Supplementary Material: Ambiguous stability of glaciers at bed peaks

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Figures begin next page

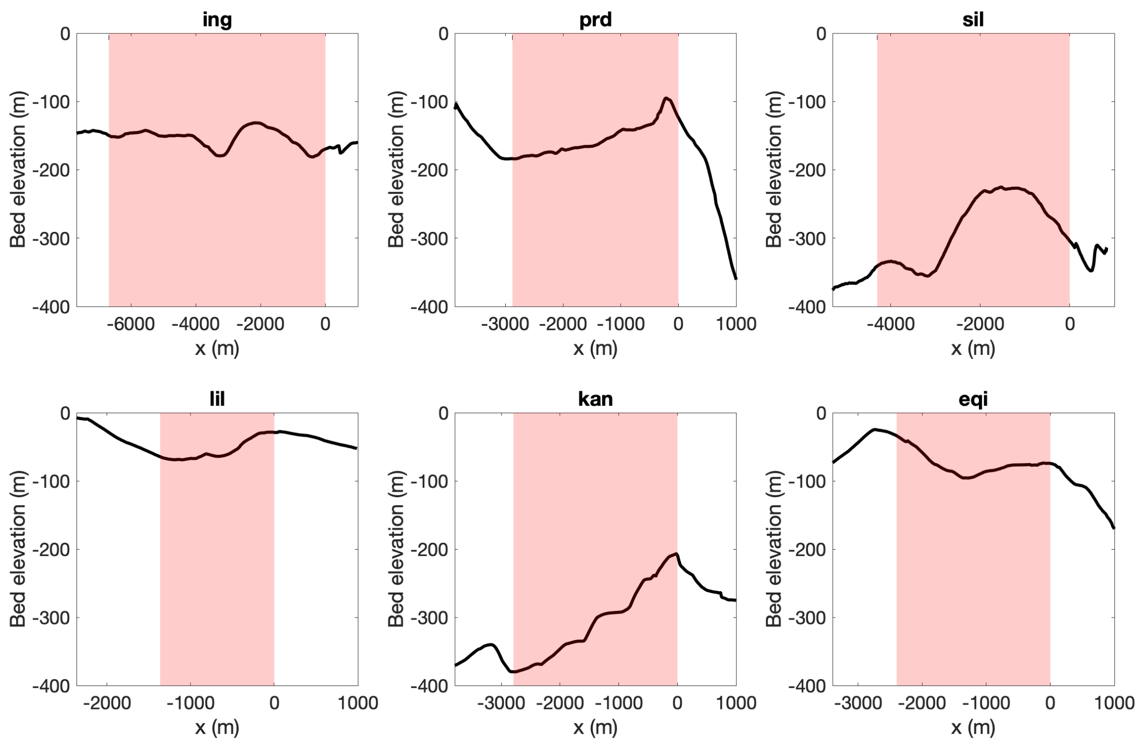

Fig. S1. Bed topography along centerlines of six glaciers in Central West Greenland that experienced retreats greater than 1 km between 1997 and 2016. Extent of retreat is shaded in red. Note that Ingia Isbrae (ING), Perdlerfiup Sermia (PRD), and Sermilik (LIL) were all still retreating at in 2016. Sermeq Silardleq (SIL), Kangilerngata Sermia (KAN), and Eqip Sermia (EQI) had all stopped retreating in 2016 as they reached new bed peaks (seen in bed topography).

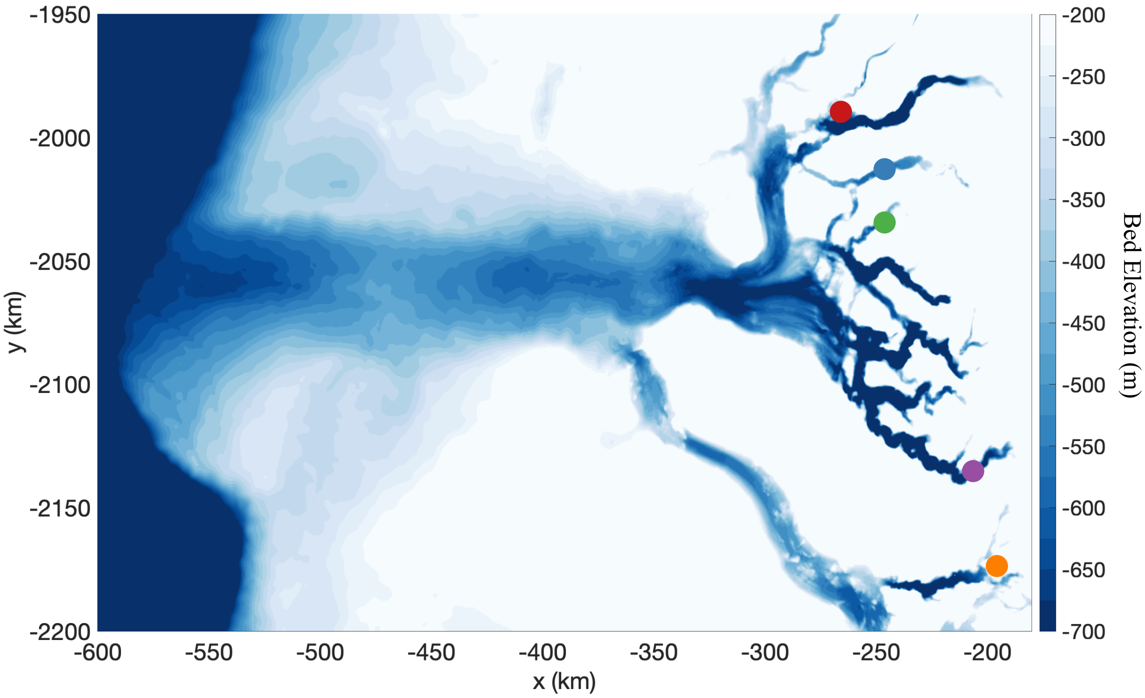

Fig. S2. Bathymetry of Central West Greenland from BedMachine v3 Morlighem and others (2017). The five glaciers highlighted in the main text are indicated by the same colored circles as in Figure 1 of the main text.

