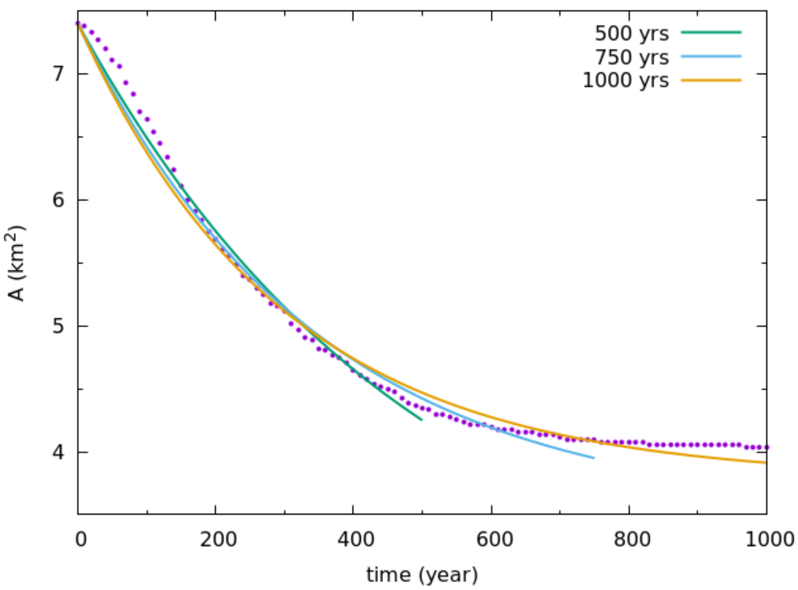

Figure S7: A reliable estimation of τ_A requires the simulation period to be significantly larger than the corresponding response time. Here, the best-fit τ_A values are 493 ± 12, 346 ± 4, and 300 ± 2 years when data of only the first 500, 750 and 1000 years, respectively, are used for fitting. This suggest a systematic overestimation of the response time, when it is comparable to the total simulation period. Accordingly, we only considered glaciers with response time smaller than 500 years in this study.

