



*Supplement of*

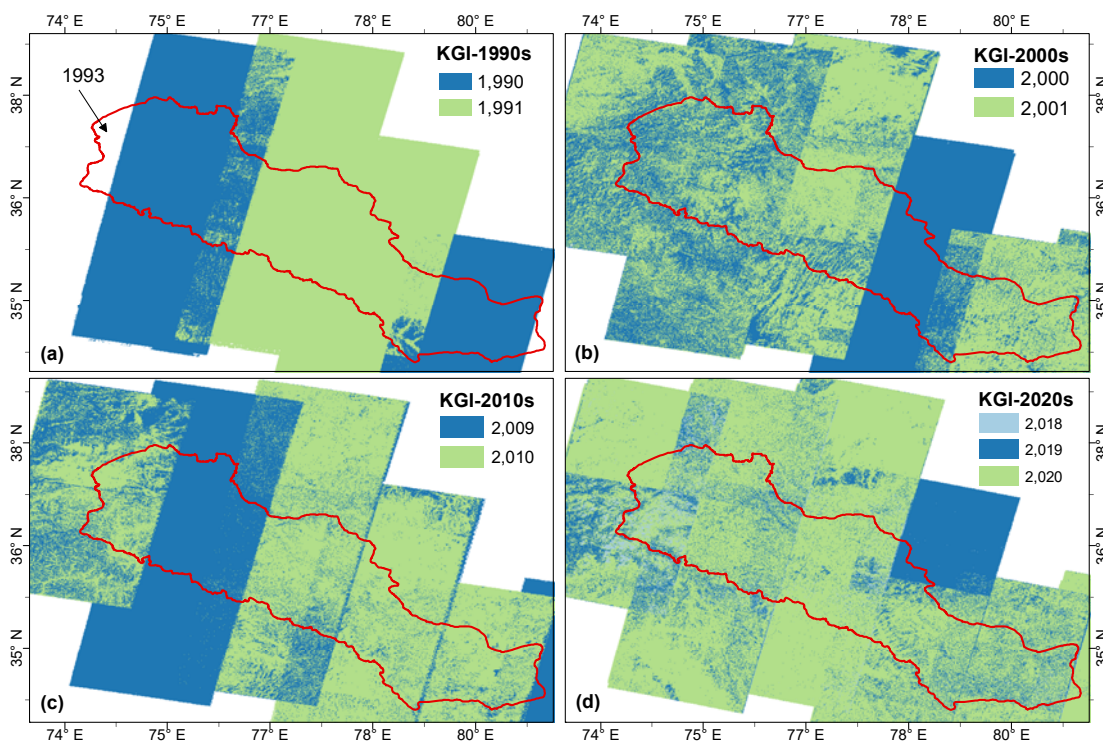
## **Interdecadal glacier inventories in the Karakoram since the 1990s**

**Fuming Xie et al.**

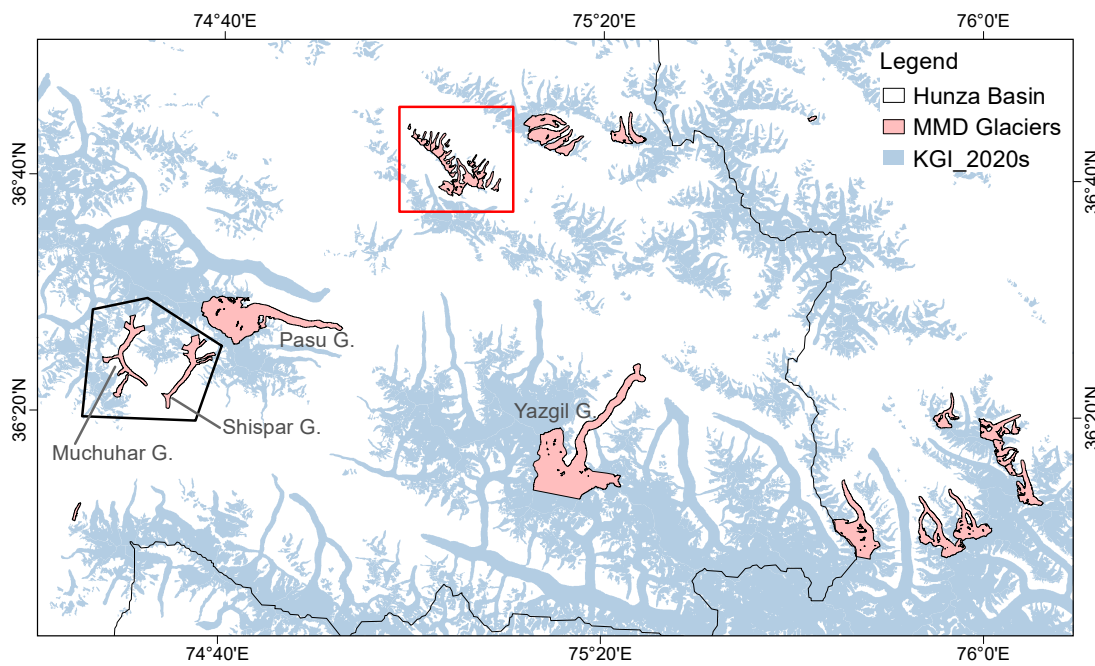
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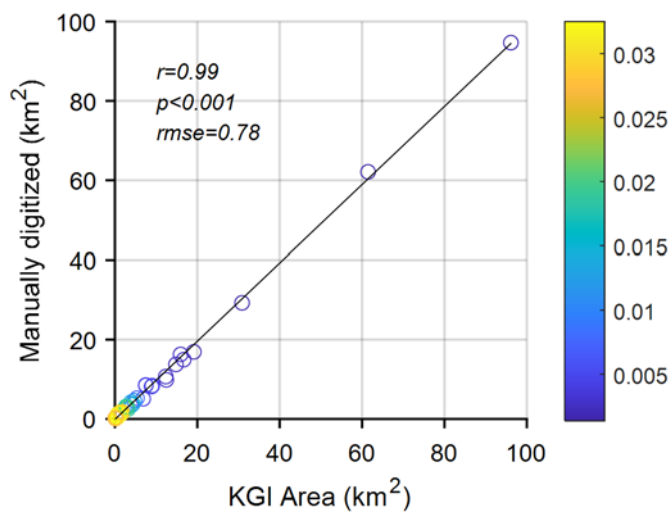
## Supplementary information



