

Contemporary Snow Changes in the Karakoram Region Attributed to Improved MODIS Data between 2003 and 2018

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This supplementary information contains eleven figures and eight tables.

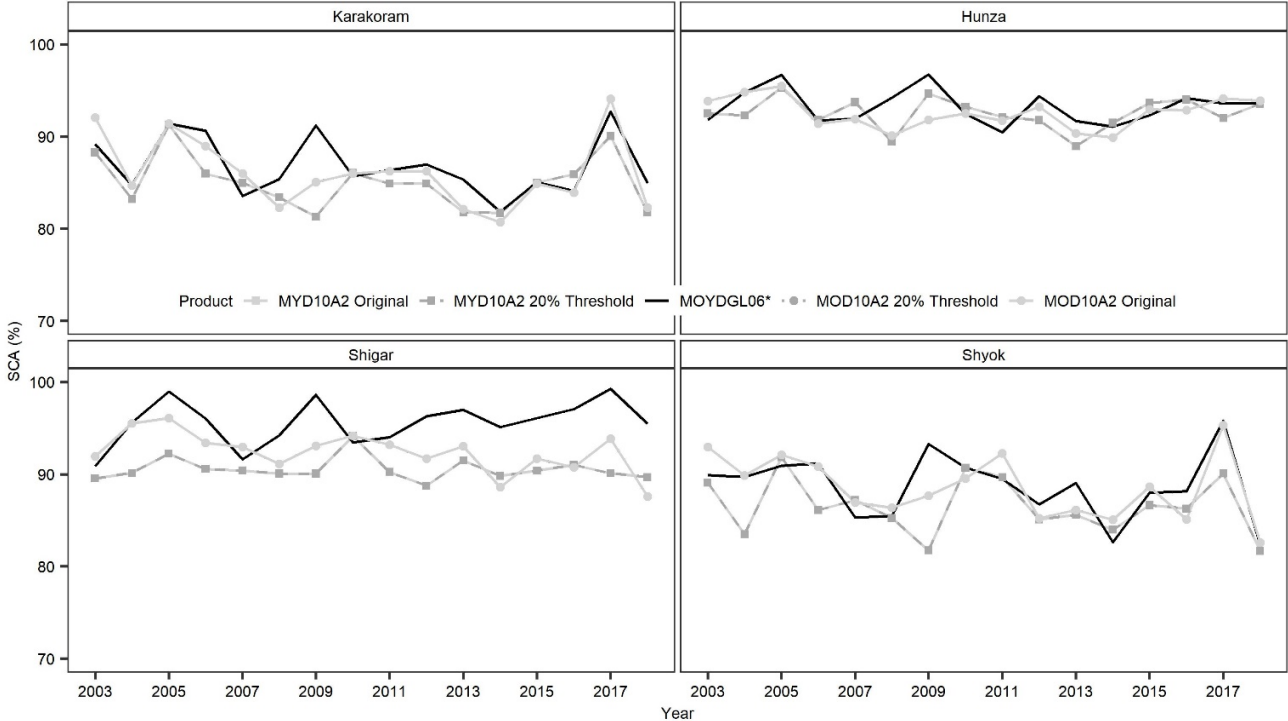


Figure S1. Time series of the annual maximum SCA from 2003 to 2018 using all the snow products.