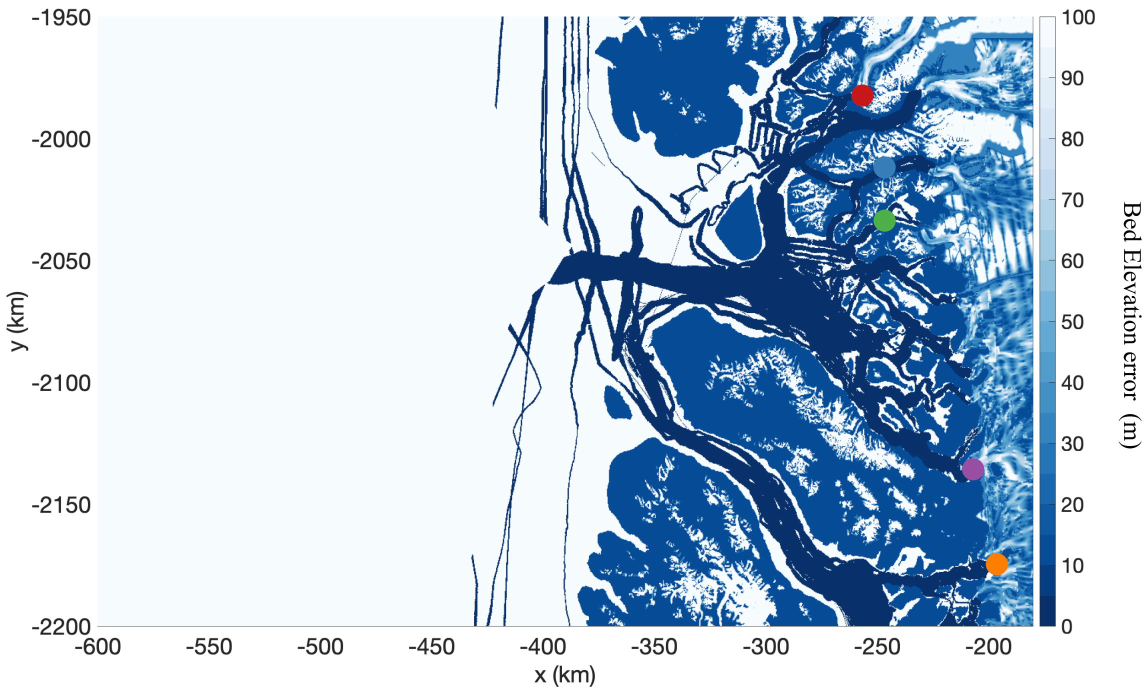

Fig. S3. Error range in bathymetry of Central West Greenland from BedMachine v3 (Morlighem and others, 2017). The five glaciers highlighted in the main text are indicated by the same colored circles as in Figure 1 of the main text.

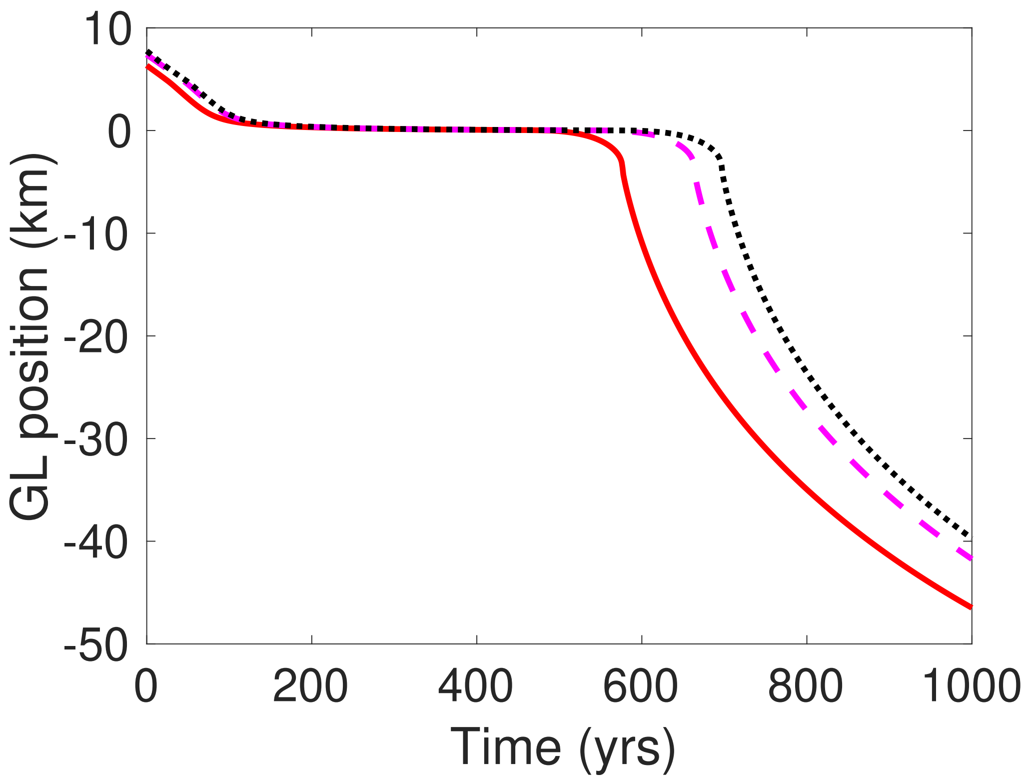

Fig. S4. Transient grounding line evolution in three simulations with different horizontal grid resolutions with bed topographies identical to the red lines in simulations plotted in Figures 3 and 4 (b_x = .004). Red solid line has grounding line horizontal resolution of 200 m. Magenta dashed line has grounding line horizontal resolution of 100 m. Black dotted line has grounding line horizontal resolution of 75 m.

