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Global glacier volume projections under high-end climate change scenarios

Sarah Shannon et al.

Correspondence to: Sarah Shannon (sarah.shannon@bristol.ac.uk)

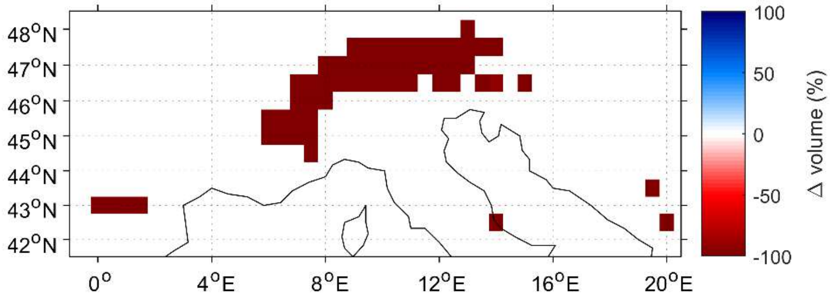

Figure S1 Percentage volume change at 2097, relative to the initial volume for Central Europe.

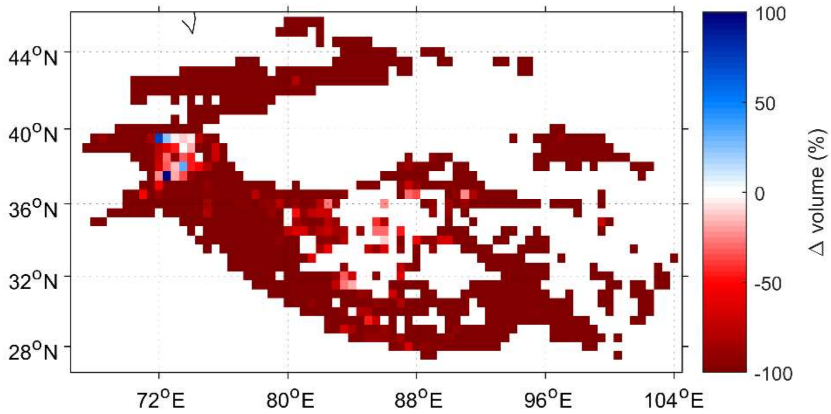

Figure S2 Percentage volume change at 2097, relative to the initial volume for Central Asia, East and West Asia.

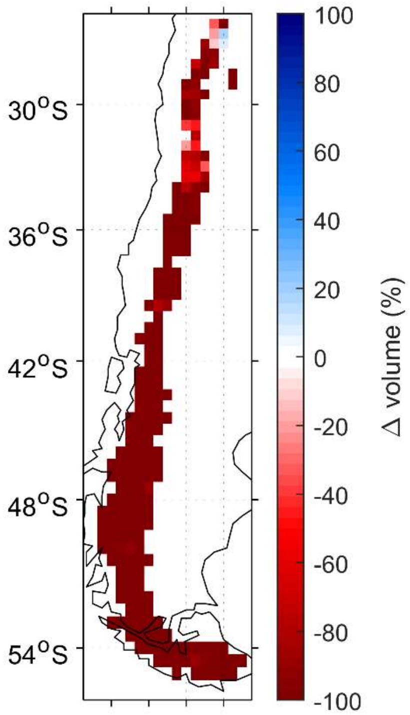

Figure S3 Percentage volume change at 2097, relative to the initial volume for the Southern Andes.

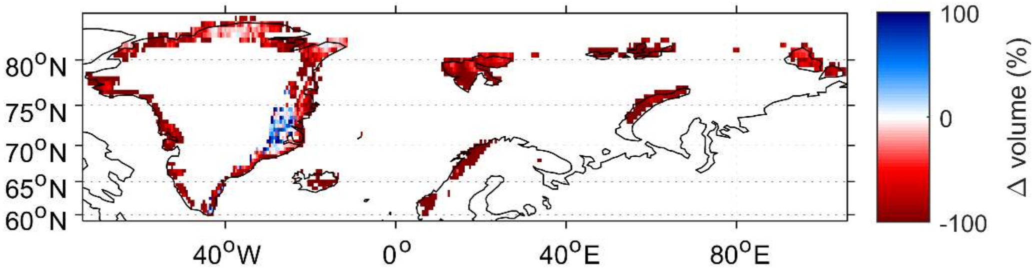

Figure S4 Percentage volume change at 2097, relative to the initial volume for Greenland, Iceland, Svalbard, Scandinavia and the Russian Arctic.