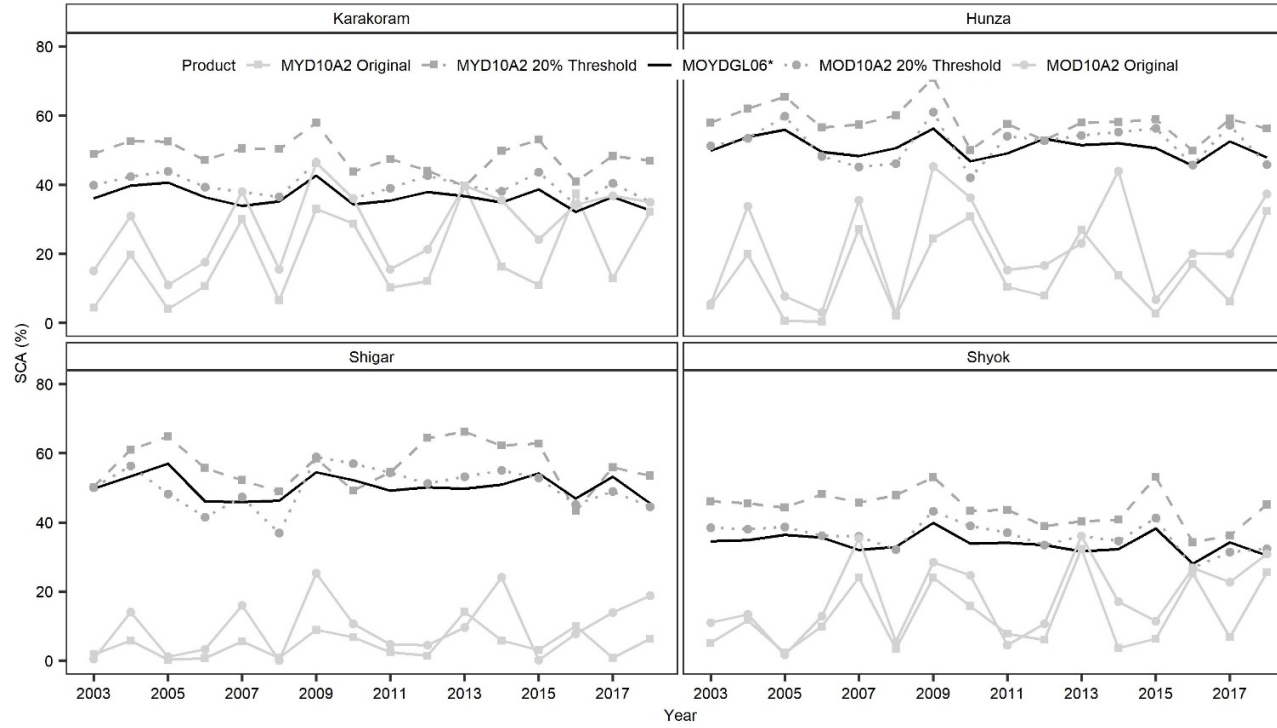


Figure S2. Time series of the annual minimum SCA from 2003 to 2018 using all the snow products.