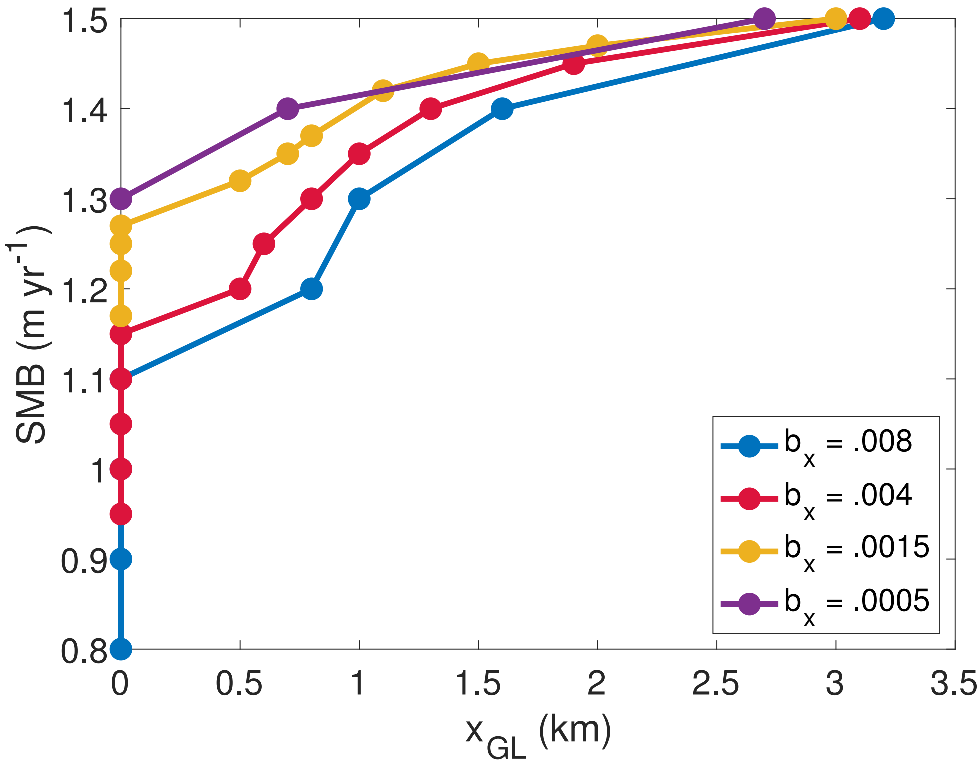

Fig. S5. Stable grounding line positions in Elmer/Ice Full Stokes simulations (along a flowline) of grounding line retreat over sharp bed peaks located at $x = 0$ on the x-axis. Bed topographies are identical to those used in simulations plotted in Figure 3. Horizontal resolution is 100 meters throughout the domain. Simulations are variants on the the Elmer/Ice MISMIP benchmark simulations.

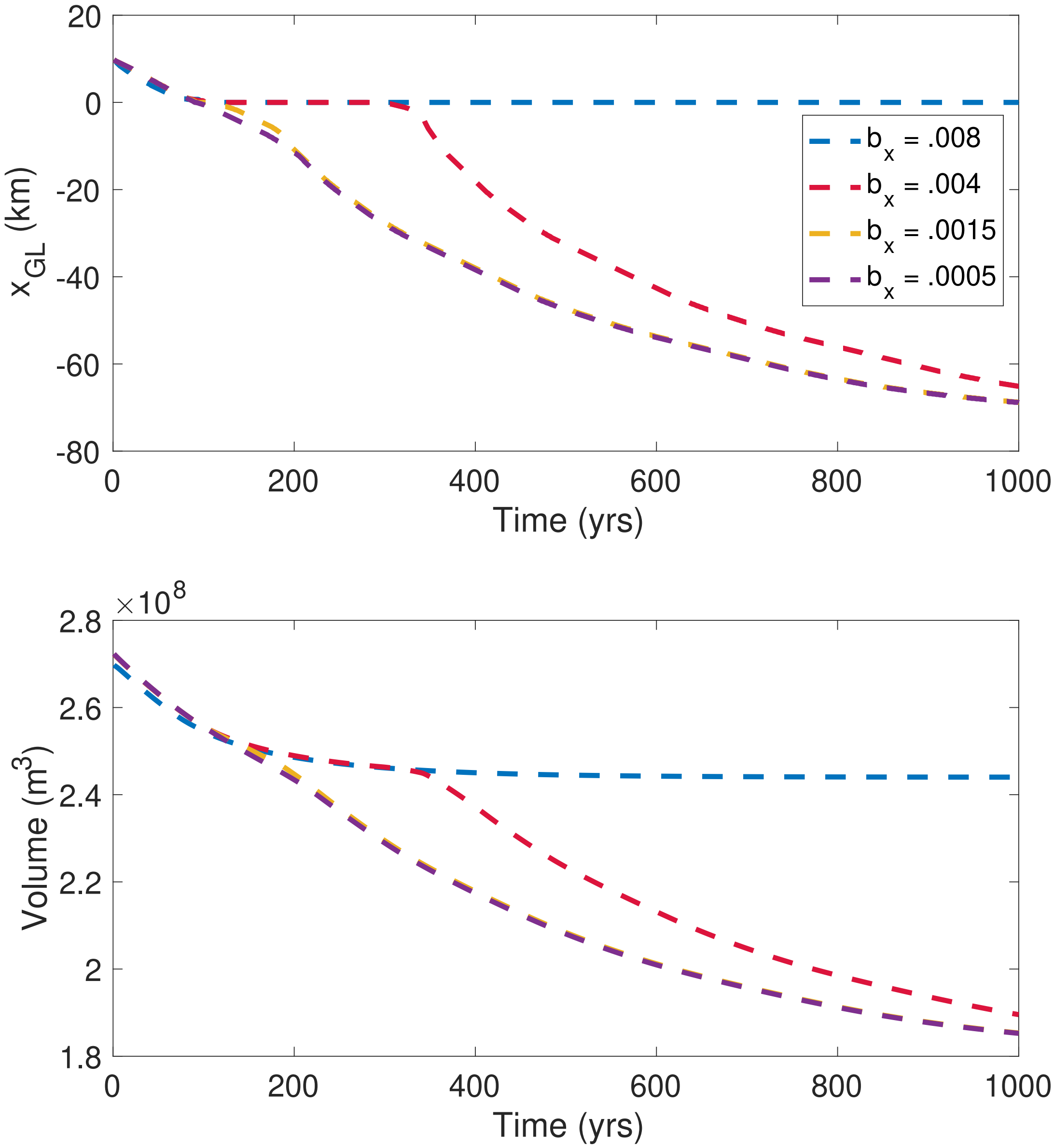

Fig. S6. Transient grounding line (top panel) and glacier volume (bottom panel) evolution in Elmer/Ice Full Stokes simulations of retreat over sharp bed peaks (simulated along a flowline). Bed topographies are identical to those used in simulations plotted in Figure 4. Due to small quantitative differences in steady-state grounding line positions in full stokes simulations, initial SMB is set to 1.5 m yr^{-1} (compared to 1.1 m yr^{-1} in SSA simulations) and then reduced by 40% at beginning of simulation, as in the SSA simulations). Horizontal resolution is 100 meters throughout the domain.