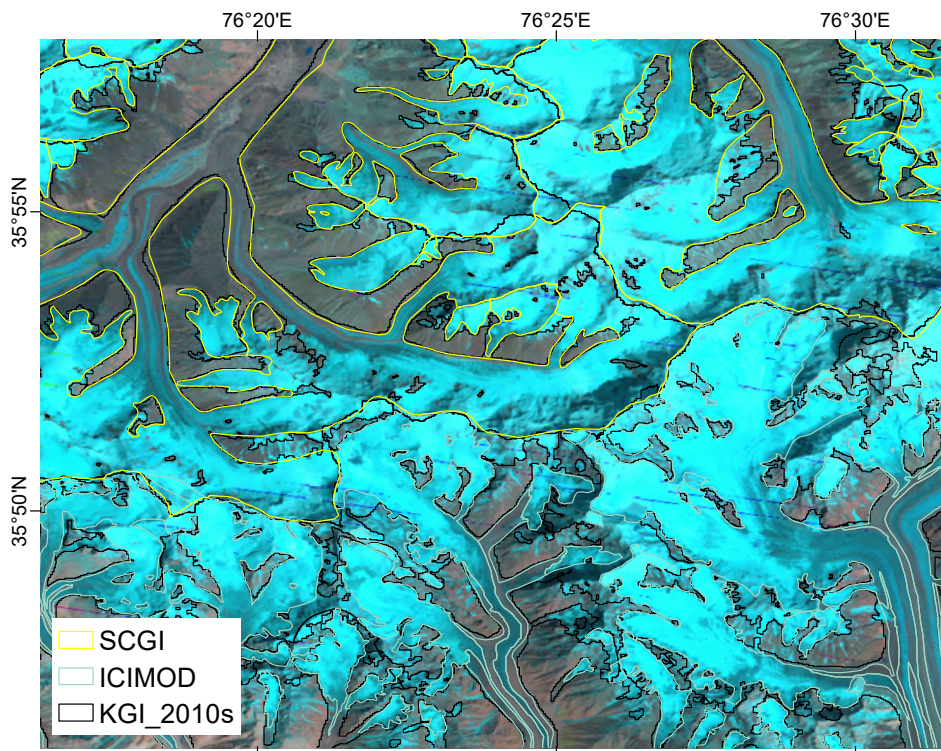
**Fig. S1** Original image date (year) for each pixel of the composite images have been used in Karakoram glacier inventory. (a) Except for the pixels from 1993, the pixels from 1990 accounted for 55.58%, while some glaciers in the central region (Fig. 1d) were manually corrected on a base image from 1994. (b) In the composite image of the 2000s, 44.25 % of the pixels were accepted from 2000 and the rest were from 2001. (c) Most of the pixels in the composited images during 2010s are from 2010, accounting for 56.93%. (d) In 2020s, 75.29% of pixels are from 2020, 4.18% in 2018 and 20.53% in 2019.



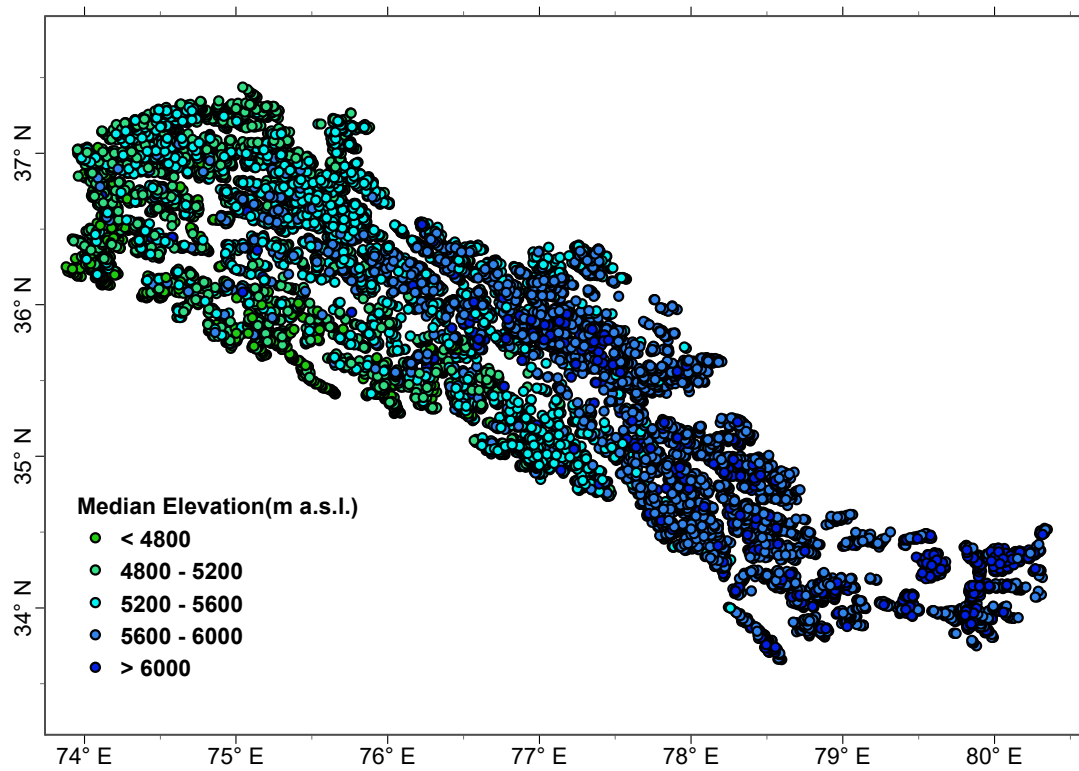
**Fig S2** Distribution of glaciers selected for the MMD experiment. All the glaciers except those in the red rectangle and black polygon are repeatedly digitized (five times) based on Sentinel-2 images. Inside the black polygonal frame is the ablation area of the Shispar and Muchuhar glacier, manually digitized (once) based on Planet 3-m image, while the red rectangle shows glaciers digitized from both Landsat-8 (four times) and Sentinel-2 images (once).