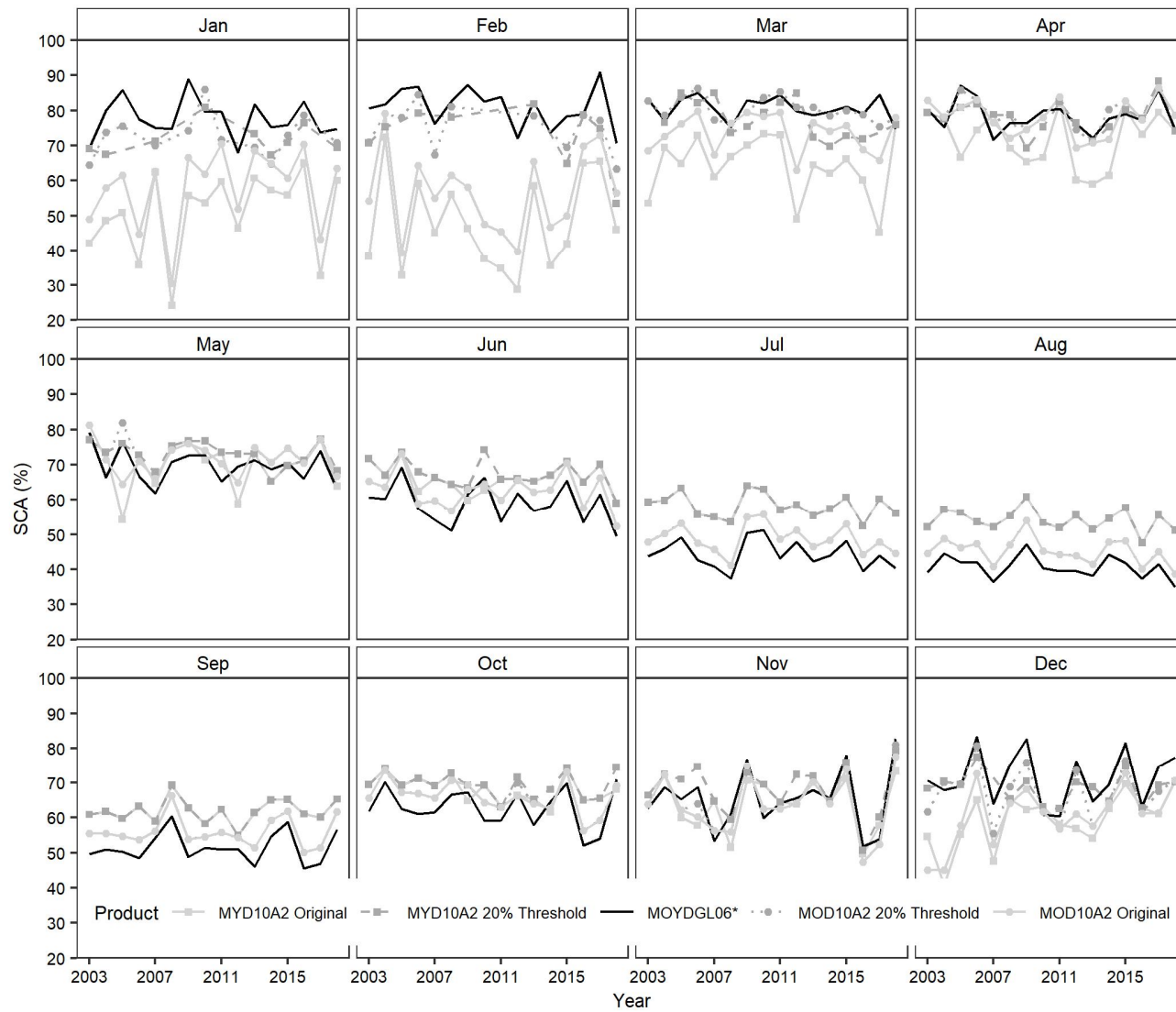


Figure S3. Monthly average snow cover area for the Karakoram region from 2003 to 2019.

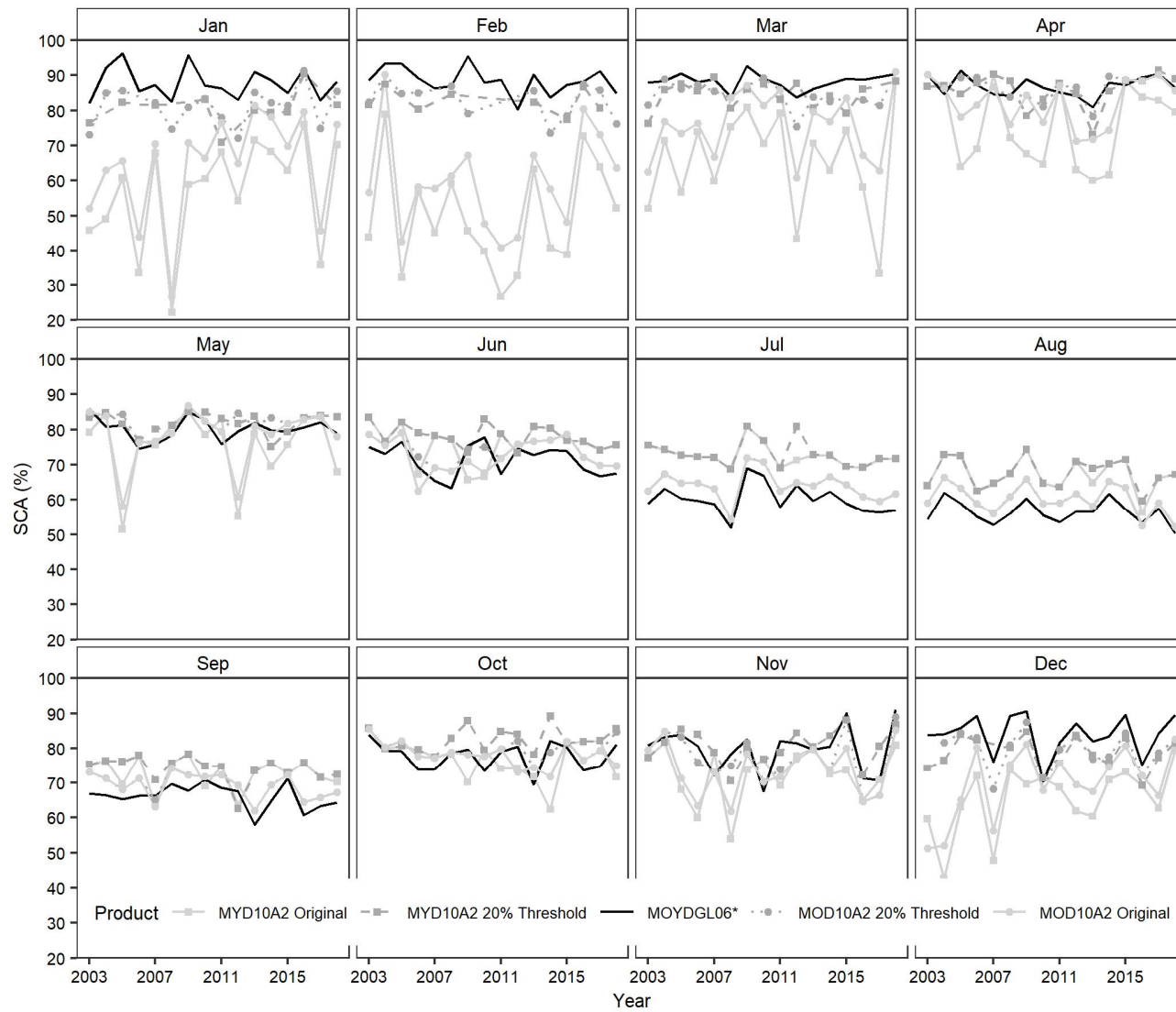


Figure S4. Monthly average snow cover area for Hunza subbasin from 2003 to 2019.

