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Supplement of

Quantifying ice loss in the eastern Himalayas since 1974 using declassified spy satellite imagery

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Supplement

Table S1. Vertical accuracy statistics[a] of Hexagon DEMs relative to the 2006 ASTER DEM (meters)

ID	Lon	Lat[b]	$RMSE_z$	Mean	Median	NMAD[c]	STD	68.3%Q	95%Q
1	90.05	28.25	8.1	0.5	0.7	6.4	8.1	6.8	15.9
2	90.26	28.24	8.6	1.2	1.3	7.3	8.5	7.5	15.6
3	89.97	28.09	11.5	1.4	1.4	8.7	11.5	9.4	22.5
4	90.12	28.10	11.6	0.7	0.8	9.2	11.6	9.8	21.9
5	90.27	28.08	12.8	0.6	1.0	8.7	12.8	9.4	24.4
6	90.42	28.14	14.9	1.6	1.5	11.6	14.8	12.7	30.3
7	90.73	28.05	8.9	0.1	0.6	6.6	8.9	7.0	17.8
8	90.66	28.25	11.8	0.4	1.1	8.9	11.8	9.5	22.5

[a] Over assumed stable terrain (i.e. excluding glaciers). [b] Center of each Hexagon DEM region.
[c] Normalized median absolute deviation. [d] Hole interpolation max area (km^2).

Table S2. Glacier Change Statistics

Glacier ID	a	b	c	d	e	f	g
Longitude (deg)	89.99	90.04	90.25	89.99	90.07	90.15	90.21
Latitude (deg)	28.21	28.18	28.19	28.16	28.14	28.16	28.13
Mean Elevation (m)	5710	5712	6183	4940	4565	4853	5012
1974 Area (km^2)	13.4 ± 1.3	25.0 ± 2.5	86.2 ± 8.6	23.5 ± 2.3	8.8 ± 0.9	30.1 ± 3.0	5.4 ± 0.5
ΔV (km^3)	-0.08 ± 0.03	-0.29 ± 0.07	-0.26 ± 0.31	-0.14 ± 0.06	-0.09 ± 0.03	-0.17 ± 0.09	-0.03 ± 0.03
ΔV_{extrap} (km^3)	-0.05 ± 0.03	-0.27 ± 0.07	0.09 ± 0.31	-0.20 ± 0.06	-0.09 ± 0.03	-0.18 ± 0.09	-0.03 ± 0.03
$\bar{h}$ (m)	-5.6 ± 2.2	-12.0 ± 3.2	-3.0 ± 3.6	-6.1 ± 2.5	-10.3 ± 4.0	-5.5 ± 2.9	-5.2 ± 5.9
$\dot{b}$ (m.w.e.)	-0.15 ± 0.06	-0.32 ± 0.09	-0.08 ± 0.10	-0.16 ± 0.07	-0.27 ± 0.11	-0.15 ± 0.08	-0.14 ± 0.16
Data coverage (%)	39	48	28	49	100	68	100
Debris coverage (%)	1	6	3	41	37	44	16
Calving (y/n)	n	y	n	n	n	n	y

Glacier ID	h	i	j	k	l	m	n
Longitude (deg)	90.27	90.33	90.35	90.39	90.47	90.7	90.75
Latitude (deg)	28.13	28.11	28.09	28.1	28.08	28.06	28.04
Mean Elevation (m)	5486	5151	5154	5749	6133	5505	5450
1974 Area (km^2)	13.8 ± 1.4	6.1 ± 0.6	5.0 ± 0.5	49.8 ± 5.0	29.7 ± 3.0	5.7 ± 0.6	9.2 ± 0.9
ΔV (km^3)	-0.12 ± 0.08	-0.10 ± 0.03	-0.04 ± 0.02	-0.52 ± 0.13	-0.02 ± 0.13	-0.02 ± 0.02	-0.08 ± 0.03
ΔV_{extrap} (km^3)	-0.16 ± 0.08	-0.10 ± 0.03	-0.08 ± 0.02	-0.45 ± 0.13	0.07 ± 0.13	-0.02 ± 0.02	-0.09 ± 0.03
$\bar{h}$ (m)	-8.5 ± 5.7	-18.3 ± 6.0	-8.7 ± 4.8	-10.7 ± 2.8	-0.6 ± 4.3	-4.4 ± 3.3	-8.4 ± 3.1
$\dot{b}$ (m.w.e.)	-0.23 ± 0.15	-0.48 ± 0.16	-0.23 ± 0.13	-0.28 ± 0.08	-0.02 ± 0.11	-0.12 ± 0.09	-0.22 ± 0.08
Data coverage (%)	30	100	58	54	26	60	76
Debris coverage (%)	17	11	10	11	14	1	1
Calving (y/n)	y	y	n	n	n	n	y