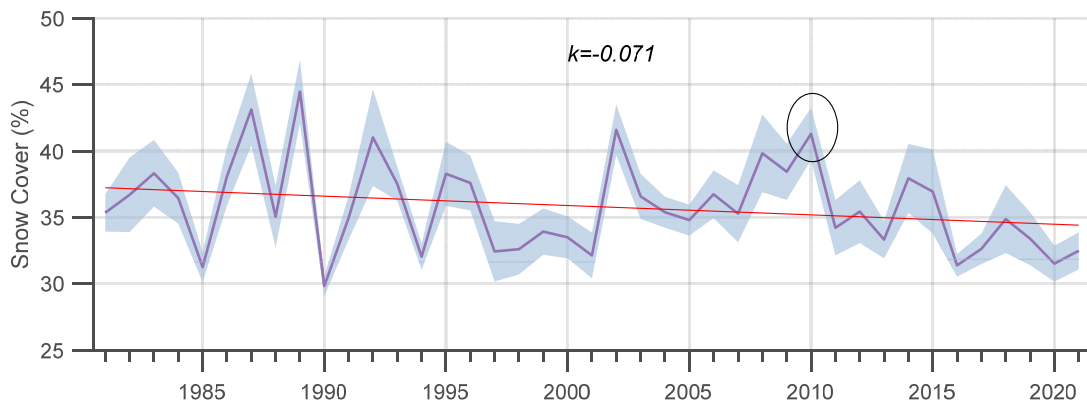
**Fig. S3** Linear fit of multi-manual digitizations (mean values) to the glacier area derived from KGI-2020s. The color bar represents the data density.



**Fig. S4** Comparison of glacier inventory among SCGI, ICIMOD and KGI-2010s.



**Fig. S5** Median elevation of the glaciers in the Karakoram.



**Fig. S6** Time series of summer melting season (DOY: 200-270) snow cover (regional median values) derived from ERA5-Land hourly climate reanalysis. Blue area refers to 95% confidence interval.

**Table S1.** List of Landsat TM/ETM+/OLI scenes used to map outlines of Karakoram glaciers. (P: WRS Path, R: WRS Row, AD: Acquired date, SA: Sun Azimuth, SE: Sun Elevation, CC: Cloud cover)

Periods	Satellite	Image ID	P	R	AD	SA(°)	SE(°)	CC(%)
1990s	LANDSAT5_TM	LT51460361990214ISP00	146	36	1990/8/2	111.4	56.32	1
	LANDSAT5_TM	LT51460371990214ISP00	146	37	1990/8/2	109.07	56.58	1
	LANDSAT5_TM	LT51470351991240ISP00	147	35	1991/8/28	125.92	52.01	1
	LANDSAT5_TM	LT51470361991240ISP00	147	36	1991/8/28	124.03	52.62	10
	LANDSAT5_TM	LT51480341991231ISP00	148	34	1991/8/19	123.75	53.26	7
	LANDSAT5_TM	LT51480341991263ISP00	148	34	1991/9/20	137.78	45.52	15
	LANDSAT5_TM	LT51480351991231ISP00	148	35	1991/8/19	121.74	53.82	16
	LANDSAT5_TM	LT51480351991263ISP00	148	35	1991/9/20	136.38	46.39	28
	LANDSAT5_TM	LT51480361991231ISP00	148	36	1991/8/19	119.68	54.33	30
	LANDSAT5_TM	LT51480361991263ISP00	148	36	1991/9/20	134.93	47.24	29
	LANDSAT5_TM	LT51490341990219ISP00	149	34	1990/8/7	117.83	54.81	1
	LANDSAT5_TM	LT51490351990219ISP00	149	35	1990/8/7	115.64	55.23	1
	LANDSAT5_TM	LT51490361990219ISP00	149	36	1990/8/7	113.42	55.59	29
	LANDSAT5_TM	LT51510351993209ISP00	151	35	1993/7/28	112.68	57.16	8
	LANDSAT5_TM	LT51480351994207ISP00	148	35	1994/7/26	110.71	56.56	12
2000s	LANDSAT7_ETM+	LE71450362000259SGS00	145	36	2000/9/15	141.72	52.06	13
	LANDSAT7_ETM+	LE71450362001261SGS00	145	36	2001/9/18	142.14	50.98	11
	LANDSAT7_ETM+	LE71450372000259SGS00	145	37	2000/9/15	140.12	53.02	18
	LANDSAT7_ETM+	LE71450372001261SGS00	145	37	2001/9/18	140.61	51.95	1
	LANDSAT7_ETM+	LE71460362000234SGS00	146	36	2000/8/21	129.75	58.41	26
	LANDSAT7_ETM+	LE71460362001268EDC00	146	36	2001/9/25	145.01	48.89	5
	LANDSAT7_ETM+	LE71460372000234SGS00	146	37	2000/8/21	127.49	59.11	6
	LANDSAT7_ETM+	LE71460372001236SGS00	146	37	2001/8/24	128.15	58.16	29
	LANDSAT7_ETM+	LE71460372001252SGS00	146	37	2001/9/9	136.36	54.39	25
	LANDSAT7_ETM+	LE71460372001268EDC00	146	37	2001/9/25	143.63	49.91	24
	LANDSAT7_ETM+	LE71470352000241SGS00	147	35	2000/8/28	135.22	55.99	8
	LANDSAT7_ETM+	LE71470362000241SGS00	147	36	2000/8/28	133.23	56.81	9