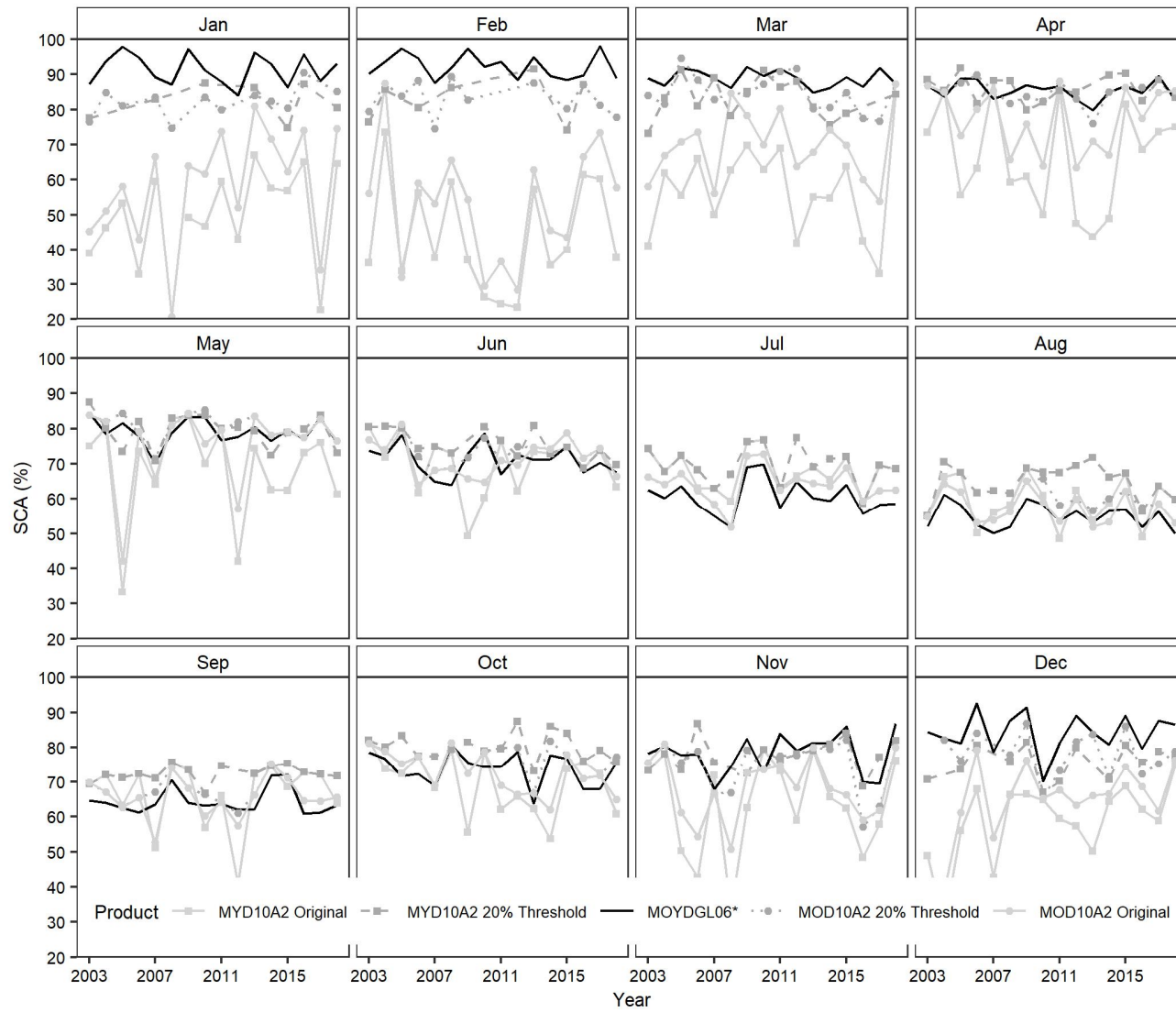


Figure S5. Monthly average snow cover area for Shigar subbasin from 2003 to 2019.