Glacier ID	o	p	q	r	s	t	u
Longitude (deg)	90.79	90.78	90.62	90.66	90.68	90.63	90.67
Latitude (deg)	28.03	28.06	28.21	28.24	28.26	28.25	28.29
Mean Elevation (m)	5216	5540	5342	5139	5304	6034	5602
1974 Area (km^2)	5.7 ± 0.6	9.1 ± 0.9	3.1 ± 0.3	12.5 ± 1.3	6.5 ± 0.7	9.8 ± 1.0	10.2 ± 1.0
ΔV (km^3)	-0.04 ± 0.02	-0.09 ± 0.02	-0.04 ± 0.02	-0.11 ± 0.04	-0.03 ± 0.03	-0.03 ± 0.03	-0.04 ± 0.03
ΔV_{extrap} (km^3)	-0.07 ± 0.02	-0.12 ± 0.02	-0.04 ± 0.02	-0.11 ± 0.04	-0.03 ± 0.03	-0.01 ± 0.03	-0.05 ± 0.03
$\bar{h}$ (m)	-7.6 ± 3.4	-10.1 ± 3.0	-11.9 ± 6.4	-9.1 ± 3.1	-5.1 ± 4.4	-3.2 ± 3.4	-4.3 ± 2.9
$\dot{b}$ (m.w.e.)	-0.20 ± 0.09	-0.27 ± 0.08	-0.32 ± 0.17	-0.24 ± 0.09	-0.13 ± 0.12	-0.08 ± 0.09	-0.11 ± 0.08
Data coverage (%)	63	41	100	84	100	55	51
Debris coverage (%)	8	1	42	39	1	19	9
Calving (y/n)	n	y	n	n	n	n	n

ΔV is ice volume change without extrapolation, ΔV_{extrap} is ice volume change after extrapolating missing data using regional data from individual elevation bands. $\bar{h}$ is the spatially-averaged elevation change of the glacier, and $\dot{b}$ is the geodetic mass balance for each glacier over the 32-year timespan.

Table S3

	clean	debris	calving	all
Area (km^2)	221 ± 11	78 ± 4	66 ± 3	365 ± 12
Area (%)	61	21	18	
	Assuming zero change for missing data			
ΔV (km^3)	-1.09 ± 0.4	-0.55 ± 0.4	-0.70 ± 0.3	-2.34 ± 0.6
ΔV (%)	46	24	30	
$\dot{b}$ (m.w.e. yr^{-1})	-0.13 ± 0.06	-0.19 ± 0.11	-0.28 ± 0.10	-0.17 ± 0.05
	Extrapolating missing data using regional profiles			
ΔV (km^3)	-0.60 ± 0.4	-0.62 ± 0.4	-0.77 ± 0.3	-1.99 ± 0.6
ΔV (%)	30	31	39	
$\dot{b}$ (m.w.e. yr^{-1})	-0.07 ± 0.06	-0.21 ± 0.11	-0.31 ± 0.10	-0.14 ± 0.05
	Assuming zero change for missing data in glacier c, extrapolating missing data for all other glaciers			
ΔV (km^3)	-0.95 ± 0.4	-0.62 ± 0.4	-0.77 ± 0.3	-2.34 ± 0.6
ΔV (%)	41	26	33	
$\dot{b}$ (m.w.e. yr^{-1})	-0.11 ± 0.06	-0.21 ± 0.11	-0.31 ± 0.10	-0.17 ± 0.05