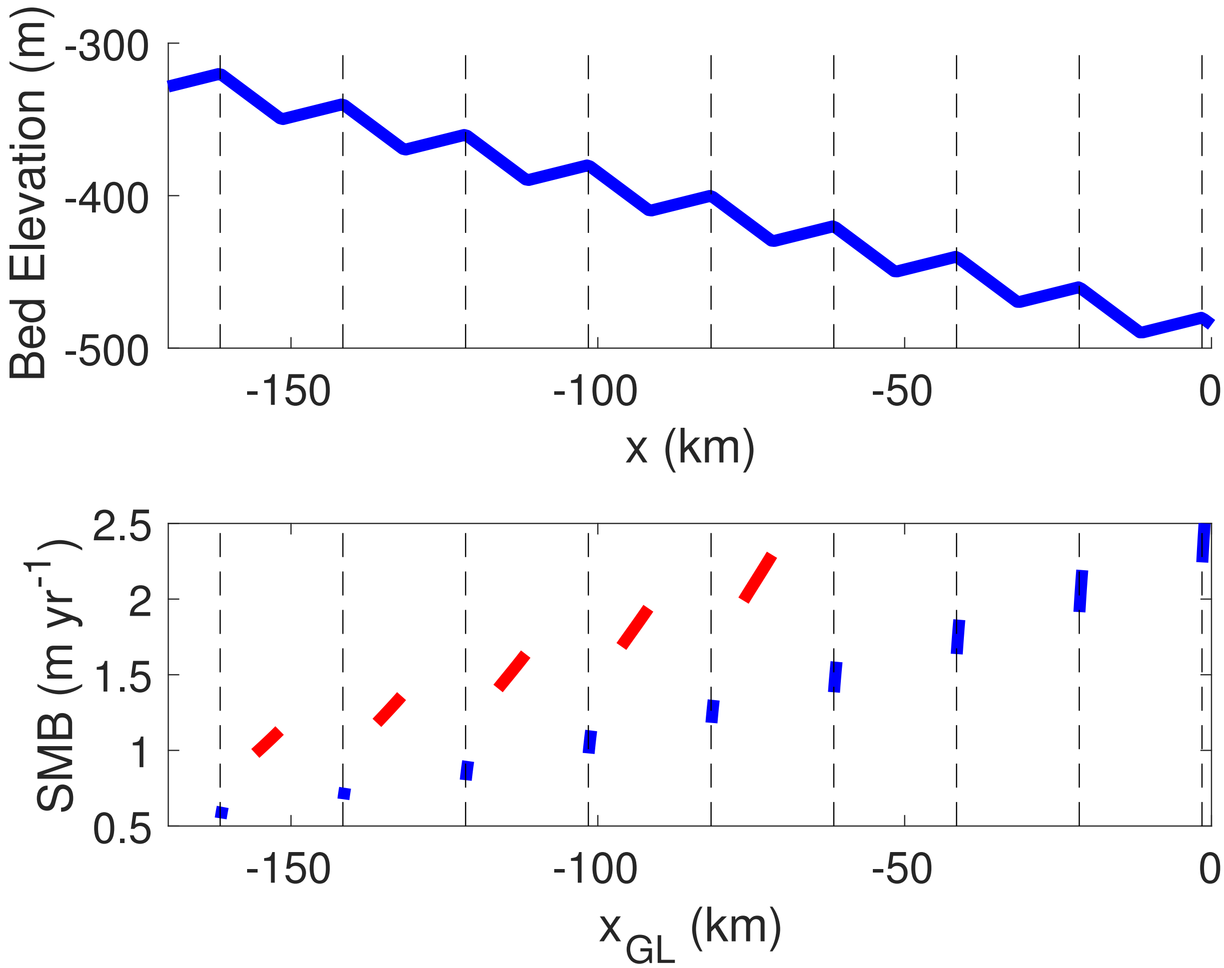

Fig. S7. Steady-state grounding line positions over a range of surface mass balance (panel b) on a corrugated bed with many bed peaks (panel a). Bed peaks are indicated with black dashed lines. Blue lines are steady-states on retreat and red lines are steady-states on advance.