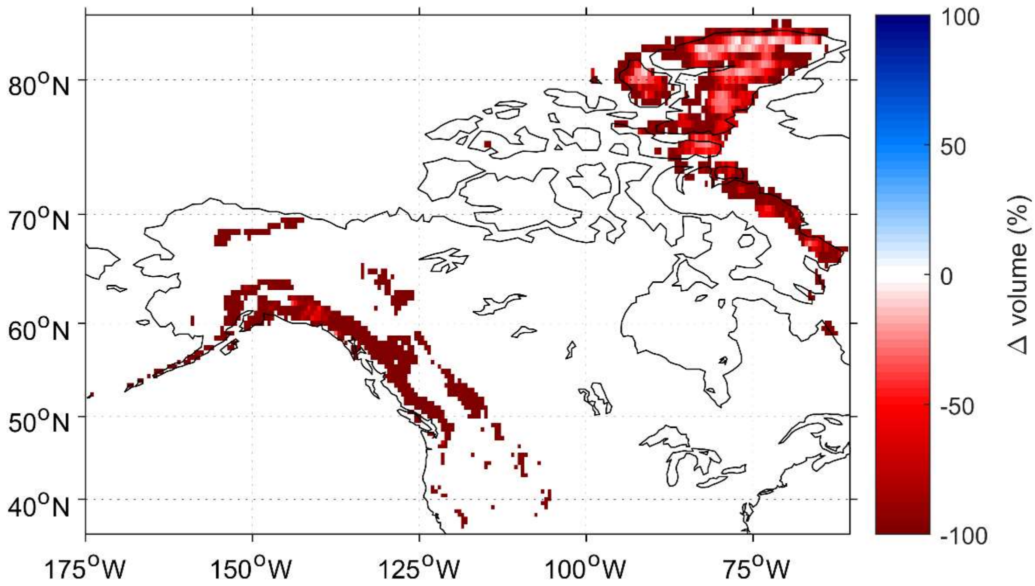

Figure S5 Percentage volume change at 2097, relative to the initial volume for Alaska, Western Canada + US, Arctic Canada North and South.

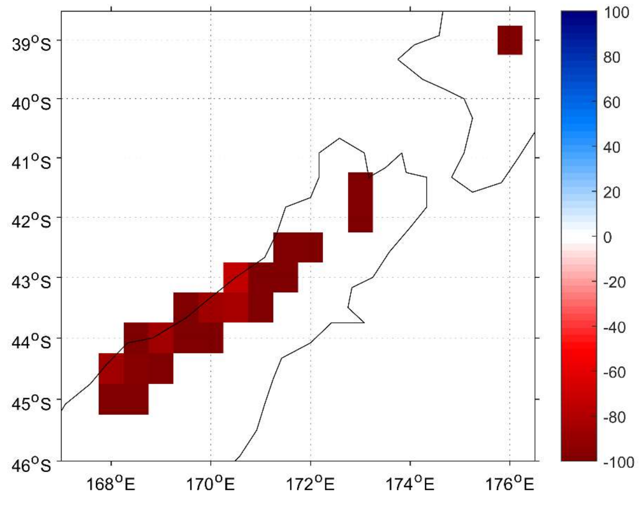

Figure S6 Percentage volume change at 2097, relative to the initial volume for New Zealand.

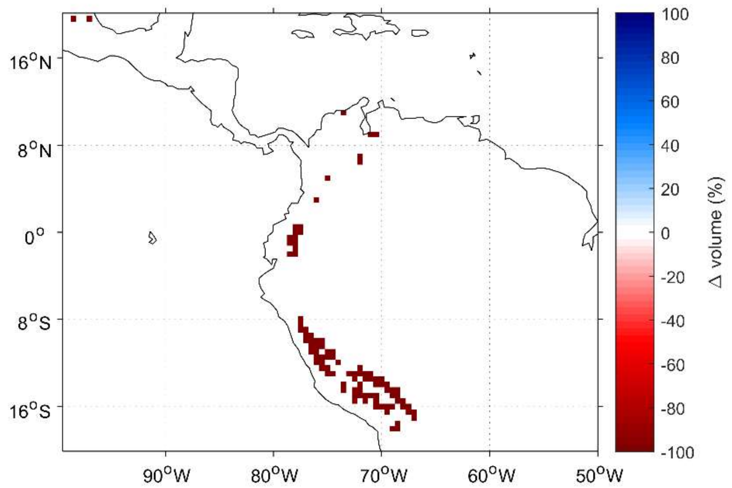

Figure S7 Percentage volume change at 2097, relative to the initial volume for south and Central America