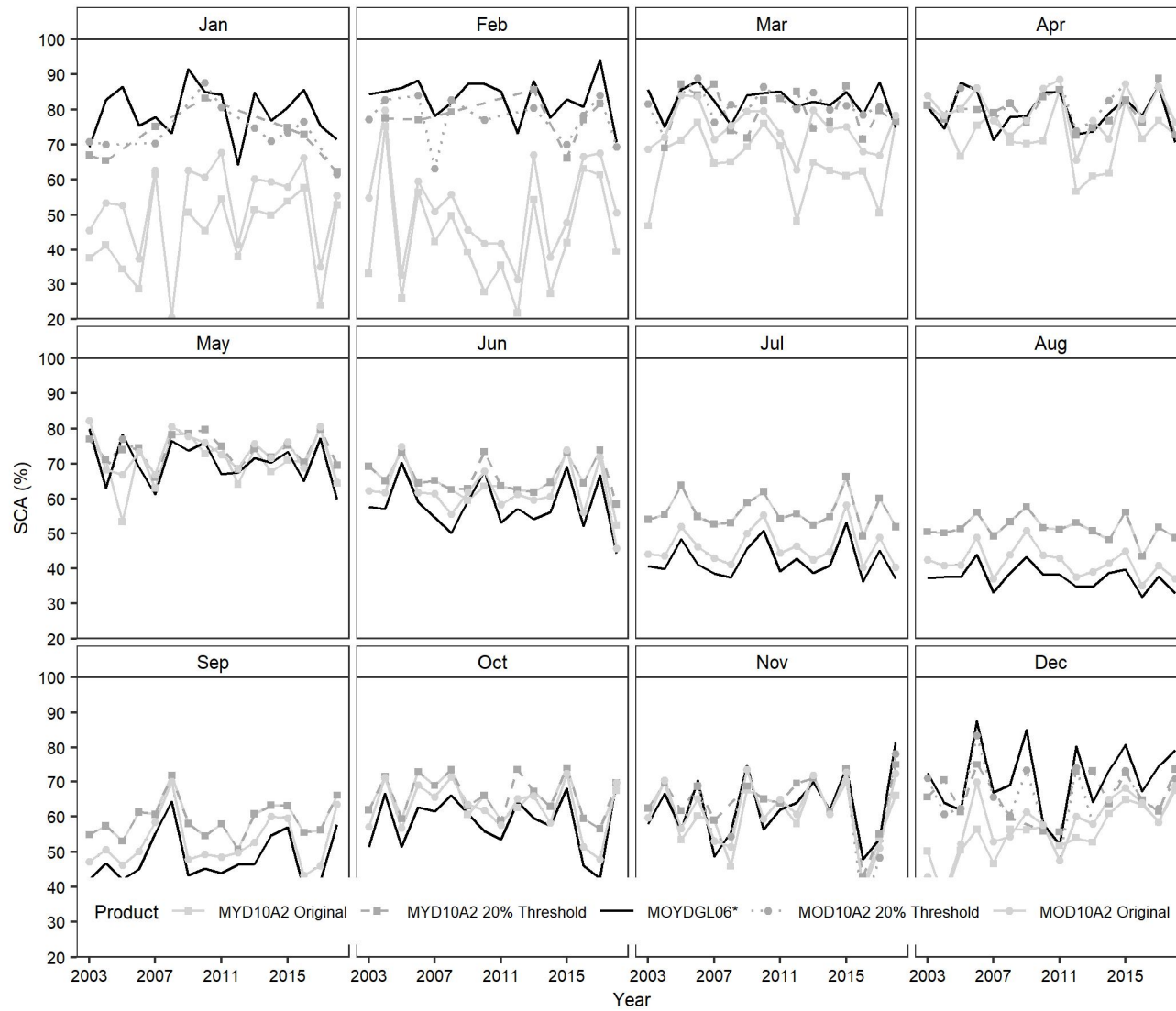


Figure S6. Monthly average snow cover area for Shyok subbasin from 2003 to 2019.