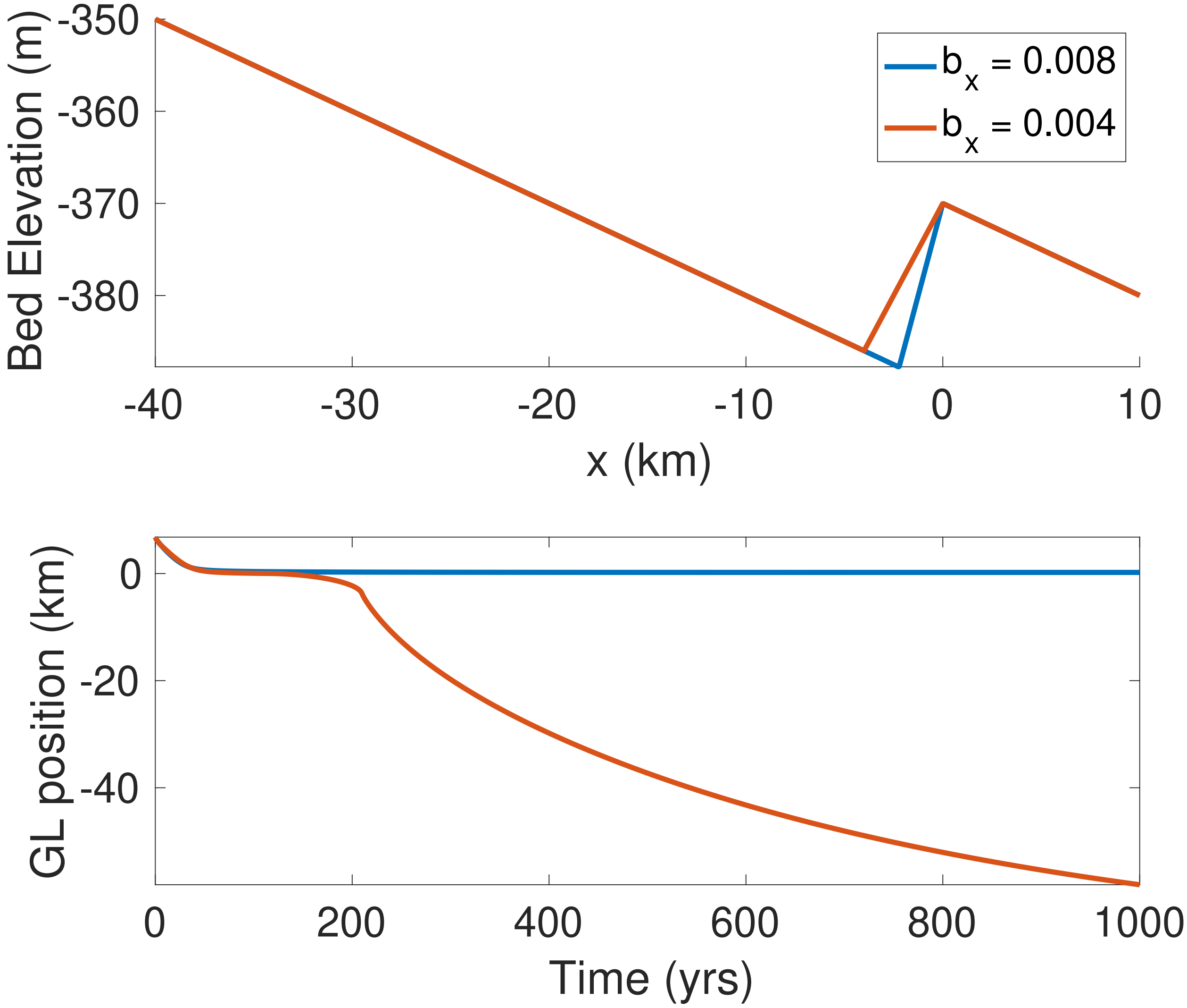

Fig. S8. Comparison between simulated transient persistence and retreat over bed peaks with different upstream bed slope under changing ocean forcing. Simulations are the transient response to a step change from zero ocean melting to 50 m yr^{-1} basal melt rate at the terminus. Submarine ocean melt is imposed as a basal melt rate at the node corresponding to the grounding line. The idealized bed topographies here correspond to the two steepest bed peaks plotted in Figures 3 and 4.

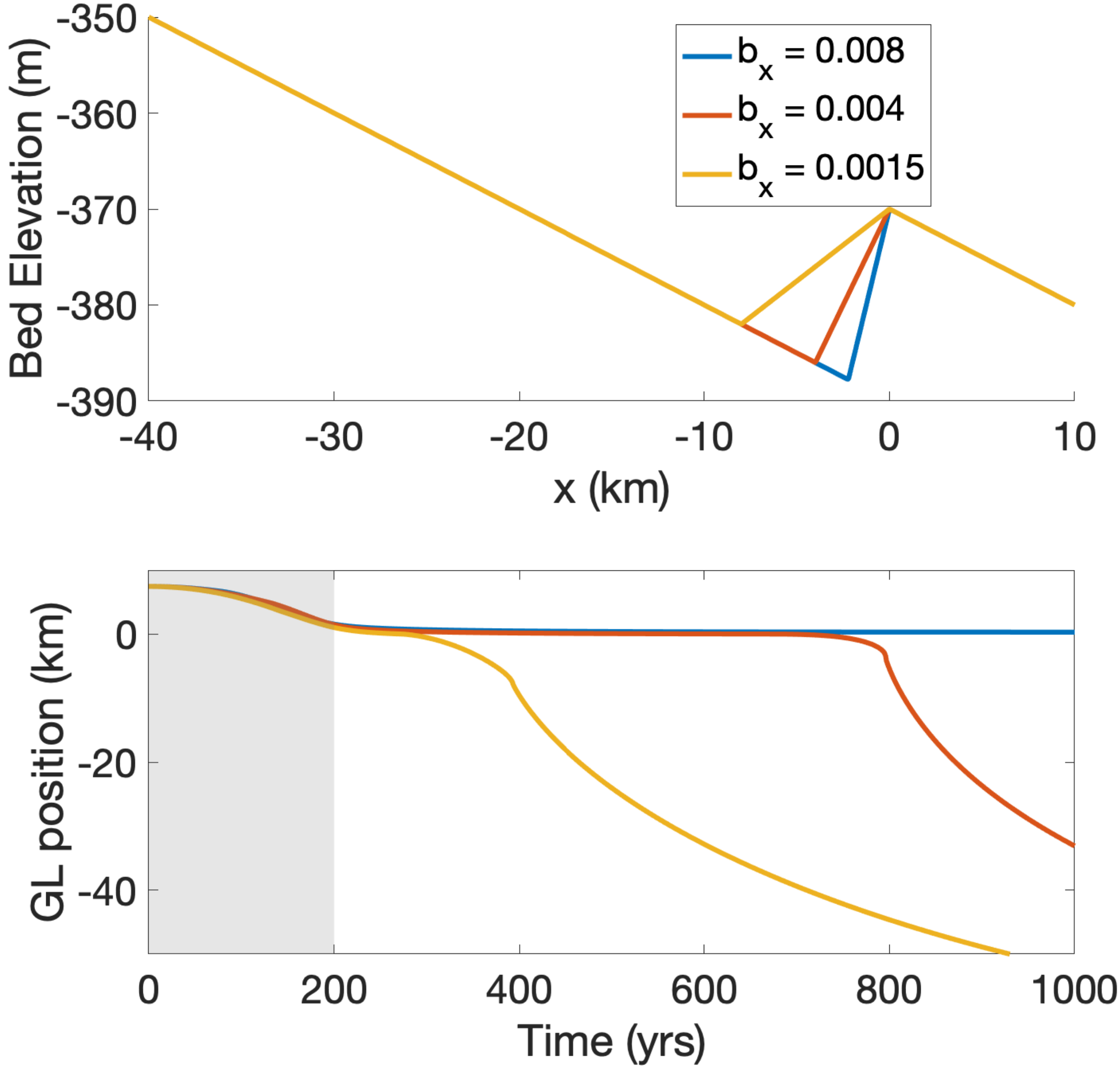

Fig. S9. Comparison between simulated transient persistence and retreat over bed peaks with different upstream bed slope. Simulations are the transient response to a linear trend in SMB over the first 200 years of the simulation. The total change in SMB (40% of initial value) is the same as in the simulations plotted in Figure 4. The idealized bed topographies here correspond to the three steepest bed peaks plotted in Fig. 2a. It can be noted that though the timing of retreat is slightly delayed (presumably due to the slower forcing), the qualitative behavior of the transient persistence at bed peaks is unchanged.