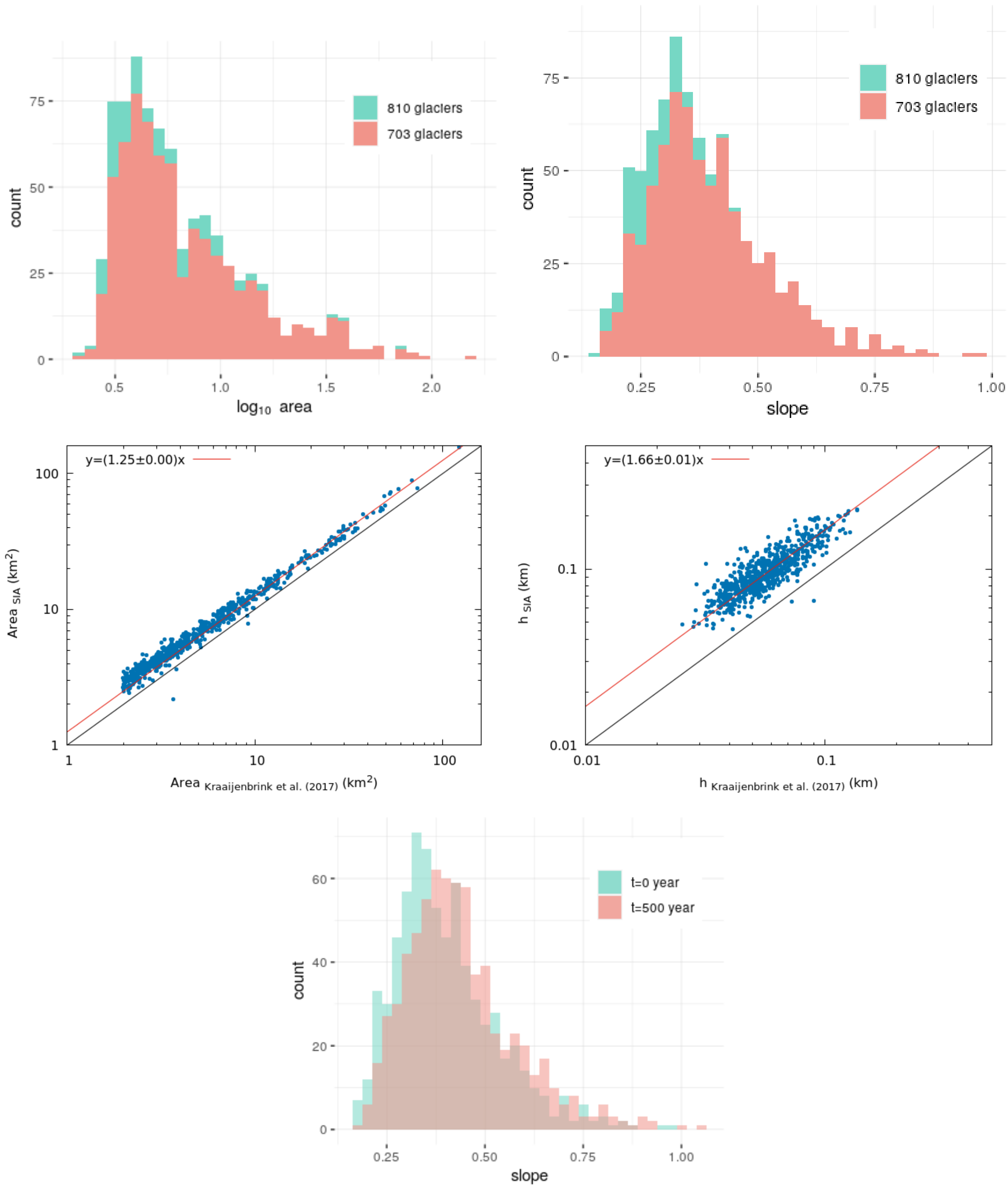

Figure S8: Top row: The frequency distributions of $\log_{10}$(area), and slope for all the 810 simulated glaciers, and that of the selected 703 glaciers in the Gangetic Himalaya are compared. Area is measured in km^2. The similarity between the two distributions confirms that the selected 703 glaciers form a representative set.

Middle row: The modelled area (left) and mean thickness (right) of the 703 steady glaciers as simulated by SIA are compared with corresponding estimates by Kraaijenbrink et al. (2017). Best-fit straight lines (red), and 1:1 lines (black) are also shown. The modelled glaciers have 1.25 times larger area and 1.66 times larger ice thickness on the average.

Bottom: The slope distributions of the 703 glaciers at t=0 and t=500 years indicates a gradual steepening of the glaciers. See main text for discussions.

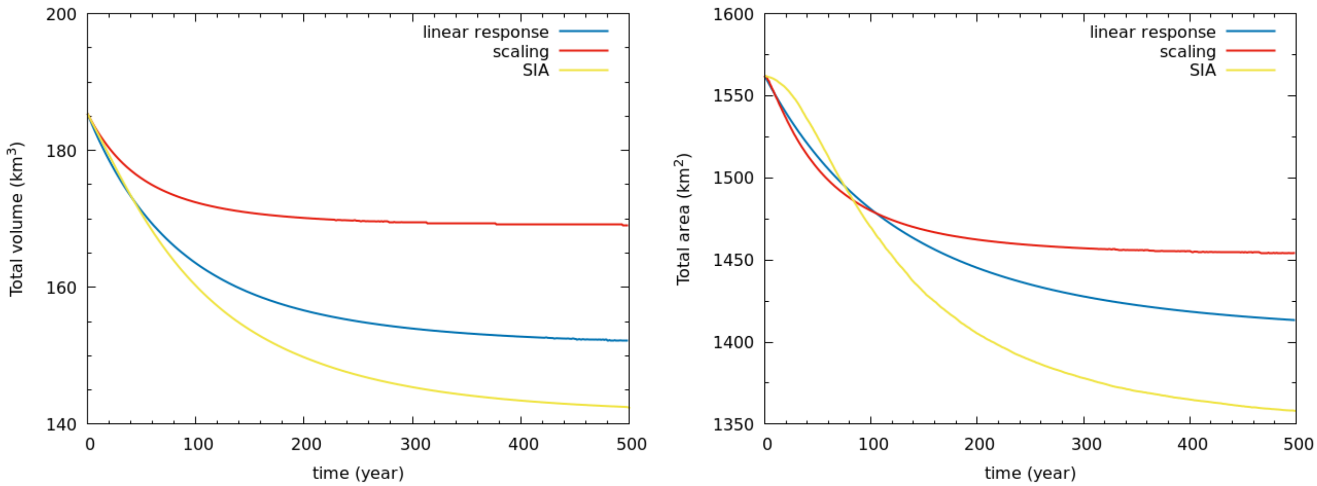

Figure S9: The evolution of the total glacier volume (A), and (B) glacierised area are shown for an ensemble of 164 glaciers from the western Himalaya as simulated by the SIA, scaling, and linear-response models. All the glaciers located within 31°N-33°N and 77°E-79°E, that are larger than 2 km^2, are considered. The modelled area ranges between 2.7 to 134.4 km^2. All other details of the experiment is identical with those for the simulation of 703 central Himalayan glaciers described in the main text.