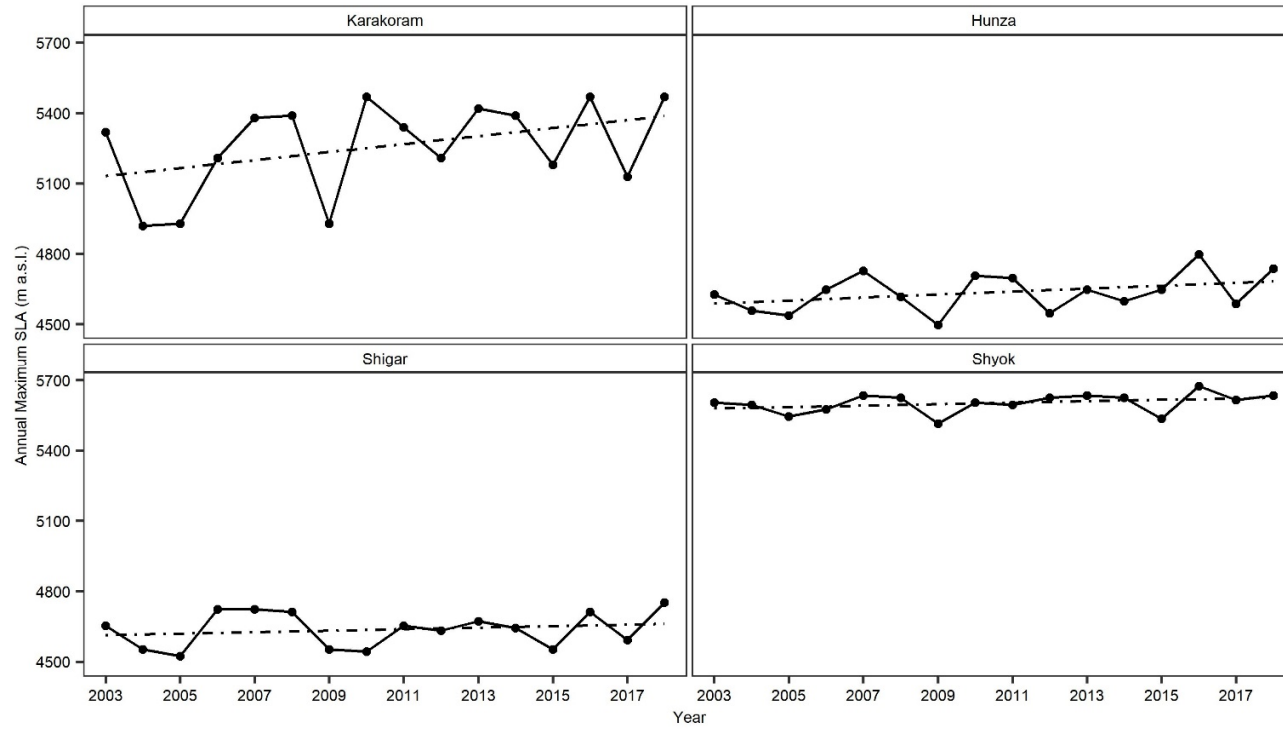


Figure S7. Annual maximum ELA in improved product from 2003-2018. The dashed black line shows the linear trend.

