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NERC SCIENCE OF THE ENVIRONMENT

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# Accelerating recent mass loss from debris-covered Khumbu Glacier, Nepal, and projected response to climate change by 2200 CE

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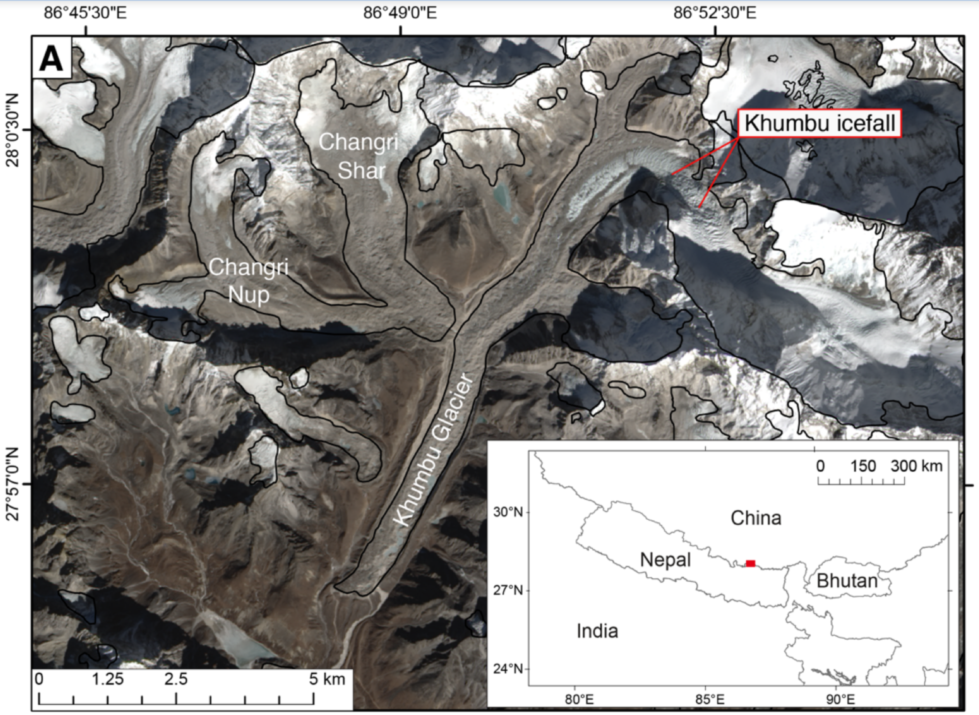
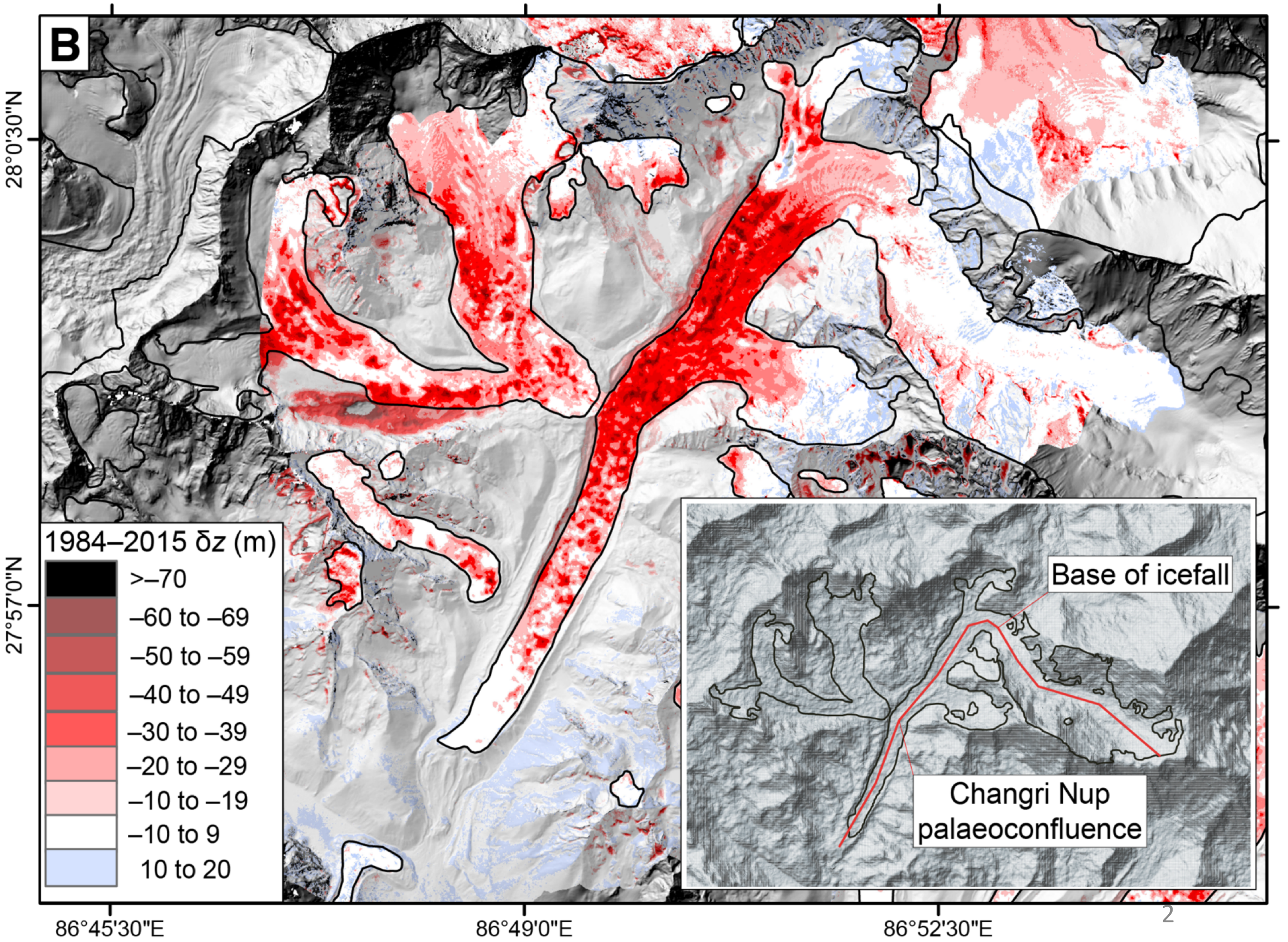
# Khumbu Glacier, Nepal: Observed surface elevation change 1984–2015 CE