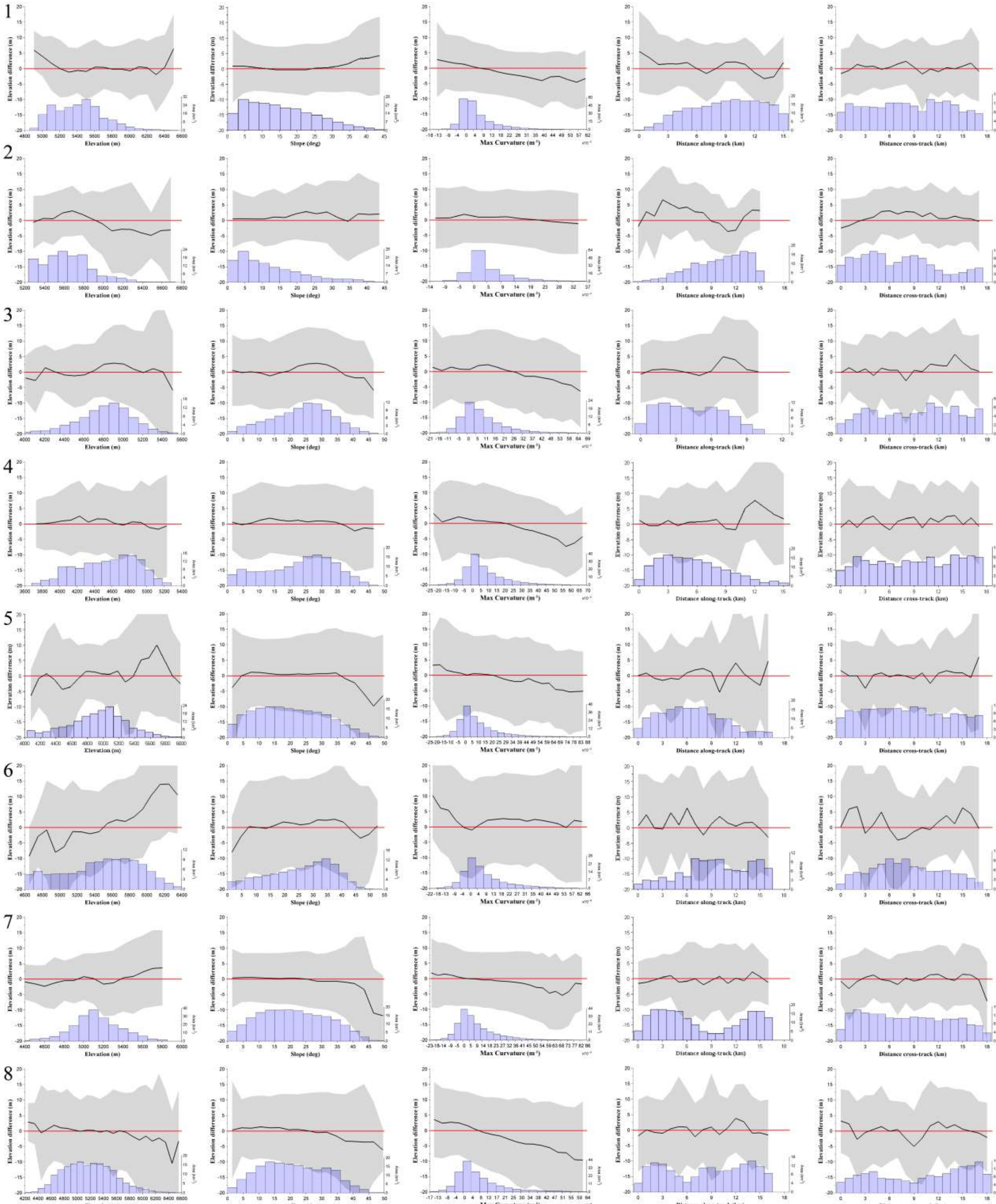
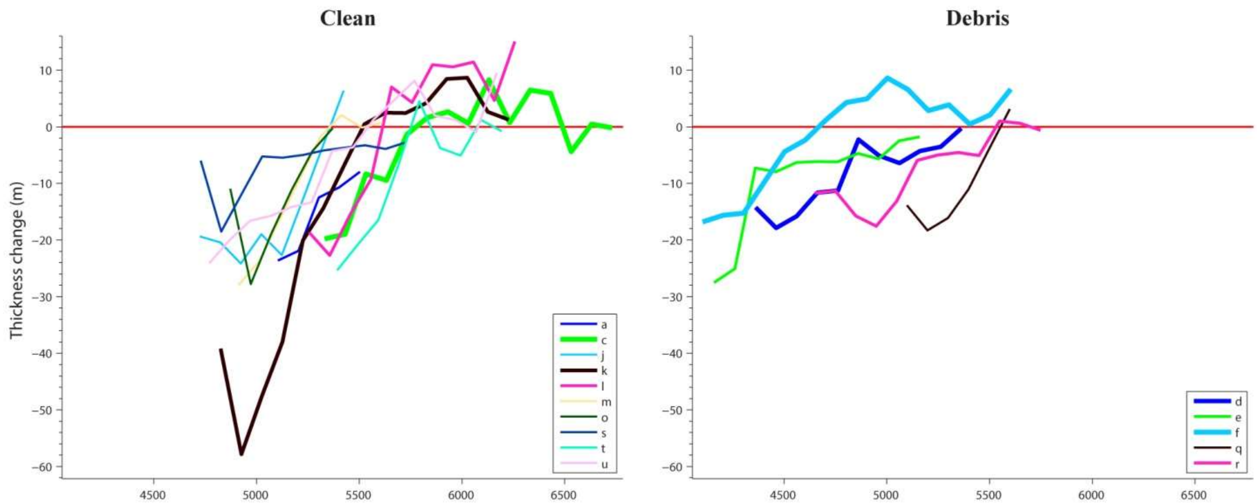