Periods	Satellite	Image ID	P	R	AD	SA(°)	SE(°)	CC(%)
	LANDSAT7_ETM+	LE71470362000257SGS00	147	36	2000/9/13	140.83	52.63	21
	LANDSAT7_ETM+	LE71470372000241SGS00	147	37	2000/8/28	131.16	57.59	24
	LANDSAT7_ETM+	LE71470372000257SGS00	147	37	2000/9/13	139.19	53.57	19
	LANDSAT7_ETM+	LE71480342000216SGS01	148	34	2000/8/3	126.46	60.67	6
	LANDSAT7_ETM+	LE71480342000232SGS00	148	34	2000/8/19	133.15	57.34	9
	LANDSAT7_ETM+	LE71480342001202SGS00	148	34	2001/7/21	121.18	62.46	14
	LANDSAT7_ETM+	LE71480342001250SGS00	148	34	2001/9/7	140.57	52.21	21
	LANDSAT7_ETM+	LE71480352000216SGS01	148	35	2000/8/3	123.89	61.28	10
	LANDSAT7_ETM+	LE71480352000248SGS00	148	35	2000/9/4	138.45	54.18	21
	LANDSAT7_ETM+	LE71480352001202SGS00	148	35	2001/7/21	118.34	62.95	8
	LANDSAT7_ETM+	LE71480352001266EDC00	148	35	2001/9/23	145.58	48.47	9
	LANDSAT7_ETM+	LE71480362000248SGS00	148	36	2000/9/4	136.65	55.07	4
	LANDSAT7_ETM+	LE71480362001266EDC00	148	36	2001/9/23	144.22	49.49	27
	LANDSAT7_ETM+	LE71490342000255SGS00	149	34	2000/9/11	143.12	51.26	3
	LANDSAT7_ETM+	LE71490342001241SGS00	149	34	2001/8/29	136.66	54.64	27
	LANDSAT7_ETM+	LE71490352000239SGS00	149	35	2000/8/26	134.29	56.48	24
	LANDSAT7_ETM+	LE71490352000255SGS00	149	35	2000/9/11	141.55	52.24	5
	LANDSAT7_ETM+	LE71490352001241SGS00	149	35	2001/8/29	134.78	55.48	10
	LANDSAT7_ETM+	LE71490362000239SGS00	149	36	2000/8/26	132.24	57.28	9
	LANDSAT7_ETM+	LE71490362000255SGS00	149	36	2000/9/11	139.93	53.19	4
	LANDSAT7_ETM+	LE71490362001241SGS00	149	36	2001/8/29	132.82	56.29	5
	LANDSAT7_ETM+	LE71500342000230SGS00	150	34	2000/8/17	132.28	57.8	15
	LANDSAT7_ETM+	LE71500342000246SGS01	150	34	2000/9/2	139.32	53.81	4
	LANDSAT7_ETM+	LE71500342001248SGS00	150	34	2001/9/5	139.72	52.77	11
	LANDSAT7_ETM+	LE71500352000230SGS00	150	35	2000/8/17	130.08	58.55	27
	LANDSAT7_ETM+	LE71500352000246SGS01	150	35	2000/9/2	137.53	54.71	21
	LANDSAT7_ETM+	LE71500352001232SGS00	150	35	2001/8/20	130.56	57.59	27
2010s	LANDSAT5_TM	LT51450362009227KHC00	145	36	2009/8/15	126.17	59.44	5
	LANDSAT5_TM	LT51450372009259KHC00	145	37	2009/9/16	140.26	52.7	7
	LANDSAT5_TM	LT51460362009218KHC00	146	36	2009/8/6	121.87	61.05	5
	LANDSAT5_TM	LT51460362009250KHC00	146	36	2009/9/7	137.67	54.19	2
	LANDSAT5_TM	LT51460362009266KHC00	146	36	2009/9/23	144.83	49.68	9
	LANDSAT5_TM	LT51460362010237KHC00	146	36	2010/8/25	131.35	57.52	13
	LANDSAT5_TM	LT51460362010269KHC00	146	36	2010/9/26	145.97	48.85	19
	LANDSAT5_TM	LT51460372009234KHC00	146	37	2009/8/22	127.45	58.71	19
	LANDSAT5_TM	LT51460372009250KHC00	146	37	2009/9/7	135.85	55.07	1
	LANDSAT5_TM	LT51460372009266KHC00	146	37	2009/9/23	143.42	50.7	3
	LANDSAT5_TM	LT51460372010205KHC00	146	37	2010/7/24	113.88	63.66	24
	LANDSAT5_TM	LT51460372010269KHC00	146	37	2010/9/26	144.61	49.89	7
	LANDSAT5_TM	LT51470352009225KHC00	147	35	2009/8/13	127.6	59.16	1
	LANDSAT5_TM	LT51470352009241KHC00	147	35	2009/8/29	135.19	55.61	2
	LANDSAT5_TM	LT51470352010260KHC00	147	35	2010/9/17	143.77	50.54	13