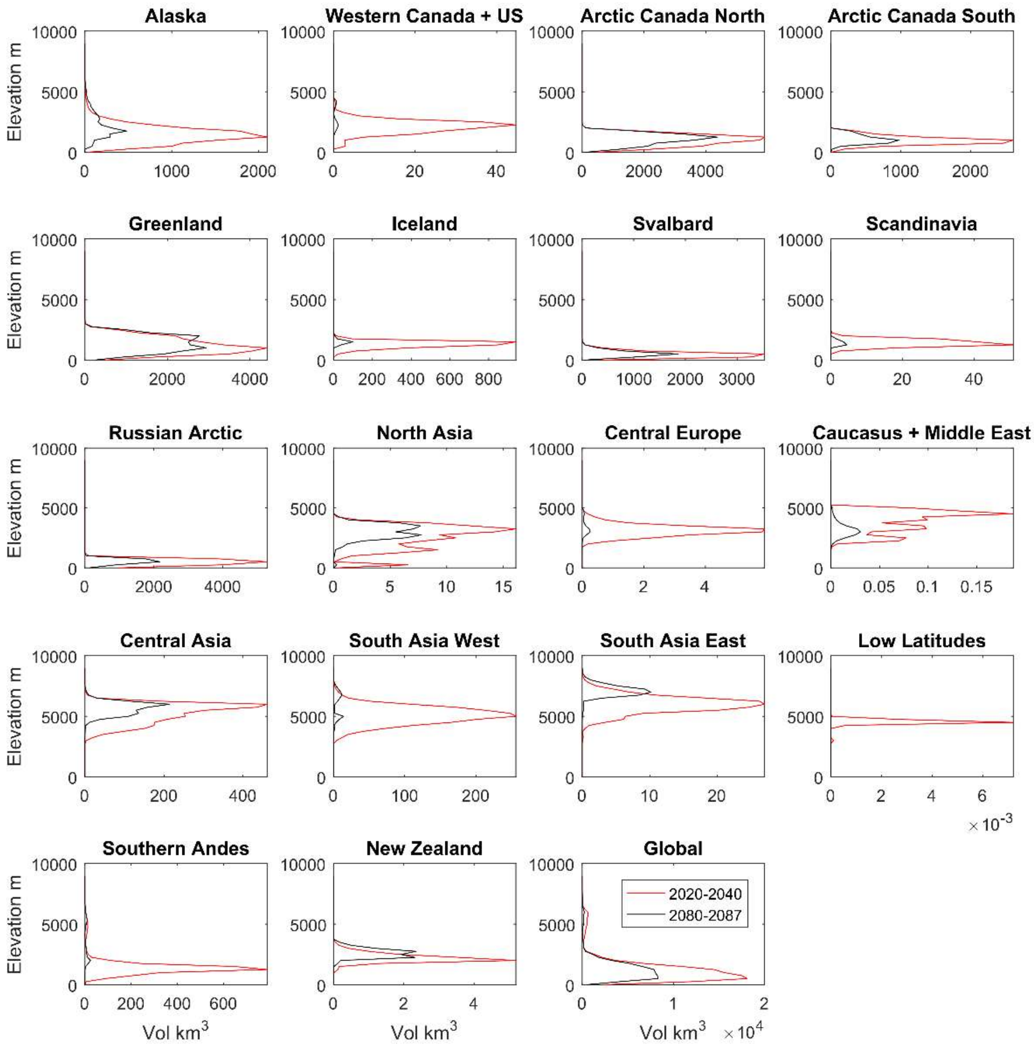

Figure S8 Cumulative mass balances as a function of height for the middle (2020-2040) and end of the century (2080-2087). The projections are the mean of the HadGEM3-A ensemble.