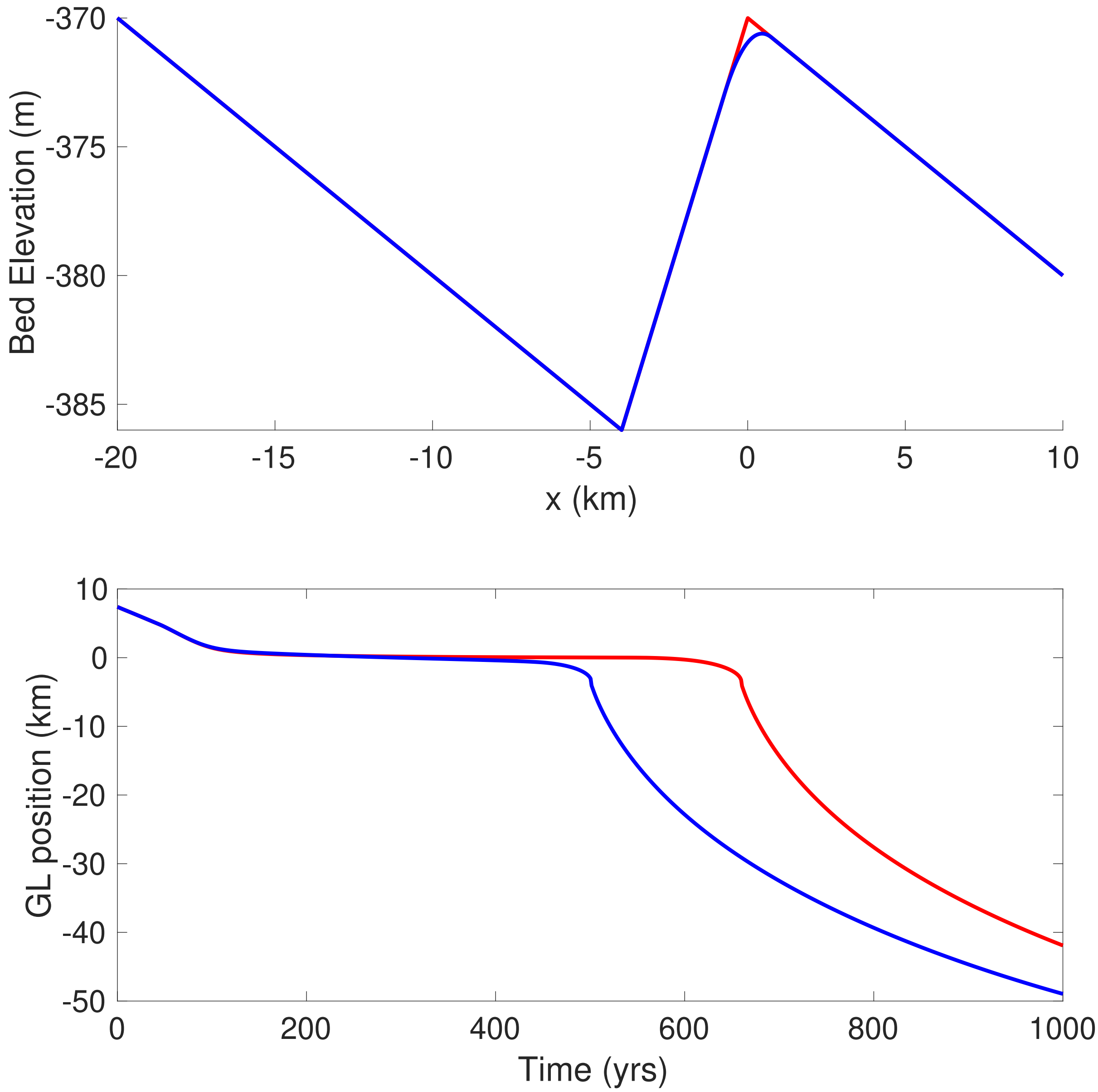

Fig. S10. Comparison between simulated transient persistence and retreat over bed peaks. Red line is the same simulation as the red line in Figure 4 in main text. Blue line is with bed peak smoothed over 1 km moving window, which also lowers the peak by approximately 1 meter and moves its lateral position seaward by several hundred meters. Multi-centennial persistence still occurs, though onset of rapid retreat is slightly early due to lower and further seaward bed peak.

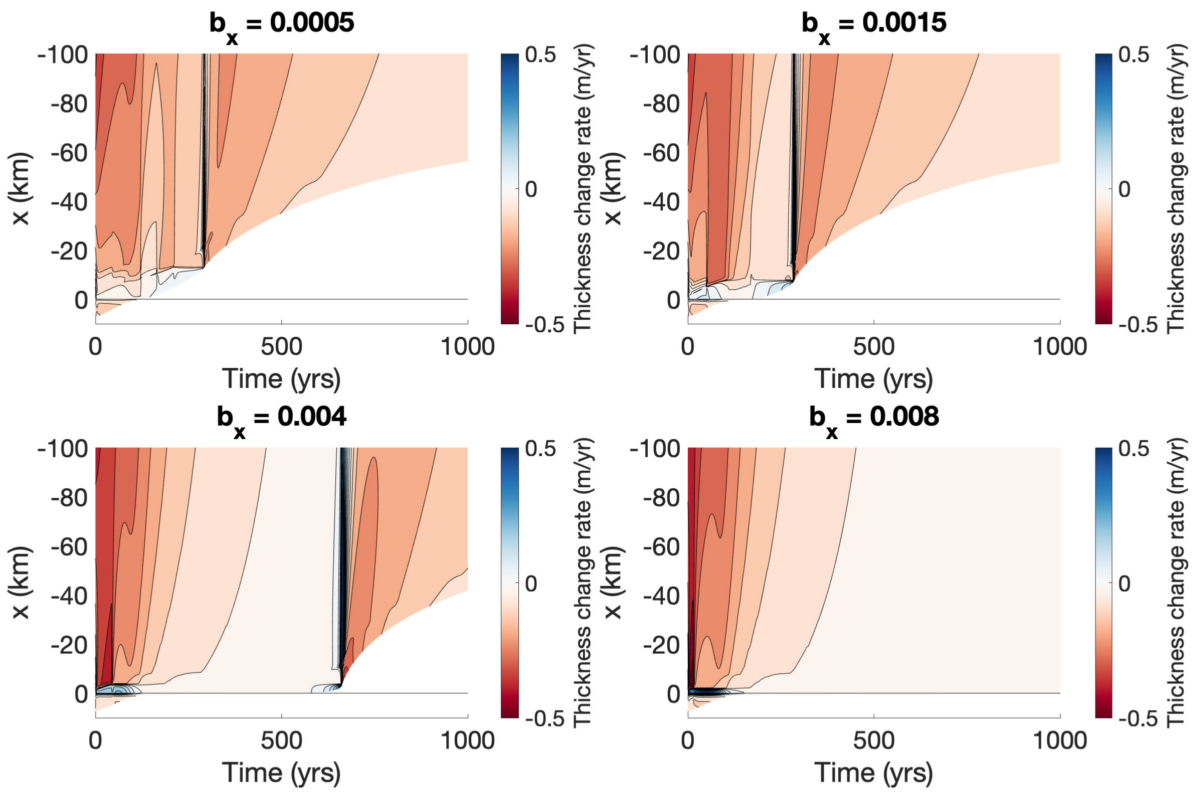

Fig. S11. Rate of change of thickness in transient simulations plotted in Figure 4 in main text. x-axis is time and y-axis is the along-stream distance relative to the terminus, where negative values are upstream.