Khumbu Glacier [A] is a large, debris-covered glacier in the Everest region of Nepal. Supraglacial debris is typically metres in thickness and acts to suppress ablation from the glacier tongue.

[B] Surface elevation change from DEMs of Difference generated from satellite imagery indicate rapid, and accelerating, ice volume loss from the upper ablation area.

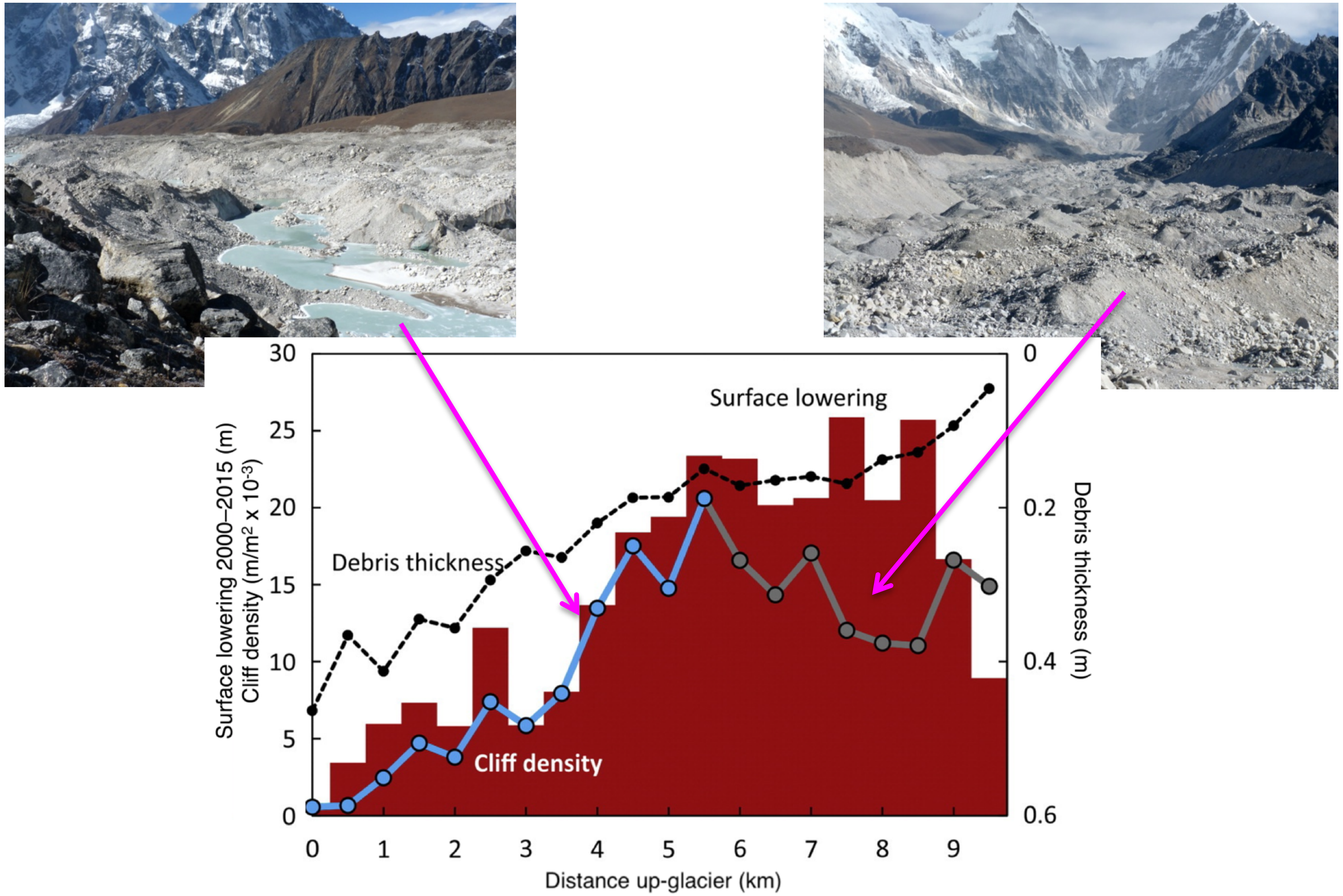


# Supraglacial and englacial processes enhance mass loss

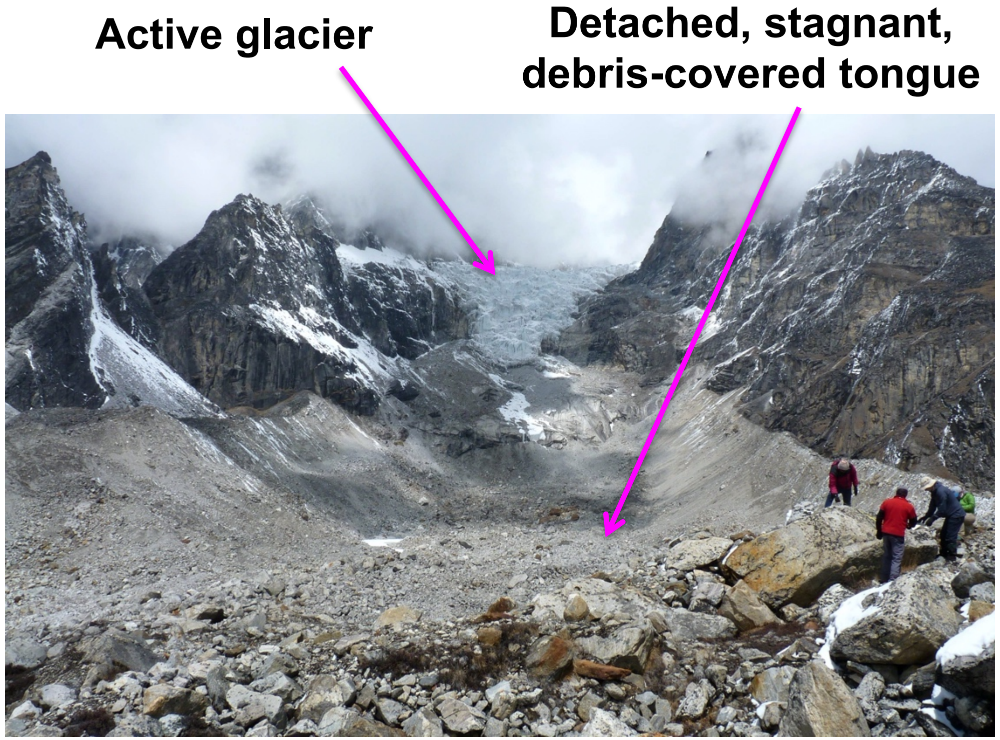
**A debris-covered anomaly? (Pellicciotti et al. 2015, *JGlacio*)** Debris-covered glaciers in High Mountain Asia are losing mass more rapidly than expected as climate warms, but the glaciological processes driving this change are not fully understood.