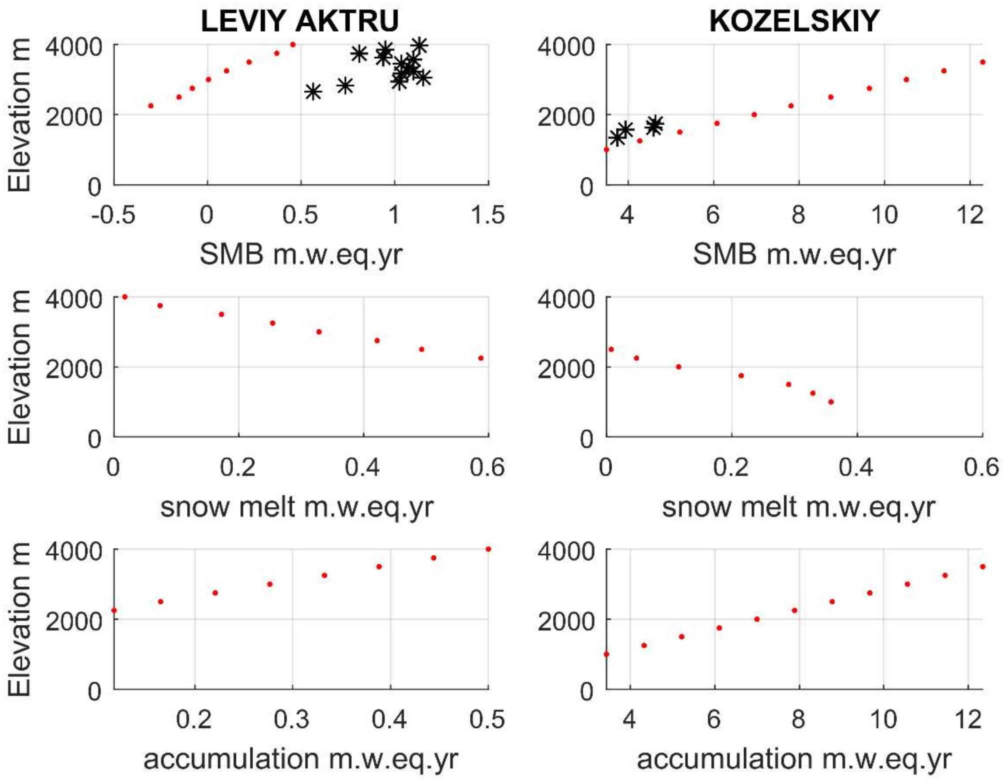

Figure S9 Simulated winter mass balance, snow melt and accumulation for the year 1989 when the model is forced with WFDEI data. The black stars are the elevation-dependant specific mass balance observations.

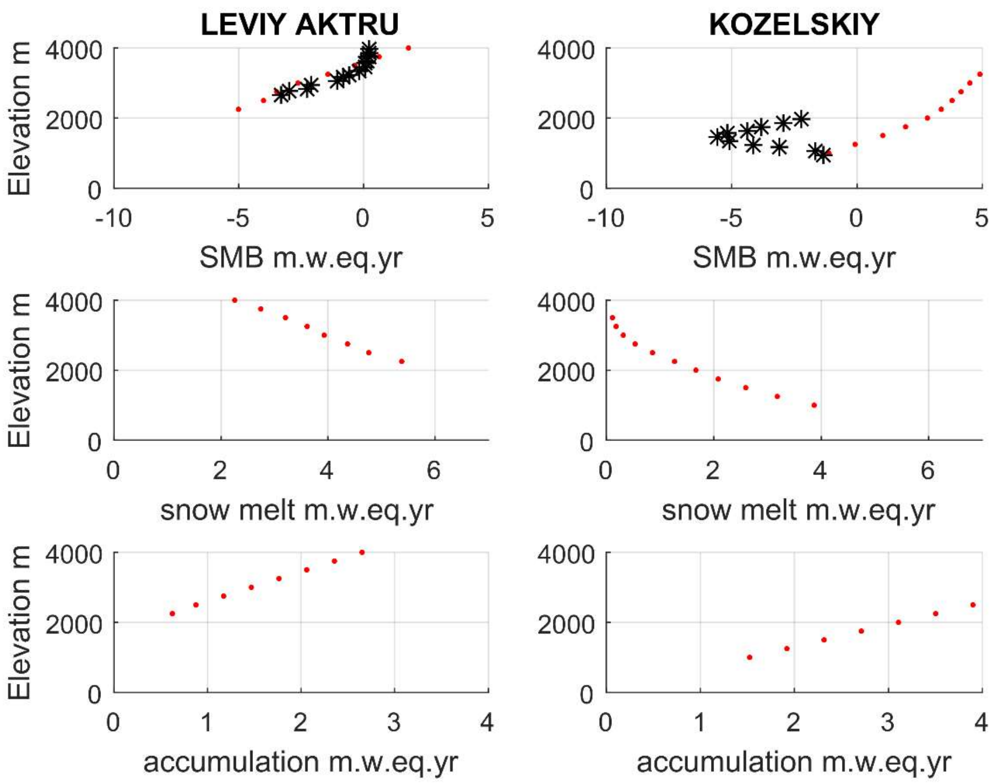

Figure S10 Simulated summer mass balance, snow melt and accumulation for the year 1992 when the model is forced with WFDEI data. The black stars are the elevation-dependant specific mass balance observations.

Table S1 Equally plausible parameter sets derived from the root mean square error for each RGI6 region. Best parameter sets are shown in bold.