Periods	Satellite	Image ID	P	R	AD	SA(°)	SE(°)	CC(%)
	LANDSAT5_TM	LT51470362009225KHC00	147	36	2009/8/13	125.2	59.81	2
	LANDSAT5_TM	LT51470362009241KHC00	147	36	2009/8/29	133.21	56.43	20
	LANDSAT5_TM	LT51470362010260KHC00	147	36	2010/9/17	142.27	51.54	3
	LANDSAT5_TM	LT51470372009225KHC00	147	37	2009/8/13	122.71	60.41	10
	LANDSAT5_TM	LT51470372009257KHC00	147	37	2009/9/14	139.32	53.24	7
	LANDSAT5_TM	LT51470372010260KHC00	147	37	2010/9/17	140.72	52.5	8
	LANDSAT5_TM	LT51480342009200KHC00	148	34	2009/7/19	120.65	62.73	14
	LANDSAT5_TM	LT51480342009216KHC00	148	34	2009/8/4	126.12	60.22	22
	LANDSAT5_TM	LT51480342009232KHC00	148	34	2009/8/20	133.01	56.94	6
	LANDSAT5_TM	LT51480342009248KHC00	148	34	2009/9/5	140.19	52.91	4
	LANDSAT5_TM	LT51480342009264KHC00	148	34	2009/9/21	146.76	48.21	1
	LANDSAT5_TM	LT51480342010235KHC00	148	34	2010/8/23	134.54	56.41	1
	LANDSAT5_TM	LT51480342010251KHC00	148	34	2010/9/8	141.55	52.19	15
	LANDSAT5_TM	LT51480352009216KHC00	148	35	2009/8/4	123.59	60.82	5
	LANDSAT5_TM	LT51480352009232KHC00	148	35	2009/8/20	130.89	57.71	14
	LANDSAT5_TM	LT51480352010235KHC00	148	35	2010/8/23	132.49	57.21	2
	LANDSAT5_TM	LT51480362009216KHC00	148	36	2009/8/4	120.96	61.37	2
	LANDSAT5_TM	LT51480362009232KHC00	148	36	2009/8/20	128.68	58.43	17
	LANDSAT5_TM	LT51480362009264KHC00	148	36	2009/9/21	144.01	50.28	3
	LANDSAT5_TM	LT51480362010235KHC00	148	36	2010/8/23	130.36	57.97	17
	LANDSAT5_TM	LT51490342009207KHC00	149	34	2009/7/26	122.8	61.72	2
	LANDSAT5_TM	LT51490342009223KHC00	149	34	2009/8/11	129.03	58.88	8
	LANDSAT5_TM	LT51490342009239KHC00	149	34	2009/8/27	136.17	55.27	2
	LANDSAT5_TM	LT51490352009207KHC00	149	35	2009/7/26	120.05	62.24	6
	LANDSAT5_TM	LT51490352009223KHC00	149	35	2009/8/11	126.68	59.55	6
	LANDSAT5_TM	LT51490352009239KHC00	149	35	2009/8/27	134.24	56.1	3
	LANDSAT5_TM	LT51490362009207KHC00	149	36	2009/7/26	117.23	62.71	16
	LANDSAT5_TM	LT51490362009223KHC00	149	36	2009/8/11	124.23	60.18	15
	LANDSAT5_TM	LT51490362009239KHC00	149	36	2009/8/27	132.21	56.9	2
	LANDSAT5_TM	LT51490362009255KHC00	149	36	2009/9/12	140.03	52.85	18
	LANDSAT5_TM	LT51500342009262KHC00	150	34	2009/9/19	146.01	48.82	12
	LANDSAT5_TM	LT51500342010233KHC02	150	34	2010/8/21	133.66	56.88	17
	LANDSAT5_TM	LT51500352009214KHC00	150	35	2009/8/2	122.76	61.15	11
	LANDSAT5_TM	LT51500352009262KHC00	150	35	2009/9/19	144.61	49.85	2
	LANDSAT5_TM	LT51500352010233KHC02	150	35	2010/8/21	131.55	57.66	7
<b>2020s</b>	LANDSAT8_OLI	LC81450362018268LGN00	145	36	2018/9/25	149.01	50.25	12.4
	LANDSAT8_OLI	LC81450362019255LGN02	145	36	2019/9/12	143.69	54.33	1.19
	LANDSAT8_OLI	LC81450362020226LGN00	145	36	2020/8/13	129.3	61.52	11.23
	LANDSAT8_OLI	LC81450362020258LGN00	145	36	2020/9/14	144.89	53.52	0.76
	LANDSAT8_OLI	LC81450372019255LGN02	145	37	2019/9/12	142.01	55.32	0.28
	LANDSAT8_OLI	LC81450372020210LGN00	145	37	2020/7/28	118.9	64.85	22.82
	LANDSAT8_OLI	LC81450372020226LGN00	145	37	2020/8/13	126.73	62.21	16.5

Periods	Satellite	Image ID	P	R	AD	SA(°)	SE(°)	CC(%)
	LANDSAT8_OLI	LC81450372020242LGN00	145	37	2020/8/29	135.26	58.77	3.55
	LANDSAT8_OLI	LC81450372020258LGN00	145	37	2020/9/14	143.28	54.53	0.2
	LANDSAT8_OLI	LC81460362018211LGN00	146	36	2018/7/30	122.34	64	10.29
	LANDSAT8_OLI	LC81460362018243LGN00	146	36	2018/8/31	137.85	57.45	0.64
	LANDSAT8_OLI	LC81460362018259LGN00	146	36	2018/9/16	145.33	53.01	17.62
	LANDSAT8_OLI	LC81460362019246LGN00	146	36	2019/9/3	139.45	56.82	1.59
	LANDSAT8_OLI	LC81460362019262LGN00	146	36	2019/9/19	146.74	52.25	2
	LANDSAT8_OLI	LC81460362020265LGN00	146	36	2020/9/21	147.83	51.39	0.66
	LANDSAT8_OLI	LC81460372018211LGN00	146	37	2018/7/30	119.35	64.52	2.93
	LANDSAT8_OLI	LC81460372018243LGN00	146	37	2018/8/31	135.83	58.33	0.88
	LANDSAT8_OLI	LC81460372018259LGN00	146	37	2018/9/16	143.77	54.03	1.2
	LANDSAT8_OLI	LC81460372019246LGN00	146	37	2019/9/3	137.51	57.73	10.1
	LANDSAT8_OLI	LC81460372019262LGN00	146	37	2019/9/19	145.24	53.3	0.68
	LANDSAT8_OLI	LC81460372020217LGN00	146	37	2020/8/4	122.15	63.79	19.34
	LANDSAT8_OLI	LC81460372020249LGN00	146	37	2020/9/5	138.9	57.01	16.01
	LANDSAT8_OLI	LC81460372020265LGN00	146	37	2020/9/21	146.41	52.46	0.35
	LANDSAT8_OLI	LC81470352018234LGN00	147	35	2018/8/22	135.53	58.79	24.69
	LANDSAT8_OLI	LC81470352019205LGN00	147	35	2019/7/24	123.18	64.51	6.03
	LANDSAT8_OLI	LC81470352019253LGN00	147	35	2019/9/10	144.43	53.9	0.74
	LANDSAT8_OLI	LC81470352019269LGN00	147	35	2019/9/26	150.79	48.95	1.06
	LANDSAT8_OLI	LC81470362018234LGN00	147	36	2018/8/22	133.33	59.62	22.71
	LANDSAT8_OLI	LC81470362019253LGN00	147	36	2019/9/10	142.78	54.9	1.61
	LANDSAT8_OLI	LC81470362019269LGN00	147	36	2019/9/26	149.51	50.07	2.91
	LANDSAT8_OLI	LC81470362020256LGN00	147	36	2020/9/12	144	54.1	9.43
	LANDSAT8_OLI	LC81470372018234LGN00	147	37	2018/8/22	131.03	60.39	21.54
	LANDSAT8_OLI	LC81470372019253LGN00	147	37	2019/9/10	141.04	55.88	1
	LANDSAT8_OLI	LC81470372019269LGN00	147	37	2019/9/26	148.18	51.17	6.28
	LANDSAT8_OLI	LC81470372020224LGN00	147	37	2020/8/11	125.69	62.58	13.69
	LANDSAT8_OLI	LC81470372020256LGN00	147	37	2020/9/12	142.35	55.1	3.04
	LANDSAT8_OLI	LC81480342019228LGN00	148	34	2019/8/16	135.12	59.51	16.89
	LANDSAT8_OLI	LC81480342019244LGN00	148	34	2019/9/1	142.2	55.46	3.58
	LANDSAT8_OLI	LC81480342020231LGN00	148	34	2020/8/18	136.3	58.85	1.25
	LANDSAT8_OLI	LC81480342020247LGN00	148	34	2020/9/3	143.36	54.68	20.88
	LANDSAT8_OLI	LC81480352018241LGN00	148	35	2018/8/29	138.85	57.06	20.12
	LANDSAT8_OLI	LC81480352019212LGN00	148	35	2019/7/31	125.79	63.41	24.49
	LANDSAT8_OLI	LC81480352020263LGN00	148	35	2020/9/19	148.43	50.93	4.49
	LANDSAT8_OLI	LC81480362018241LGN00	148	36	2018/8/29	136.86	57.95	5.56
	LANDSAT8_OLI	LC81480362019228LGN00	148	36	2019/8/16	130.45	61.08	12.62
	LANDSAT8_OLI	LC81480362020215LGN00	148	36	2020/8/2	124.09	63.54	23
	LANDSAT8_OLI	LC81480362020247LGN00	148	36	2020/9/3	139.79	56.61	15.4
	LANDSAT8_OLI	LC81480362020263LGN00	148	36	2020/9/19	147.02	52.01	1.5
	LANDSAT8_OLI	LC81490342018200LGN00	149	34	2018/7/19	124.43	64.49	23.06