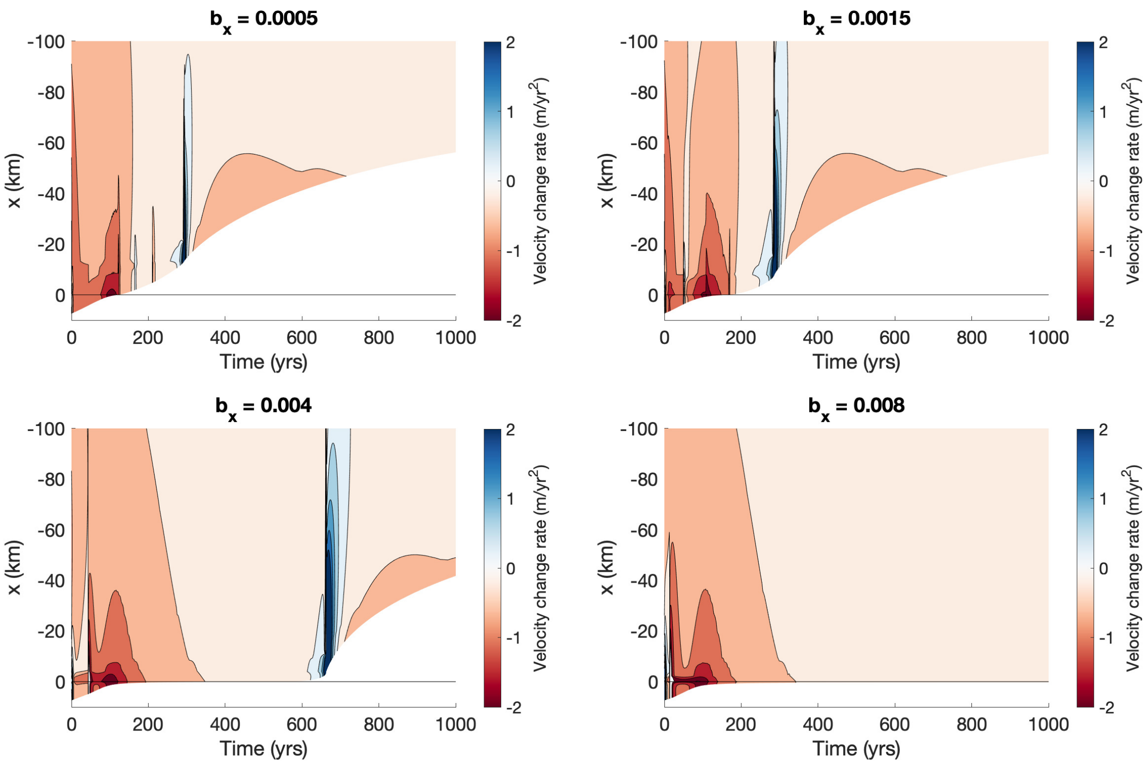

Fig. S12. Rate of change of ice velocity in transient simulations plotted in Figure 4 in main text. x-axis is time and y-axis is the along-stream distance relative to the terminus, where negative values are upstream.