	$\alpha_{vis,snow}$	$\alpha_{nir,snow}$	$\alpha_{vis,ice}$	$\alpha_{nir,ice}$	γ_{temp} (°K km^{-1})	γ_{precip} (%/100m)	γ_{wind}
Alaska	**0.88**	**0.65**	**0.56**	**0.27**	**8.16**	**16.46**	**1.32**
	0.95	0.72	0.41	0.19	7.96	14.71	1.07
	0.96	0.76	0.48	0.24	9.11	11.10	1.28
	0.93	0.71	0.65	0.23	7.83	7.80	1.08
Western Canada and US	**0.97**	**0.64**	**0.45**	**0.26**	**9.35**	**7.87**	**2.29**
	0.99	0.79	0.32	0.16	7.67	7.11	2.19
	0.89	0.67	0.49	0.37	8.44	8.22	1.87
Arctic Canada North	**0.96**	**0.70**	**0.49**	**0.12**	**4.22**	**7.35**	**1.10**
	0.98	0.68	0.53	0.23	6.53	6.91	1.46
	0.93	0.71	0.65	0.23	7.83	7.80	1.08
Arctic Canada South	**0.94**	**0.77**	**0.68**	**0.53**	**8.30**	**16.34**	**2.15**
	0.89	0.67	0.49	0.37	8.44	8.22	1.87
	0.91	0.73	0.67	0.56	5.32	8.57	1.55
Greenland	**0.95**	**0.72**	**0.41**	**0.19**	**7.96**	**14.71**	**1.07**
	0.93	0.71	0.65	0.23	7.83	7.80	1.08
	0.93	0.60	0.58	0.10	8.97	22.26	1.10
	0.91	0.65	0.64	0.44	5.74	12.56	1.01
	0.95	0.76	0.54	0.35	9.01	13.93	1.02
	0.79	0.63	0.61	0.30	5.75	22.57	1.07
Svalbard	**0.95**	**0.76**	**0.54**	**0.35**	**9.01**	**13.93**	**1.02**
	0.94	0.74	0.69	0.50	8.13	19.39	1.40
Scandinavia	**0.95**	**0.76**	**0.54**	**0.35**	**9.01**	**13.93**	**1.02**
	0.93	0.71	0.65	0.23	7.83	7.80	1.08
	0.96	0.76	0.48	0.24	9.11	11.10	1.28
	0.95	0.72	0.41	0.19	7.96	14.71	1.07
North Asia	**0.94**	**0.74**	**0.69**	**0.50**	**8.13**	**19.39**	**1.40**
	0.95	0.76	0.54	0.35	9.01	13.93	1.02
	0.94	0.77	0.68	0.53	8.30	16.34	2.15
	0.96	0.74	0.67	0.30	9.17	24.59	1.68
	0.88	0.72	0.64	0.52	8.22	22.92	1.19
	0.99	0.74	0.64	0.24	7.38	21.88	1.46
Central Europe	**0.83**	**0.63**	**0.59**	**0.35**	**5.79**	**7.24**	**1.83**
	0.77	0.58	0.58	0.13	4.19	10.34	1.19
	0.86	0.69	0.68	0.32	4.35	8.51	1.02
	0.89	0.66	0.29	0.20	9.50	7.21	1.11
	0.90	0.58	0.53	0.25	8.85	7.90	3.64
	0.98	0.73	0.63	0.29	9.71	14.56	2.81
	0.87	0.62	0.61	0.21	9.75	7.67	2.19
	0.88	0.62	0.18	0.12	9.70	13.38	2.92

	0.98	0.69	0.60	0.35	9.76	23.50	2.62
Caucasus and Middle East	**0.90**	**0.71**	**0.53**	**0.28**	**8.29**	**5.03**	**3.32**
	0.85	0.63	0.59	0.41	9.79	5.72	2.98
	0.74	0.55	0.54	0.30	9.30	6.31	2.05
Central Asia	**0.94**	**0.74**	**0.69**	**0.50**	**8.13**	**19.39**	**1.40**
	0.94	0.77	0.68	0.53	8.30	16.34	2.15
	0.95	0.76	0.54	0.35	9.01	13.93	1.02
	0.96	0.74	0.67	0.30	9.17	24.59	1.68
	0.99	0.74	0.64	0.24	7.38	21.88	1.46
	0.88	0.72	0.64	0.52	8.22	22.92	1.19
South Asia West	**0.99**	**0.73**	**0.60**	**0.30**	**4.05**	**23.95**	**1.69**
	0.99	0.74	0.64	0.24	7.38	21.88	1.46
	0.94	0.77	0.68	0.53	8.30	16.34	2.15
	0.95	0.76	0.54	0.35	9.01	13.93	1.02
	0.96	0.74	0.67	0.30	9.17	24.59	1.68
	0.88	0.72	0.64	0.52	8.22	22.92	1.19
	0.94	0.78	0.60	0.23	5.88	19.24	1.75
	0.89	0.71	0.61	0.50	5.93	23.79	1.63
South Asia East	**0.91**	**0.73**	**0.67**	**0.56**	**5.32**	**8.57**	**1.55**
	0.94	0.77	0.68	0.53	8.30	16.34	2.15
	0.88	0.72	0.64	0.52	8.22	22.92	1.19
Low Latitudes	**0.94**	**0.74**	**0.69**	**0.50**	**8.13**	**19.39**	**1.40**
	0.96	0.74	0.67	0.30	9.17	24.59	1.68
	0.94	0.77	0.68	0.53	8.30	16.34	2.15
	0.88	0.72	0.64	0.52	8.22	22.92	1.19
	0.95	0.76	0.54	0.35	9.01	13.93	1.02
	0.99	0.74	0.64	0.24	7.38	21.88	1.46
Southern Andes	**0.95**	**0.76**	**0.54**	**0.35**	**9.01**	**13.93**	**1.02**
	0.88	0.72	0.64	0.52	8.22	22.92	1.19
	0.93	0.71	0.65	0.23	7.83	7.80	1.08
	0.94	0.74	0.69	0.50	8.13	19.39	1.40
	0.91	0.65	0.64	0.44	5.74	12.56	1.01
New Zealand	**0.94**	**0.74**	**0.69**	**0.50**	**8.13**	**19.39**	**1.40**
	0.88	0.72	0.64	0.52	8.22	22.92	1.19
	0.95	0.76	0.54	0.35	9.01	13.93	1.02
	0.99	0.74	0.64	0.24	7.38	21.88	1.46
	0.96	0.74	0.67	0.30	9.17	24.59	1.68