Periods	Satellite	Image ID	P	R	AD	SA(°)	SE(°)	CC(%)
	LANDSAT8_OLI	LC81490342018216LGN00	149	34	2018/8/4	129.89	61.86	10.01
	LANDSAT8_OLI	LC81490342018232LGN00	149	34	2018/8/20	136.73	58.42	16.87
	LANDSAT8_OLI	LC81490342018264LGN00	149	34	2018/9/21	150.14	49.3	12.04
	LANDSAT8_OLI	LC81490342019235LGN00	149	34	2019/8/23	138.22	57.83	10.16
	LANDSAT8_OLI	LC81490342019267LGN00	149	34	2019/9/24	151.33	48.47	0.48
	LANDSAT8_OLI	LC81490342020206LGN00	149	34	2020/7/24	126.32	63.77	11.4
	LANDSAT8_OLI	LC81490342020238LGN00	149	34	2020/8/25	139.41	57.12	1.92
	LANDSAT8_OLI	LC81490342020254LGN00	149	34	2020/9/10	146.29	52.63	16.63
	LANDSAT8_OLI	LC81490352018216LGN00	149	35	2018/8/4	127.27	62.55	2.57
	LANDSAT8_OLI	LC81490352018232LGN00	149	35	2018/8/20	134.58	59.26	17.03
	LANDSAT8_OLI	LC81490352018264LGN00	149	35	2018/9/21	148.82	50.41	10.56
	LANDSAT8_OLI	LC81490352019203LGN00	149	35	2019/7/22	122.52	64.8	22.71
	LANDSAT8_OLI	LC81490352019219LGN00	149	35	2019/8/7	128.73	62.15	9.79
	LANDSAT8_OLI	LC81490352019235LGN00	149	35	2019/8/23	136.15	58.71	19.61
	LANDSAT8_OLI	LC81490352019267LGN00	149	35	2019/9/24	150.07	49.59	1.11
	LANDSAT8_OLI	LC81490352020206LGN00	149	35	2020/7/24	123.4	64.38	3.22
	LANDSAT8_OLI	LC81490352020238LGN00	149	35	2020/8/25	137.42	58.02	5.48
	LANDSAT8_OLI	LC81490362018216LGN00	149	36	2018/8/4	124.54	63.19	10.23
	LANDSAT8_OLI	LC81490362018232LGN00	149	36	2018/8/20	132.33	60.06	15.61
	LANDSAT8_OLI	LC81490362018264LGN00	149	36	2018/9/21	147.44	51.49	5.24
	LANDSAT8_OLI	LC81490362019235LGN00	149	36	2019/8/23	133.98	59.54	18.28
	LANDSAT8_OLI	LC81490362019251LGN00	149	36	2019/9/8	141.85	55.46	16.34
	LANDSAT8_OLI	LC81490362019267LGN00	149	36	2019/9/24	148.75	50.7	8.73
	LANDSAT8_OLI	LC81490362020206LGN00	149	36	2020/7/24	120.37	64.92	14.55
	LANDSAT8_OLI	LC81490362020254LGN00	149	36	2020/9/10	143.1	54.68	11.55
	LANDSAT8_OLI	LC81500342018255LGN00	150	34	2018/9/12	146.69	52.12	1.74
	LANDSAT8_OLI	LC81500342019258LGN00	150	34	2019/9/15	148.01	51.34	13.81
	LANDSAT8_OLI	LC81500342020213LGN00	150	34	2020/7/31	128.78	62.59	4.44
	LANDSAT8_OLI	LC81500342020229LGN00	150	34	2020/8/16	135.42	59.32	1.48
	LANDSAT8_OLI	LC81500352018223LGN00	150	35	2018/8/11	130.37	61.21	4.18
	LANDSAT8_OLI	LC81500352018255LGN00	150	35	2018/9/12	145.17	53.16	1.41
	LANDSAT8_OLI	LC81500352019258LGN00	150	35	2019/9/15	146.56	52.41	16.99
	LANDSAT8_OLI	LC81500352020229LGN00	150	35	2020/8/16	133.16	60.13	2.24

**Table S2** The results of multi-manual digitization of 37 glaciers. STD is standard deviation and Diff. is glacier area difference between the mean of MMD results and KGI-2020s.