Figure S1. Plots of elevation change vs. elevation, slope, maximum curvature, and ASTER along-track and cross-track directions for assumed stable terrain in each of the 8 Hexagon DEM regions given in Table S1. Black curves and grey shaded regions indicate the mean and standard deviation of each bin, respectively. The area (km^2) contained in each bin is indicated by the blue histogram bars, calculated as the number of pixels per bin * pixel resolution^2.



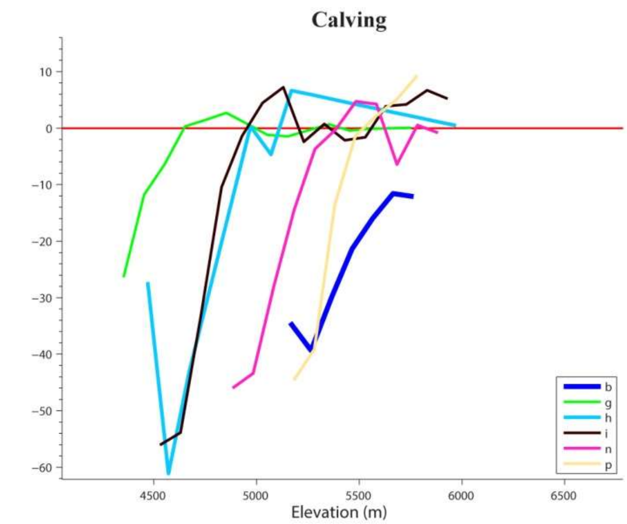


Figure S2. Ice thickness change profiles for individual glaciers. Similar to Figure 4, **Thickness changes are separated into 100 m bins, and the horizontal red lines indicate zero change.**