Table S2 Optimum regional parameter sets when we maximise the correlation coefficient between the simulated and observed specific mass balance.

Region	$\alpha_{vis,snow}$	$\alpha_{nir,snow}$	$\alpha_{vis,ice}$	$\alpha_{nir,ice}$	γ_{temp} (°K km^{-1})	γ_{precip} (%/100m)	γ_{wind}
Alaska	0.96	0.74	0.67	0.30	9.20	25.00	1.68
Western Canada and US	0.85	0.61	0.36	0.17	9.60	12.00	3.71

Arctic Canada North	0.99	0.74	0.64	0.24	7.40	22.00	1.46
Arctic Canada South	0.97	0.68	0.65	0.52	9.40	23.00	3.48
Greenland	0.99	0.71	0.32	0.15	9.20	20.00	2.12
Iceland	0.95	0.69	0.48	0.25	8.67	19.31	2.79
Svalbard	0.98	0.76	0.58	0.34	9.00	9.00	3.69
Scandinavia	0.96	0.74	0.67	0.30	9.20	25.00	1.68
Russian Arctic	0.95	0.69	0.48	0.25	8.67	19.31	2.79
North Asia	0.98	0.66	0.25	0.18	9.60	21.00	3.12
Central Europe	0.94	0.61	0.23	0.16	9.10	22.00	1.49
Caucasus and Middle East	0.98	0.66	0.25	0.18	9.60	21.00	3.12
Central Asia	0.98	0.66	0.25	0.18	9.60	21.00	3.12
South Asia West	0.97	0.75	0.44	0.12	7.70	17.00	3.77
South Asia East	0.86	0.61	0.57	0.28	8.70	22.00	3.95
Low Latitudes	0.97	0.68	0.65	0.52	9.40	23.00	3.48
Southern Andes	0.86	0.69	0.68	0.32	4.30	9.00	1.02
New Zealand	0.97	0.75	0.44	0.12	7.70	17.00	3.77
Mean	0.95	0.69	0.48	0.25	8.67	19.31	2.79

Table S3 Optimum regional parameter sets when we minimise the bias between the simulated and observed specific mass balance.

Region	$\alpha_{vis,snow}$	$\alpha_{nir,snow}$	$\alpha_{vis,ice}$	$\alpha_{nir,ice}$	γ_{temp} ($^oK\ km^{-1}$)	γ_{precip} (%/100m)	γ_{wind}
Alaska	0.88	0.63	0.42	0.24	8.20	19.00	1.21
Western Canada + US	0.87	0.72	0.56	0.33	6.00	10.00	2.25
Arctic Canada North	0.83	0.66	0.20	0.14	5.30	7.00	3.21
Arctic Canada South	0.82	0.66	0.16	0.12	9.30	21.00	1.74
Greenland	0.84	0.67	0.64	0.29	5.80	17.00	1.42
Iceland	0.90	0.71	0.52	0.27	7.53	17.38	1.84
Svalbard	0.95	0.76	0.54	0.35	9.00	14.00	1.02
Scandinavia	0.92	0.68	0.52	0.25	5.40	20.00	1.48
Russian Arctic	0.90	0.71	0.52	0.27	7.53	17.38	1.84
North Asia	0.94	0.74	0.69	0.50	8.10	19.00	1.40
Central Europe	0.76	0.51	0.48	0.19	4.90	24.00	3.73
Caucasus and Middle East	0.90	0.75	0.41	0.11	6.90	5.00	3.22
Central Asia	0.96	0.74	0.67	0.30	9.20	25.00	1.68
South Asia West	0.95	0.76	0.54	0.35	9.00	14.00	1.02
South Asia East	0.94	0.78	0.60	0.23	5.90	19.00	1.76
Low Latitudes	0.96	0.74	0.67	0.30	9.20	25.00	1.68
Southern Andes	0.95	0.76	0.54	0.35	9.00	14.00	1.02
New Zealand	0.96	0.74	0.67	0.30	9.20	25.00	1.68
Mean	0.90	0.71	0.52	0.27	7.53	17.38	1.84