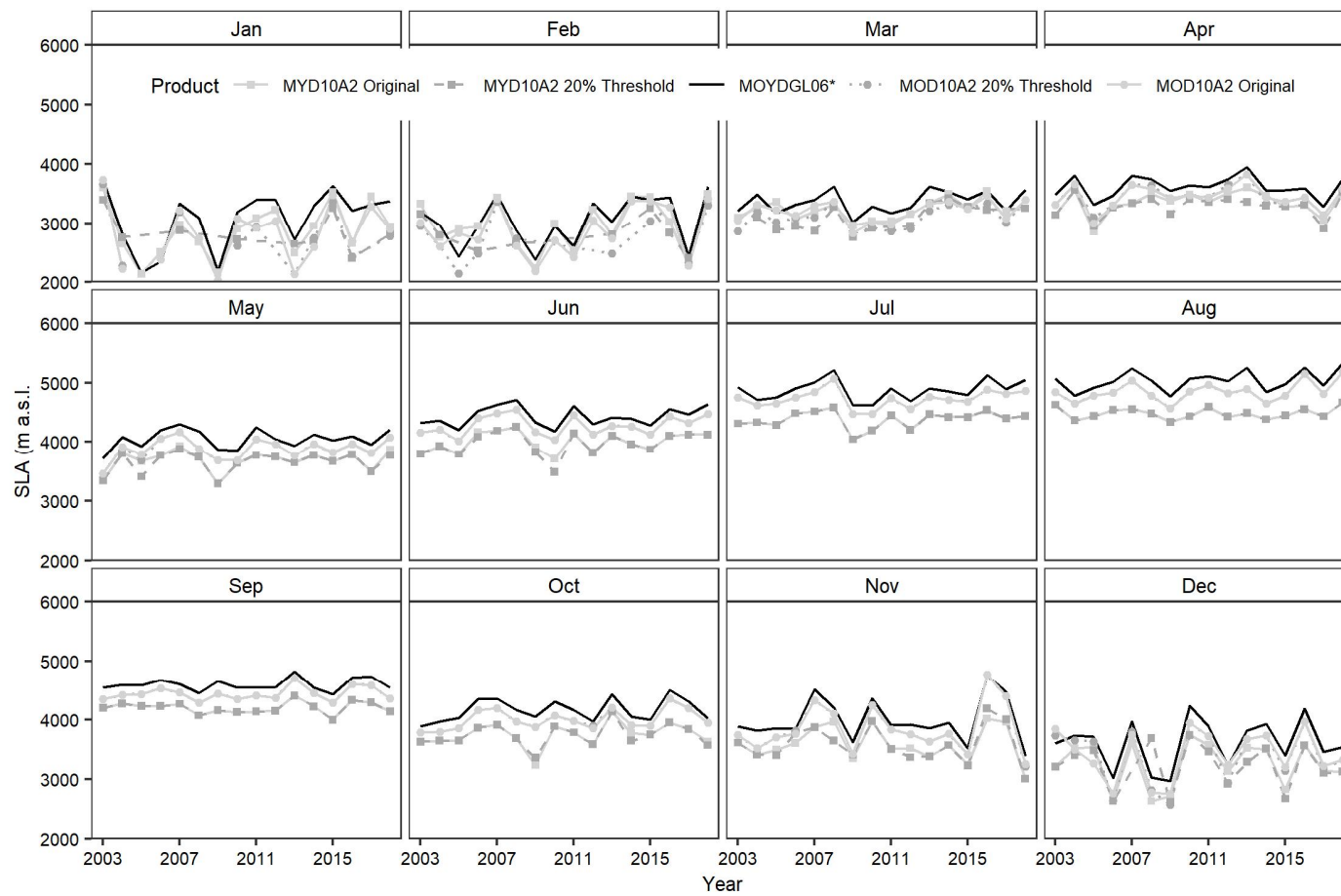


Figure S8. Time series of monthly average SLA for Karakoram region from 2003 to 2019.