Images of Khumbu Glacier showing [above] lower section of ablation area where velocities are very low and surface change is slower, and [right] looking upglacier into region of most rapid surface elevation change where topographic inversion occurs.

# Impact of surface processes and glacier dynamics on response to climate change



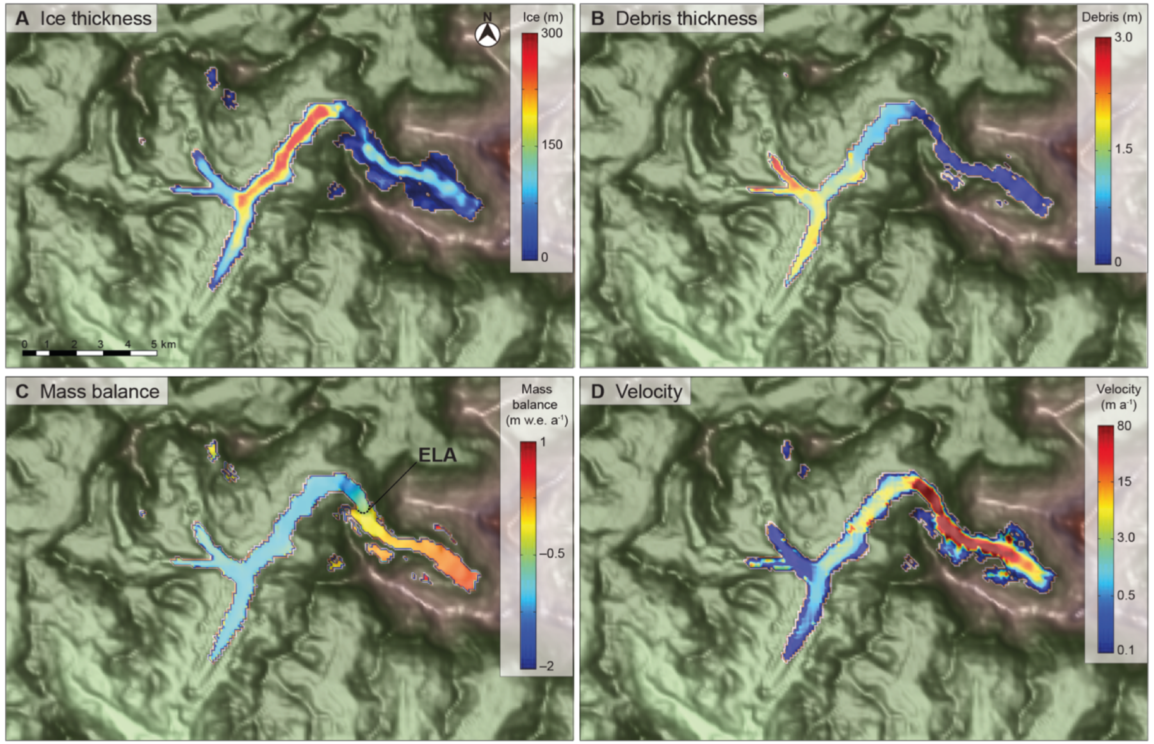

Physical detachment of the debris-covered tongue from the upper active glacier is expected to occur within 150 years after present day (Rowan et al., 2015, *EPSL*), and has already occurred for many other glaciers in Nepal, such as Lobuche Glacier.