Table S4 Comparison of percentage volume change relative to initial volume, from this study with Huss and Hock (2015)

	This study ΔV % 2097-2011	Huss & Hock (2015) ΔV % 2100-2010	This study minus Huss & Hock (2015)
Alaska	-89±2	-58±14	-30
Western Canada and US	-100±0	-95±5	-5
Arctic Canada North	-47±3	-30±12	-9
Arctic Canada South	-74±8	-52±14	-22
Greenland	-31±5	-52±13	20
Iceland	-98±3	-62±18	-36
Svalbard	-68±16	-82±18	14
Scandinavia	-98±3	-96±4	-2
Russian Arctic	-79±10	-70±19	-7
North Asia	-71±5	-81±7	10
Central Europe	-99±0	-98±2	-1
Caucasus and Middle East	-100±0	-96±3	-4
Central Asia	-80±7	-88±7	8
South Asia West	-98±1	-87±9	-11
South Asia East	-95±2	-92±5	-3
Low Latitudes	-100±0	-98±0	-2
Southern Andes	-98±1	-44±14	-54
New Zealand	-88±5	-82±8	4

Table S5 Comparison of volume losses for this study with two other studies (Huss and Hock 2015, Radic et al. 2014). Volume loss is expressed in terms of sea level equivalent (mm). The last column lists volume losses when we correct the bias in the calibrated mass balance. There were no observations available to calibrate the present-day mass balance for Iceland and the Russian Arctic, so there is no bias corrected volume loss for these regions.

	This study 2097-2011	Huss 2100-2010	Radic 2100-2006	This study minus Hock	This study minus Radic	Bias corrected
Alaska	44.6±1.1	24.9±6.3	25.4	23.1	22.6	45.0±1.1
Western Canada and US	2.8±0.0	2.2±0.1	2.6	0.7	0.3	2.2±0.0
Arctic Canada North	35.8±3.0	19.7±7.8	42.2	15.1	-7.4	37.8±2.9
Arctic Canada South	18.1±2.1	9.9±2.8	15.0	10.1	5.0	18.3±2.2
Greenland	20.1±4.4	17.7±4.6	20.4	9.1	6.4	21.9±4.3
Iceland	9.3±0.3	4.7±1.7	4.9	5.4	5.2	-
Svalbard	17.0±4.6	13.9±3.1	15.8	5.0	3.1	15.6±4.6
Scandinavia	0.6±0.0	0.3±0.0	0.5	0.4	0.2	0.8±0.0
Russian Arctic	33.3±4.8	18.1±5.5	28.3	18.0	7.8	-
North Asia	0.3±0.0	0.2±0.0	0.6	0.1	-0.3	0.2±0.0
Central Europe	0.3±0.0	0.3±0.0	0.3	0.0	0.0	0.4±0.0
Caucasus and Middle East	0.2±0.0	0.1±0.0	0.2	0.1	0.0	0.2±0.0
Central Asia	8.0±0.7	9.2±1.1	11.9	-0.7	-3.4	6.0±0.8
South Asia West	8.1±0.1	6.2±1.0	7.1	2.5	1.6	7.9±0.1

South Asia East	1.9±0.0	2.4±0.7	3.5	-0.4	-1.4	1.7±0.0
Low Latitudes	0.2±0.0	0.2±0.0	0.5	0.0	-0.3	0.2±0.0
Southern Andes	14.4±0.1	5.8±1.8	8.5	9.7	7.0	7.6±0.3
New Zealand	0.1±0.0	0.1±0.0	0.1	0.0	0.0	0.01±0.0
Global	215.2±21.3	135.9±13.0	187.9	98.3	46.4	222.5±20.1

Table S6 Comparison of modelled and observed energy balance components at five elevation levels on the Pasterze glacier, Austria. Information about the observations are detailed in Greuell and Smeets (2001). The table contains data from two experiments, the first where wind speed in not tuned (γ_{wind} = 1) and the second where wind speed is increased to four times the surface wind speed (γ_{wind} = 4).