MMD Type	Glacier	MMD results				This Study			
		Area(km <sup>2</sup> )				%	KGI-2020s	Diff.(km <sup>2</sup> )	Diff.(%)
		MIN	MAX	MEAN	STD	STD	Area(km <sup>2</sup> )		
<b>Image: Landsat 8 30 m image</b>	1	0.74	0.98	0.87	0.10	11.81	0.69	-0.18	-26.18
<b>Date:2020-08-25</b>	2	2.40	3.27	2.87	0.36	12.60	2.56	-0.31	-10.87
<b>Number of digitization: 4</b>	3	1.71	2.02	1.84	0.15	8.09	1.74	-0.10	-5.53
	4	0.55	0.83	0.68	0.12	17.63	0.84	0.16	23.16
	5	0.64	0.84	0.69	0.10	14.09	0.61	-0.08	-11.88
	6	0.13	0.21	0.15	0.04	25.93	0.13	-0.03	-18.12
	7	0.14	0.17	0.15	0.01	9.83	0.14	-0.01	-7.53
	8	2.95	3.07	3.01	0.05	1.54	2.75	-0.25	-8.42
	9	8.33	8.59	8.46	0.11	1.34	7.49	-0.97	-11.42
	10	4.26	4.87	4.57	0.25	5.46	4.71	0.14	3.00
	11	0.26	0.37	0.33	0.05	15.62	0.32	-0.01	-3.41
	12	2.62	3.07	2.89	0.21	7.34	3.03	0.14	4.80
	13	1.23	1.31	1.28	0.04	3.17	1.28	0.00	-0.30
	14	1.36	1.50	1.42	0.07	4.63	1.21	-0.21	-14.75
	15	1.55	2.15	1.86	0.25	13.57	1.43	-0.44	-23.38
	16	0.53	0.66	0.61	0.05	9.04	0.65	0.05	7.88
	17	0.17	0.22	0.19	0.02	11.53	0.10	-0.09	-49.01
	All	29.55	34.12	31.88	0.73	2.29	29.67	-2.21	-6.92
<b>Image: Sentinel-2 10 m images</b>	18	1.13	1.24	1.20	0.05	4.04	1.15	-0.06	-4.65
<b>Date:2020-08-25, 2020-08-23</b>	19	2.32	2.68	2.47	0.12	4.85	3.17	0.70	28.29
<b>Number of digitization: 5</b>	20	10.58	10.75	10.67	0.08	0.75	12.33	1.67	15.63
	21	4.88	5.25	5.06	0.16	3.10	6.85	1.78	35.24
	22	4.23	4.28	4.25	0.02	0.48	3.95	-0.30	-7.00
	23	0.51	0.59	0.54	0.03	6.42	0.61	0.07	13.41
	24	3.50	3.60	3.55	0.04	1.02	4.11	0.56	15.84
	25	3.68	3.75	3.72	0.03	0.71	4.15	0.43	11.56
	26	7.81	8.80	8.40	0.18	2.16	9.07	0.68	8.04
	27	4.80	5.58	5.24	0.24	4.51	5.35	0.11	2.13
	28	9.22	10.32	9.85	0.21	2.17	12.47	2.61	26.54
	29	3.64	4.21	3.78	0.28	7.39	4.33	0.55	14.42
	30	60.44	64.59	62.12	1.85	2.97	61.45	-0.68	-1.09
	31	29.02	29.93	29.26	0.44	1.51	30.87	1.61	5.49
	32	14.77	15.11	14.93	0.13	0.90	16.69	1.76	11.79
	33	93.46	95.51	94.70	0.48	0.51	96.13	1.43	1.51
	34	8.05	8.34	8.15	0.14	1.71	8.88	0.73	8.94
	35	16.80	17.15	16.91	0.16	0.94	19.15	2.25	13.29
	All	278.85	291.67	284.81	3.58	1.26	300.71	15.90	5.58
<b>Image: Sentinel-2 10 m image</b>	1	-	-	1.22	-	-	0.69	-0.53	-77.18
<b>Date:2020-08-25</b>	2	-	-	2.57	-	-	2.56	-0.01	-0.46
<b>Number of digitization: 1</b>	3	-	-	1.46	-	-	1.74	0.28	16.16

MMD Type	Glacier	MMD results				This Study			
		Area(km <sup>2</sup> )		%		KGI-2020s	Diff.(km <sup>2</sup> )	Diff.(%)	
		MIN	MAX	MEAN	STD	STD	Area(km <sup>2</sup> )		
	4	-	-	0.69	-	-	0.84	0.15	18.00
	5	-	-	0.70	-	-	0.61	-0.09	-14.85
	6	-	-	0.14	-	-	0.13	-0.02	-13.43
	7	-	-	0.16	-	-	0.14	-0.02	-11.67
	8	-	-	3.17	-	-	2.75	-0.42	-15.29
	9	-	-	8.55	-	-	7.49	-1.06	-14.13
	10	-	-	4.59	-	-	4.71	0.12	2.50
	11	-	-	0.23	-	-	0.32	0.08	26.18
	12	-	-	3.02	-	-	3.03	0.01	0.45
	13	-	-	1.25	-	-	1.28	0.03	2.38
	14	-	-	1.31	-	-	1.21	-0.10	-8.65
	15	-	-	1.68	-	-	1.43	-0.25	-17.41
	16	-	-	0.60	-	-	0.65	0.05	7.66
	17	-	-	0.22	-	-	0.10	-0.12	-124.73
	All	-	-	31.57	-	-	29.67	-1.90	-6.39
<b>Image: Planet 3m image</b>	36	-	-	13.74	-	-	14.83	1.09	7.34
<b>Date:2019-05-29</b>	37	-	-	16.26	-	-	15.94	-0.32	-2.01
<b>Number of digitization: 1</b>	All	-	-	30.00	-	-	30.76	0.77	2.56
<b>All types</b>	Total	-	-	376.95	-	-	390.83	13.88	3.68