Lobuche Glacier, Khumbu valley

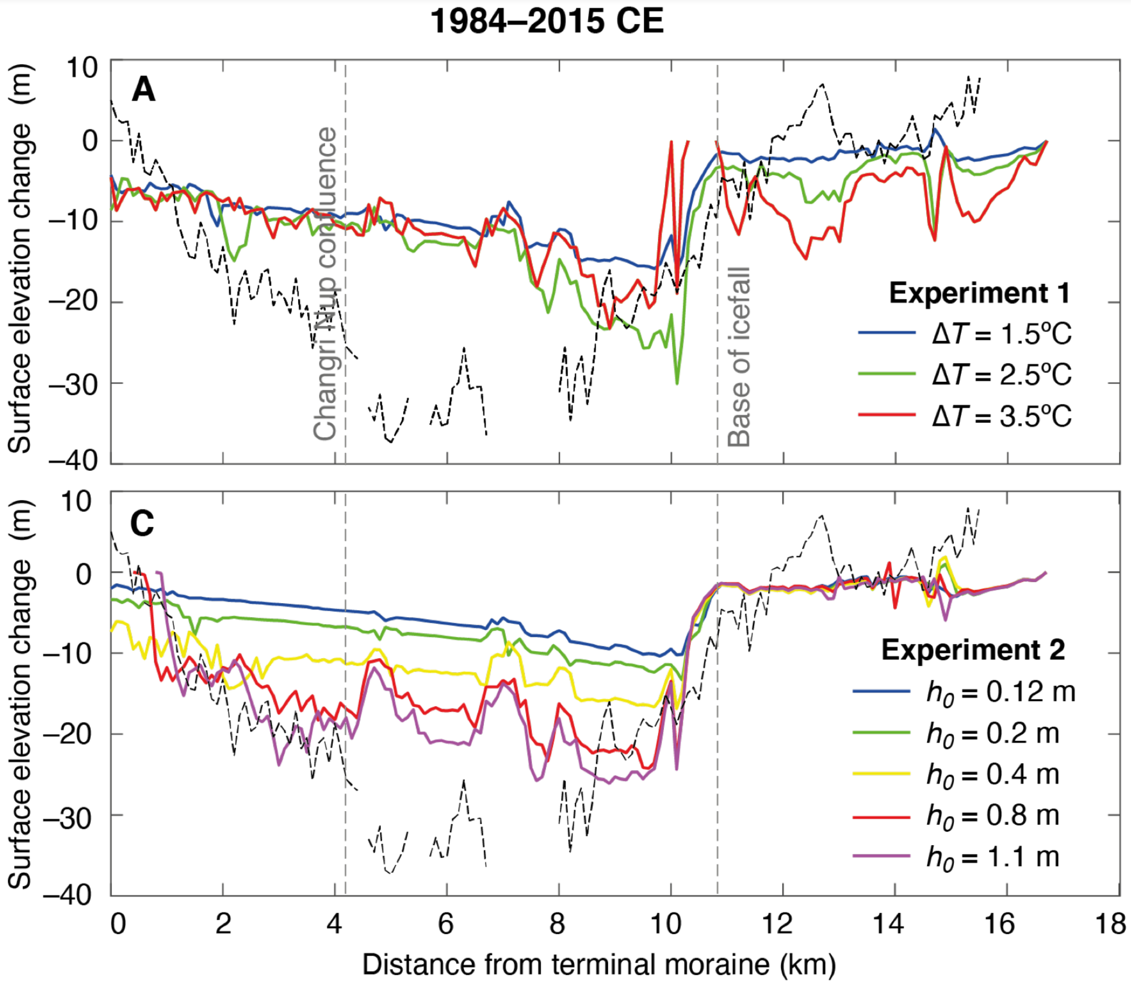
Glacier-wide mass loss is enhanced at ablation "hotspots" (e.g. ice cliffs, supraglacial ponds). But, cliff density does not correlate with surface lowering where mass loss is greatest in the upper ablation area (Watson et al., 2017, *Geomorph.*)