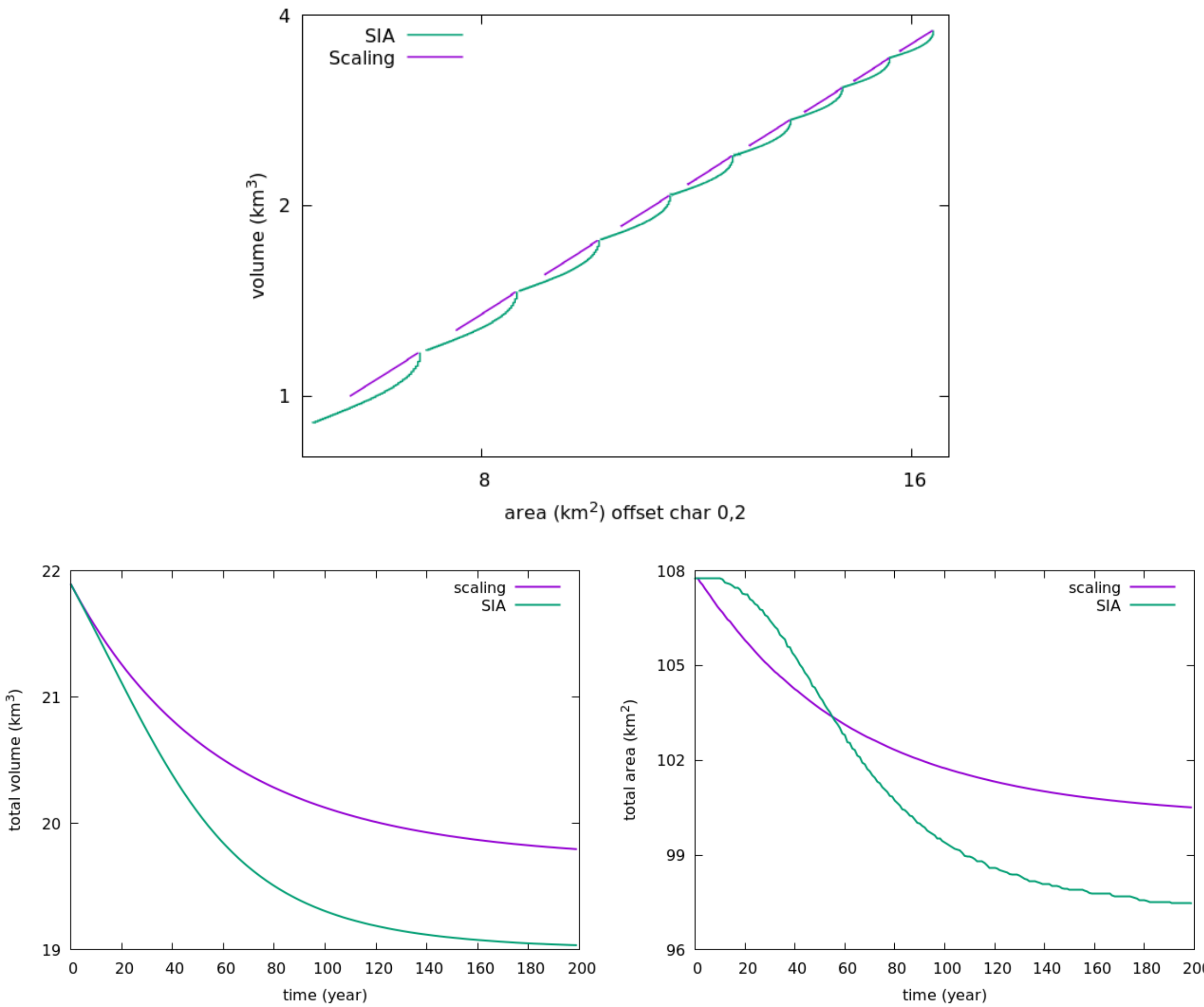

Figure S10: A 50 m step-change in ELA applied to 9 highly idealised steady-state glaciers that have identical linear mass-balance profile ($\beta = 0.007$ yr $^{-1}$), identical linear bedrock (slope=0.1), and the same uniform width. The initial ELA values were 5400, 5450, ..., and 5800 m (separated by 50 m).

Top: $V - A$ trajectories of the transient glaciers simulated with the scaling (purple line) and 1-d SIA (green line) models for 200 years. Just like main fig. 1b, a delayed response of glacier area and a longer area response time in the 1-d SIA model produced curved $V - A$ trajectories. As the SIA-simulated trajectories went below the corresponding scaling model trajectories, the best-fit c reduced for the transient states. However, unlike main fig. 1B, here the initial and final steady states had the same c. Please note that the initial and final steady glaciers contained 7 common states (with ELA of 5450, ..., and 5800 m).

Bottom: The evolution of total volume and area of the 9 glaciers as obtained from the scaling and SIA models with the former model underestimating the long-term changes in total area and volume. Please note the general similarity with main fig. 4.