**Table S3.** Debris cover area of glaciers according to different size class or regions during 1990~2020.

Size / Regions	Glacier Aara (%)	Debris Area (DA) (km <sup>2</sup> )				DA (%)	DA Change (1990-2020)	
	2020s	1990s	2000s	2010s	2020s	2020s	(km <sup>2</sup> )	(%)
< 0.05	0.16	0.03	2.37	0.04	0.16	0.01	0.14	528.2
0.05 ~ 0.1	0.53	0.06	0.27	0.05	0.53	0.02	0.47	799.04
0.1 ~ 0.5	4.11	8.43	12.65	5.28	9.58	0.42	1.15	13.65
0.5 ~ 1	4.52	21.74	33.9	22.37	39.46	1.72	17.72	81.47
1 ~ 5	18.72	179.17	219.31	196.44	258.3	11.27	79.12	44.16
5 ~ 10	9.91	129.23	159.55	144.31	170.76	7.45	41.53	32.14
10 ~ 50	19.12	356.49	384.38	355.69	413.90	18.07	57.41	16.1
50 ~ 100	9.77	280.04	317.26	294.72	321.21	14.02	41.17	14.7
> 100	33.01	975.65	1044.23	999.36	1088.83	47.53	113.18	11.60
WK	27.15	734.92	781.57	695.62	804.32	35.11	69.4	9.44
CK	55.28	1162.03	1293.82	1228.2	1382.68	60.35	220.65	18.99
EK	17.57	50.69	84.87	91.55	103.95	4.54	53.25	105.05
NK	54.74	621.21	690.84	694.06	790.1	34.49	168.89	27.19
SK	45.26	1326.44	1469.42	1321.31	1500.85	65.51	174.41	13.15
<b>Total</b>	-	1947.65	2160.26	2015.37	2290.95	-	343.30	17.63

**Table S4.** KGI-2020s inventory topographic parameters (elevation units: m a.s.l.)

Glacier size (km <sup>2</sup> )	< 0.05	0.05 - 0.1	0.1 - 0.5	0.5 - 1	1 - 5	5 - 10	10- 50	50 - 100	> 100	DF	DC
<b>Min elevation</b>	4143	3988	3609	3237	2719	2801	2401	2412	2608	3175	2401
<b>Max elevation</b>	7856	7265	7923	6739	7146	7810	7681	8546	8564	7923	8564
<b>Median elevation</b>	5713	5543	5493	5471	5468	5487	5465	5280	5388	5567	5270
<b>Elevation range</b>	3713	3277	4314	3502	4427	5009	5280	6134	5956	4748	6163
<b>Mean slope (°)</b>	28.76	30.72	29.76	27.25	23.62	20.71	20.03	21.75	19.6	28.45	24.63

\* DF: Debris-free (clean ice/snow); DC: Debris-covered

**Table S5.** Number and area of glaciers according to different regions during 1990~2020.

Regions	Glacier Number (GN)				Glacier Area (GA) (km <sup>2</sup> )				GN (%)	GA (%)	AC (%)
	1990s	2000s	2010s	2020s	1990s	2000s	2010s	2020s	2020s		1990-2020
<b>WK</b>	3124	3108	3031	3054	6036.59	6063.33	6135.14	6112.65	29.09	27.15	1.26
<b>CK</b>	4722	4379	4687	4589	12362.89	12416.84	12547.12	12443.78	43.71	55.28	0.65
<b>EK</b>	2797	2764	2733	2855	4087.81	4096.51	4122.60	3954.3	27.20	17.57	-3.27
<b>NK</b>	7084	6723	7061	7080	12382.92	12461.6	12533.17	12321.74	67.44	54.74	-0.49
<b>SK</b>	3559	3528	3390	3418	10104.36	10115.08	10271.69	10188.99	32.56	45.26	0.84
<b>Total</b>	10643	10251	10451	10498	22487.28	22576.68	22804.86	22510.73	100	100	0.1

**Table S6** Glacier, debris cover, median glacier altitude and its variation ( $\Delta G$ ,  $\Delta D$  and  $\Delta E$ ) in sub-basin of Karakoram mountains during 1999~2020. Note that the basin scale median elevation is calculated from that of all individual glaciers and its error refers to 95% confidence interval.

Sub-Basin	Glacier 2020s	Area-2020s	Debris-2020s	Median Elevation (m a.s.l.)				1990-2020		
	km <sup>2</sup>		(%)	1990s	2000s	2010s	2020s	$\Delta G$	$\Delta D$	$\Delta E$
<b>GH</b>	4974.34±250.21		14.72	5219±16.81	5220±16.06	5214±16.27	5213±16.27	62.58±3.15	29.90±1.5	-6
<b>Shigar</b>	3481.02±175.1		16.64	5114±29.88	5111±28.92	5102±30.5	5107±30.2	49.37±2.48	48.59±2.44	-7
<b>Shyok</b>	7918.54±398.3		7.78	5814±10	5817±10	5814±10.11	5831±10	-31.86±1.6	156.81±7.89	+7
<b>ST</b>	5574.06±280.38		5.87	5595±9.55	5592±9.73	5593±9.73	5601±9.72	-50.08±2.52	80.96±4.07	+6
<b>Wakhan</b>	562.77±28.31		6.3	5122.5±14.62	5124±14.73	5213±14.68	5122±14.46	-06.55±0.33	26.38±1.33	-5
<b>All</b>	<b>22510.73 ± 1132.29</b>		10.18	5555±7.76	5553±7.76	5555±7.84	5568±7.85	23.45±1.18	343.30±17.26	+13

\* GH: Gilgit-Hunza; ST: Sub-Tarim