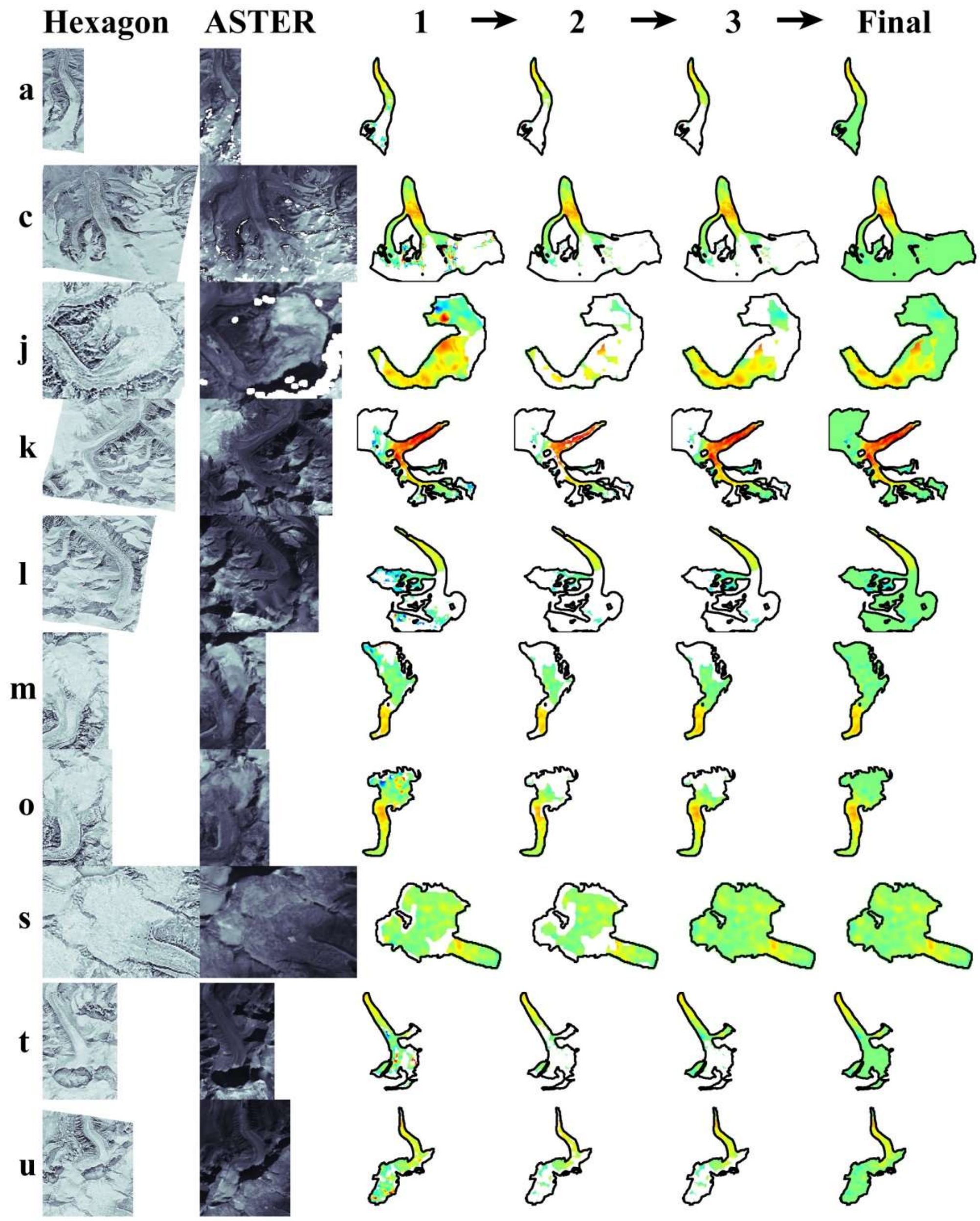


Figure S3. Hexagon and ASTER images, along with thickness change map processing stages for clean ice glaciers. Stage 1: raw elevation change maps; stage 2: after excluding erroneous pixels (see section 2.3), stage 3: after interpolating gaps smaller than 2 km^2, and stage 4: after filling remaining accumulation zone gaps with zero elevation change.