# Simulation of glacier change due to differential ablation processes



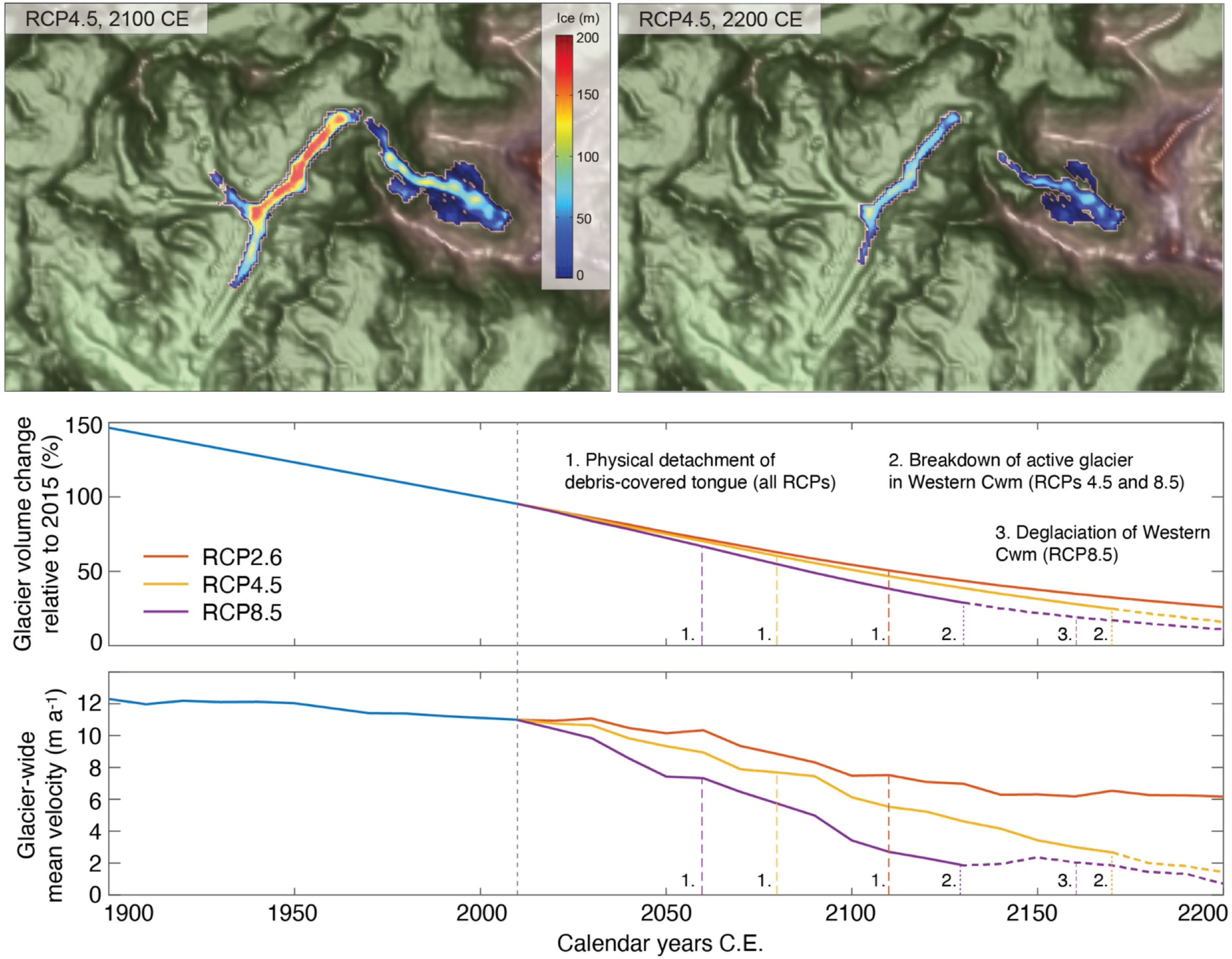

Parameterising our ice flow model iSOSIA (Egholm et al., 2012, *Geomorph*.; Rowan et al. 2015, *EPSL*) that captures the feedbacks between ice flow, debris transport and mass balance using a reciprocal function that represents different distributions of debris thickness.

A positively skewed distribution ($h_0$ = 0.8 and 1.1) gives a better fit to observed change than any other distribution (uniform, normal, negatively skewed).




Simulated surface elevation change compared to observed values for 1984–2015 CE (black lines). **Exp. 1** assuming an exponential relationship between sub-debris melt and cell-averaged debris thickness forced by change in MAAT. **Exp. 2** using a range of debris thickness distributions represented by $h_0$ and no change in MAAT.

# Acceleration in ice volume loss and future change by 2200 CE




Our optimal simulation of differential ablation using a positively skewed distribution ($h_0$ = 1.1) using data from Ngozumpa Glacier (Nicholson and Mertes, 2017, *JGlacio*) captures 79% of the observed surface elevation change between 1984–2015 CE.

The remaining volume change can be attributed to several processes, particularly decreasing ice mass flux from the upper active glacier to the debris-covered ablation area. Mass loss appears to have accelerated over the last 15 years compared to the last 31 years.

Under RCP4.5 (a moderate future warming scenario), **Khumbu Glacier is projected to lose at least 46% of ice volume by 2100 CE and 83% by 2200 CE**.

Physical detachment of the debris-covered tongue from the upper active section will occur before the end of the century, followed by dynamic shutdown that causes the death of this iconic glacier by 2170 CE.