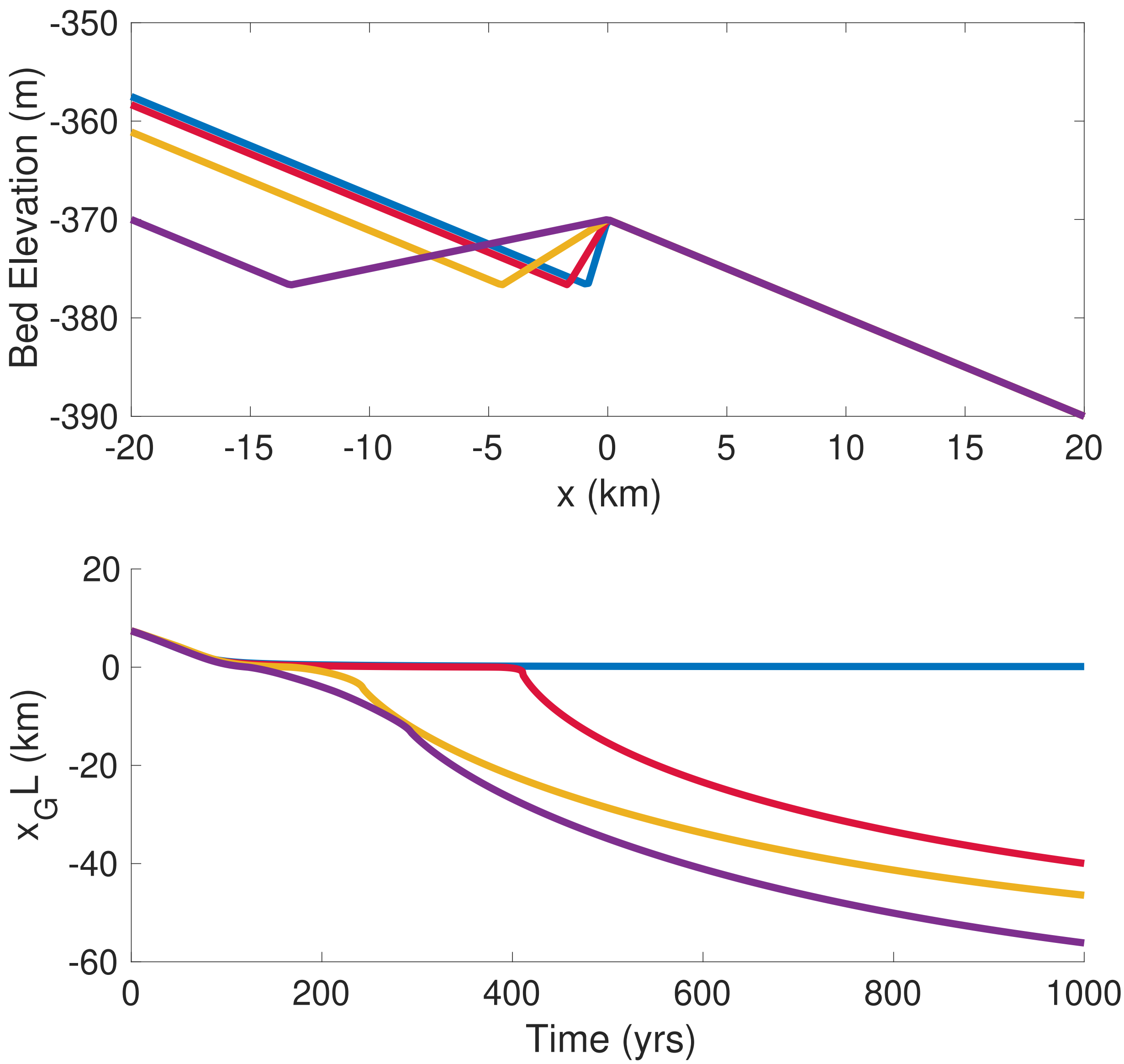

Fig. S13. Transient simulations of glacier retreat with all parameters and model configurations the same as in Figure 4 of the main text, except bed peaks are constrained to be the same height from bottom to top. There are some expected quantitative differences with the timing of retreat. However, the qualitative conclusion of the study is confirmed in these simulations, where the stability and persistence of a glacier at the bed peak is mainly dependent on the slope of the bed just upstream of the bed peak.

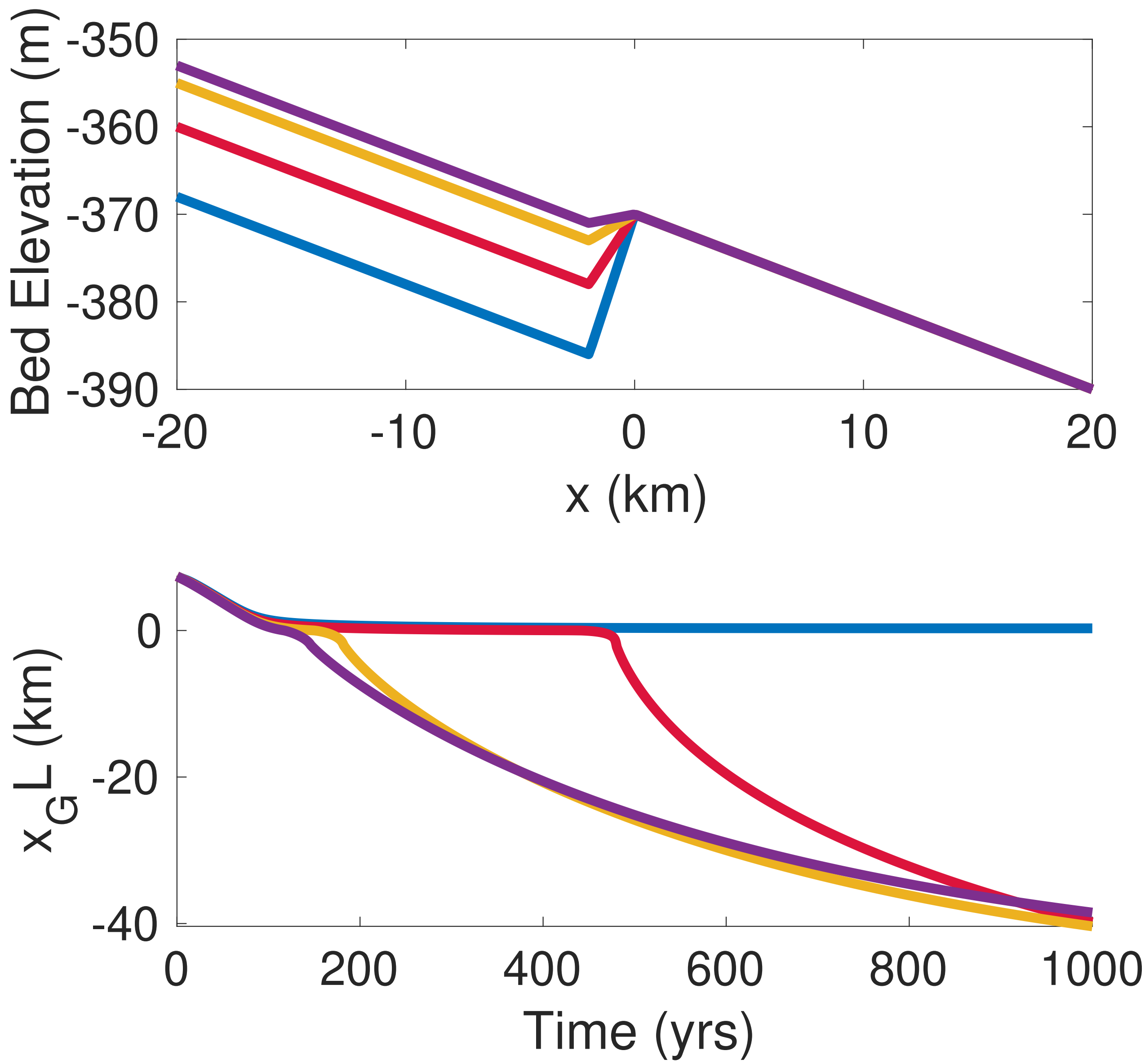

Fig. S14. Transient simulations of glacier retreat with all parameters and model configurations the same as in Figure 4 of the main text, except bed peaks are constrained to be the same width from peak to trough. There are some expected quantitative differences with the timing of retreat. However, the qualitative conclusion of the study is confirmed in these simulations, where the stability and persistence of a glacier at the bed peak is mainly dependent on the slope of the bed just upstream of the bed peak.

REFERENCES

Morlighem M, Williams CN, Rignot E, An L, Arndt JE, Bamber JL, Catania G, Chauché N, Dowdeswell JA, Dorschel B and others (2017) Bedmachine v3: Complete bed topography and ocean bathymetry mapping of Greenland from multibeam echo sounding combined with mass conservation. *Geophysical Research Letters*, **44**(21), 11051–11061 (doi: 10.1002/2017GL074954)