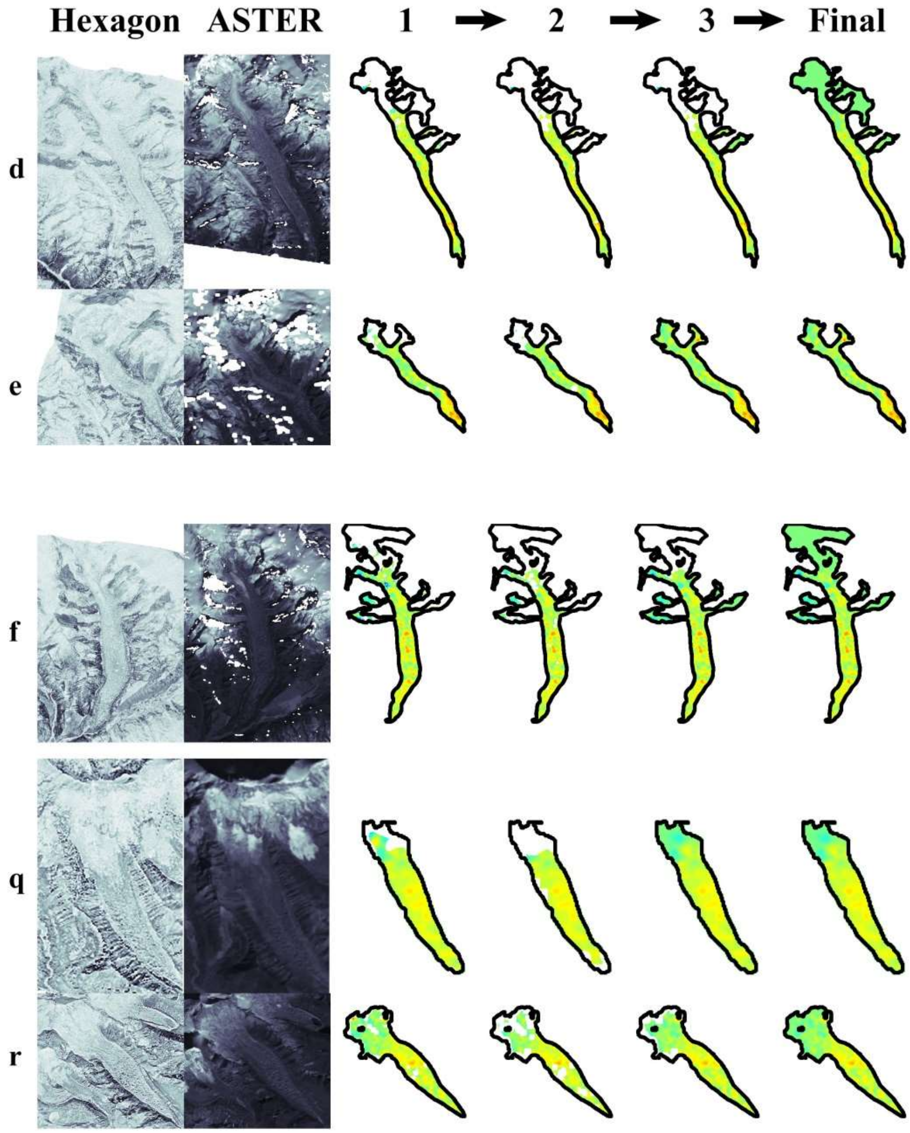


Figure S4. Same as Fig. S3, but for debris-covered glaciers.

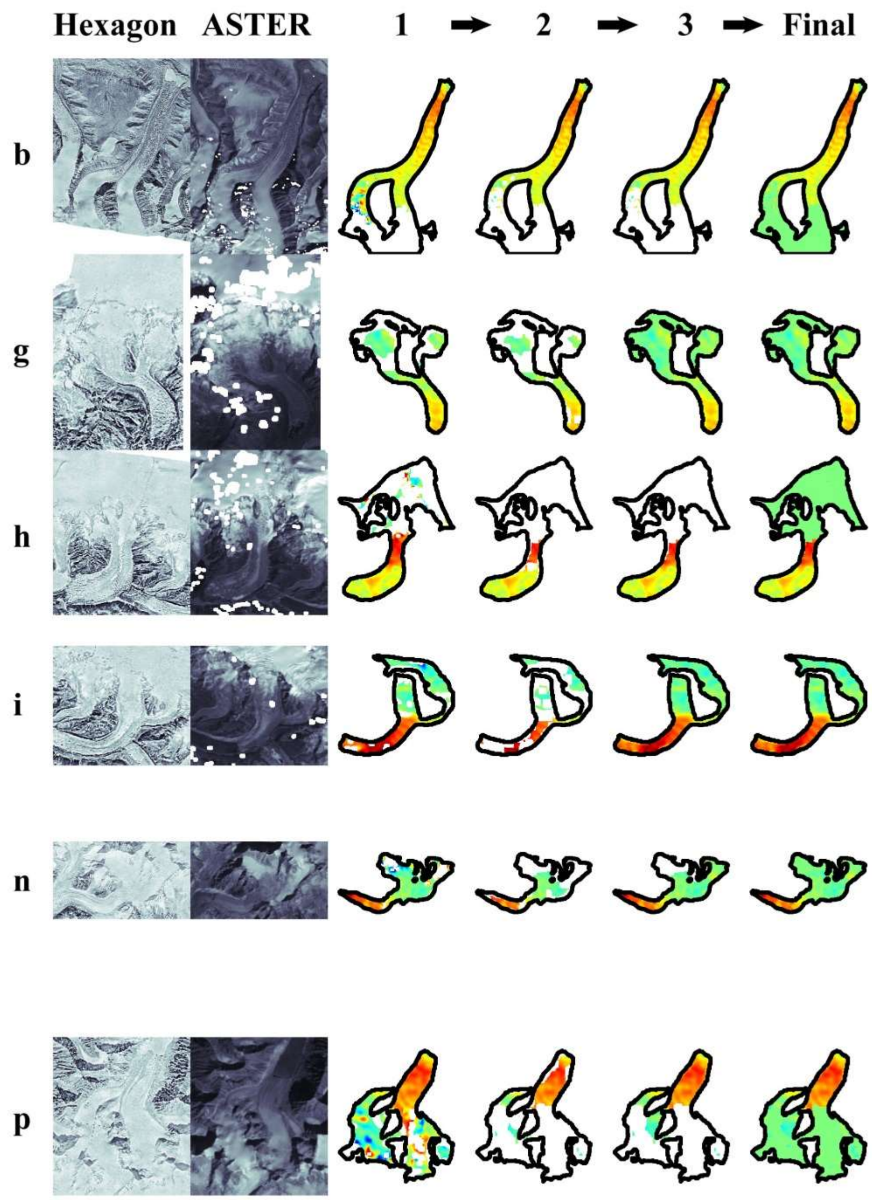


Figure S5. Same as Fig. S3, but for calving glaciers.