Elevation		Observations	γ_{wind} = 1	γ_{wind} = 4
2205m	Incoming short-wave radiation (Wm^{-2})	256.0	262.9	262.9
	Albedo (visible)	0.2	0.1	0.2
	Incoming long-wave radiation (Wm^{-2})	299.0	295.7	295.7
	Outgoing long-wave radiation (Wm^{-2})	315.0	305.8	309.5
	Elevated air temperature (°C)	6.8	9.1	9.1
	Surface temperature (°C)	-0.1	-1.5	-0.7
	Roughness length (mm)	2.6	3.0	3.0
	Sensible heat flux (Wm^{-2})	**48.0**	**0.2**	**22.2**
	Latent heat flux (Wm^{-2})	10.0	0.2	13.0
	Net radiation on tiles (Wm^{-2})	282.2	223.7	219.1
	Wind speed (ms^{-1})	**4.1**	**1.1**	**4.3**
	Ablation rate (mm water equivalent day^{-1})	61.3	52.7	58.4
2310m	Incoming short-wave radiation (Wm^{-2})	272.0	262.9	262.9
	Albedo (visible)	0.3	0.1	0.2
	Incoming long-wave radiation (Wm^{-2})	299.0	295.7	295.7
	Outgoing long-wave radiation (Wm^{-2})	315.0	305.8	309.6
	Elevated air temperature (°C)	6.4	8.4	8.4
	Surface temperature (°C)	-0.1	-1.5	-0.6
	Roughness length (mm)	1.2	3.0	3.0
	Sensible heat flux (Wm^{-2})	**53.0**	**0.2**	**21.5**
	Latent heat flux (Wm^{-2})	11.0	0.2	12.7
	Net radiation on tiles (Wm^{-2})	283.1	223.4	218.5
	Wind speed (ms^{-1})	**4.5**	**1.1**	**4.3**
	Ablation rate (mm water equivalent day^{-1})	63.1	52.6	57.9
2420m	Incoming short-wave radiation (Wm^{-2})	278.0	262.9	262.9
	Albedo (visible)	0.3	0.2	0.2
	Incoming long-wave radiation (Wm^{-2})	296.0	295.7	295.7
	Outgoing long-wave radiation (Wm^{-2})	315.0	305.8	309.7
	Elevated air temperature (°C)	7.1	7.6	7.6
	Surface temperature (°C)	-0.1	-1.5	-0.6
	Roughness length (mm)	5.8	3.0	3.0
	Sensible heat flux (Wm^{-2})	**63.0**	**0.1**	**20.7**
	Latent heat flux (Wm^{-2})	10.0	0.1	12.1
	Net radiation on tiles (Wm^{-2})	315.5	218.2	212.7
	Wind speed (ms^{-1})	**4.6**	**1.1**	**4.3**
	Ablation rate (mm water equivalent day^{-1})	66.9	51.3	56.3
	Incoming short-wave radiation (Wm^{-2})	307.0	262.9	262.9

2945m	Albedo (visible)	0.6	0.4	0.4
	Incoming long-wave radiation (Wm^{-2})	282.0	295.7	295.7
	Outgoing long-wave radiation (Wm^{-2})	314.0	307.7	311.0
	Elevated air temperature (°C)	3.5	4.2	4.2
	Surface temperature (°C)	-0.3	-1.1	-0.3
	Roughness length (mm)	1.3	3.0	3.0
	Sensible heat flux (Wm^{-2})	**23.0**	**1.3**	**15.9**
	Latent heat flux (Wm^{-2})	5.0	1.2	9.1
	Net radiation on tiles (Wm^{-2})	139.9	183.4	178.3
	Wind speed (ms^{-1})	**4.3**	**1.1**	**4.3**
	Ablation rate (mm water equivalent day^{-1})	32.1	46.0	50.7
3225m	Incoming short-wave radiation (Wm^{-2})	286.0	262.9	262.9
	Albedo (visible)	0.6	0.5	0.5
	Incoming long-wave radiation (Wm^{-2})	274.0	295.7	295.7
	Outgoing long-wave radiation (Wm^{-2})	313.0	308.0	310.7
	Elevated air temperature (°C)	3.2	2.6	2.6
	Surface temperature (°C)	-0.7	-1.0	-0.4
	Roughness length (mm)	2.0	3.0	3.0
	Sensible heat flux (Wm^{-2})	**20.0**	**2.4**	**11.5**
	Latent heat flux (Wm^{-2})	1.0	2.2	6.9
	Net radiation on tiles (Wm^{-2})	115.4	169.8	165.4
	Wind speed (ms^{-1})	**4.4**	**1.1**	**4.3**
	Ablation rate (mm water equivalent day^{-1})	24.0	43.5	47.3

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