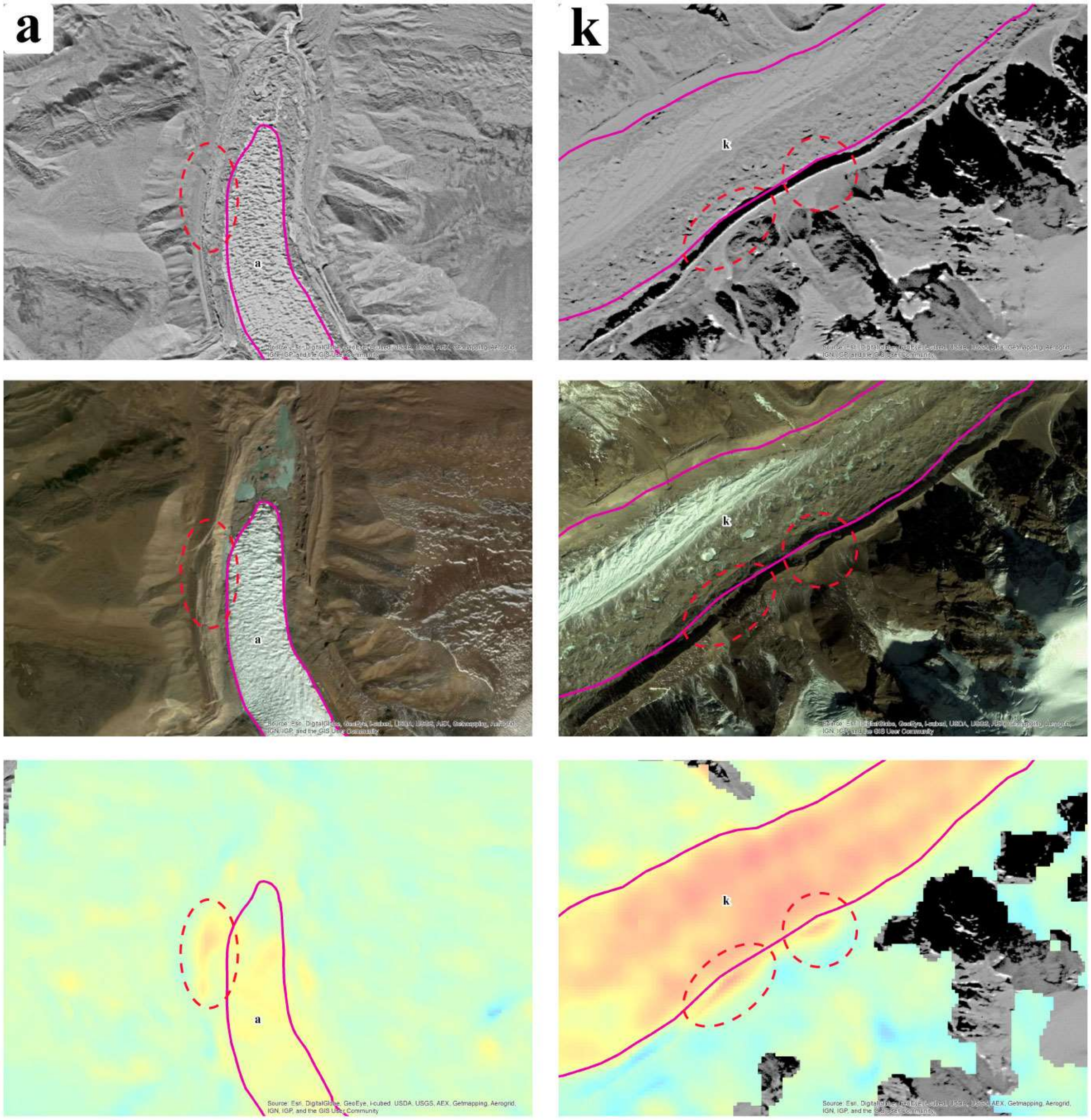
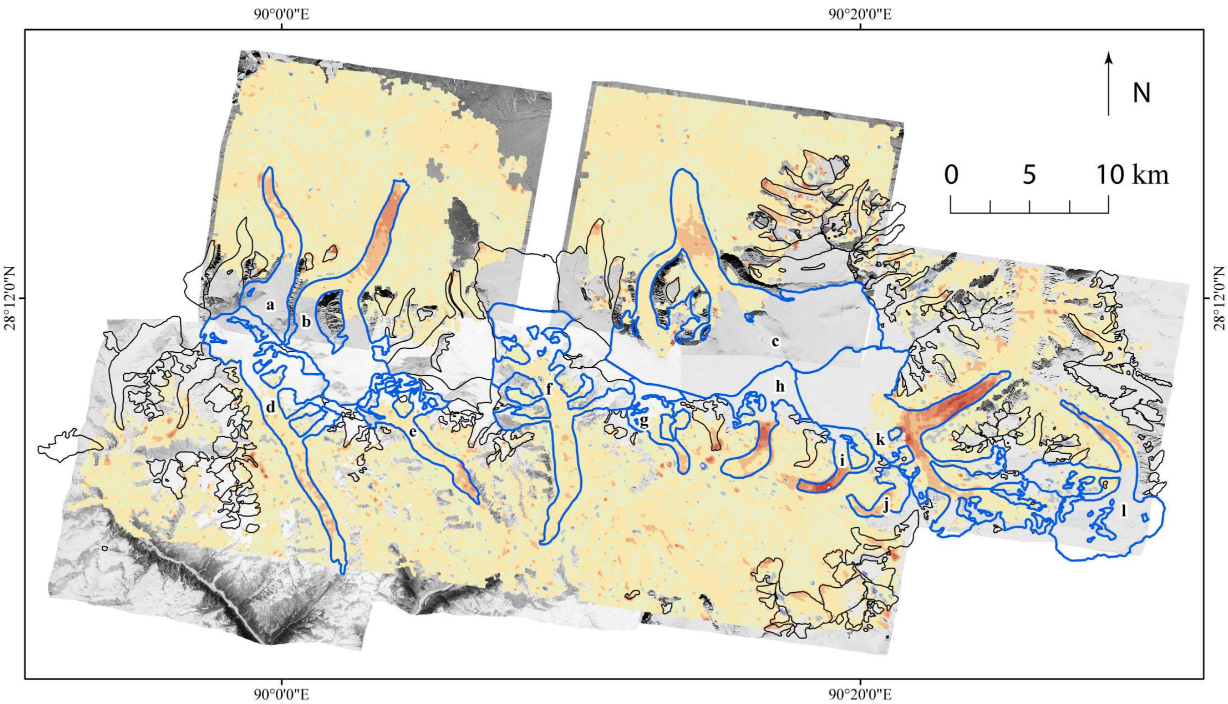
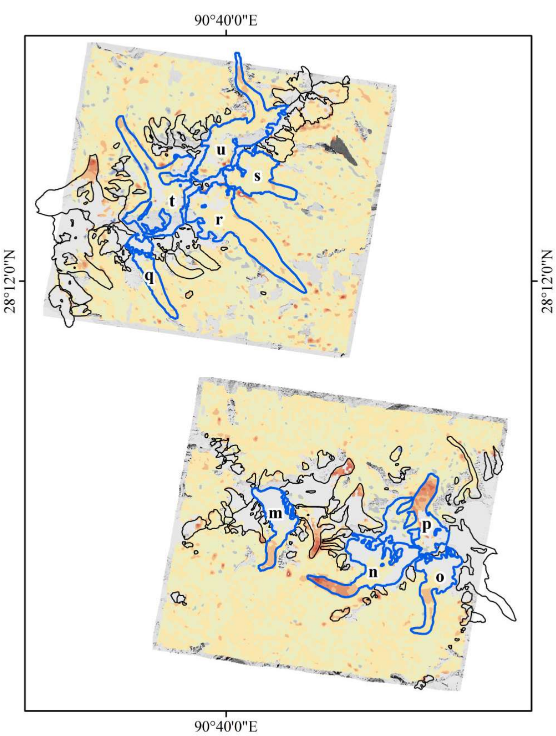


Figure S6. Two examples of unstable moraine ridges. Red dotted ellipses indicate sections which have collapsed near glaciers a and k.





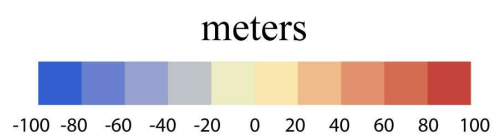


Figure S7. Same as Fig. 3, except elevation changes are visualized as discrete classes rather than using continuous color coding.