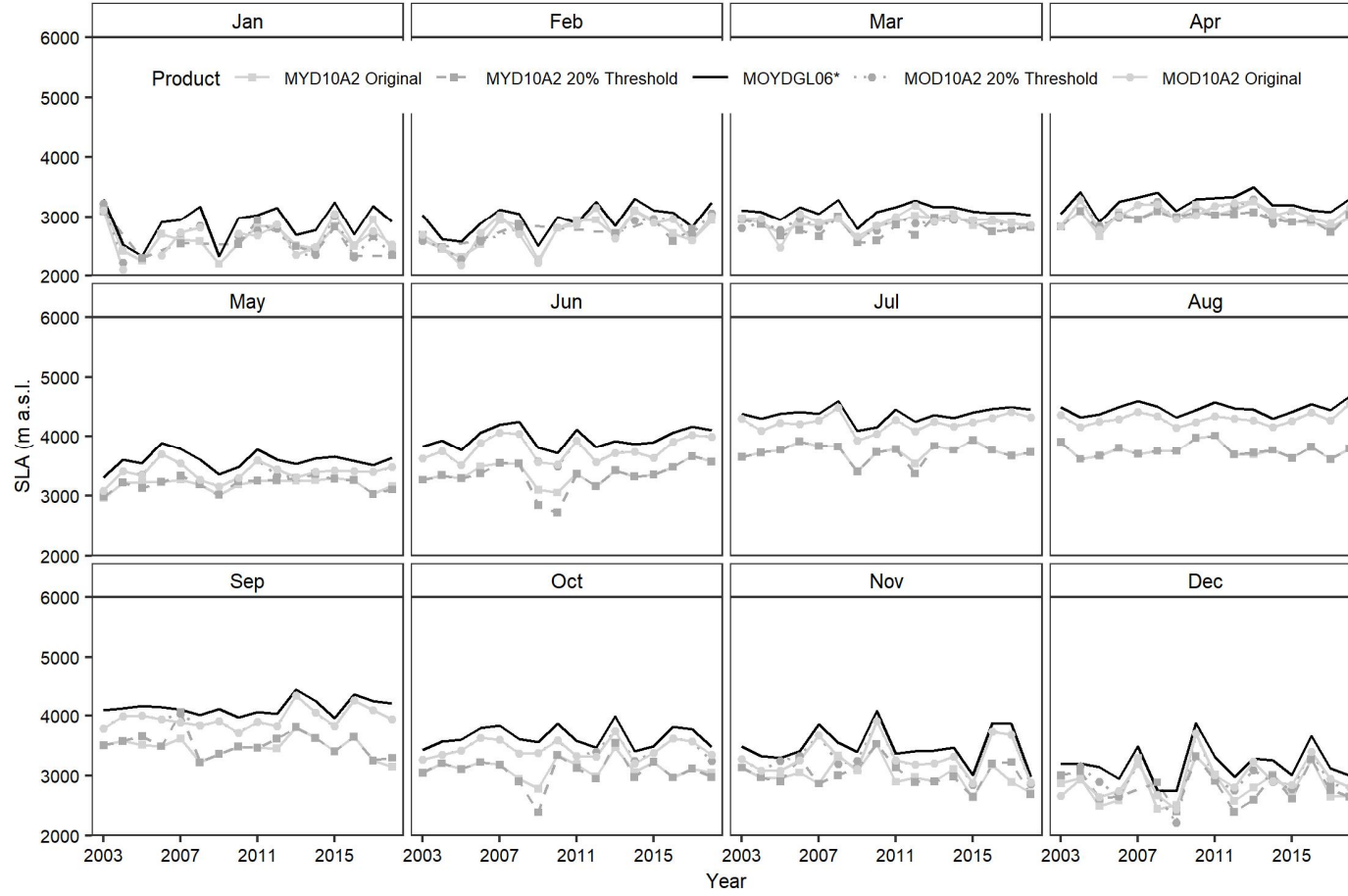


Figure S9. Time series of monthly average SLA for Hunza subbasin from 2003 to 2019.

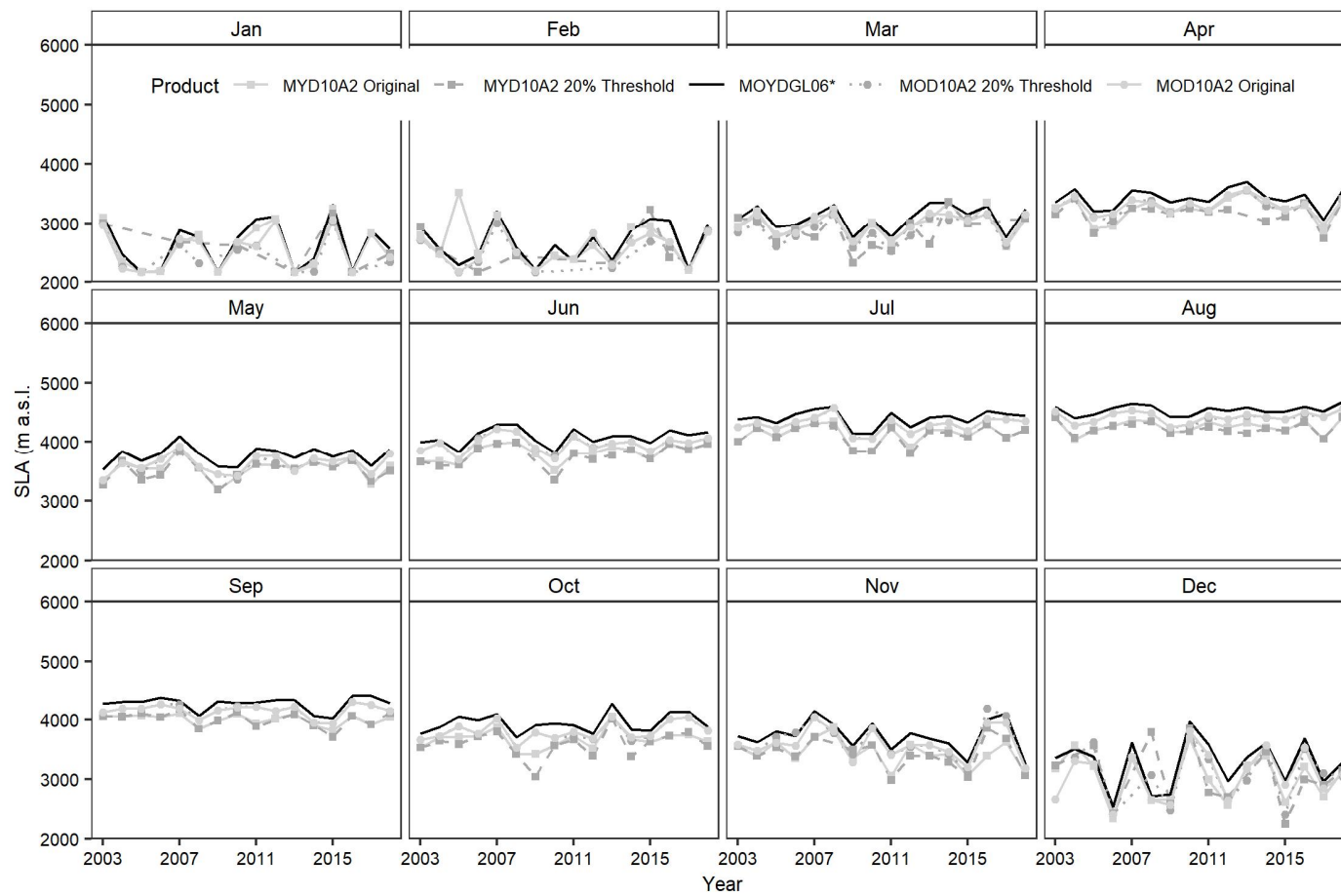


Figure S10. Time series of monthly average SLA for Shigar subbasin from 2003 to 2019.

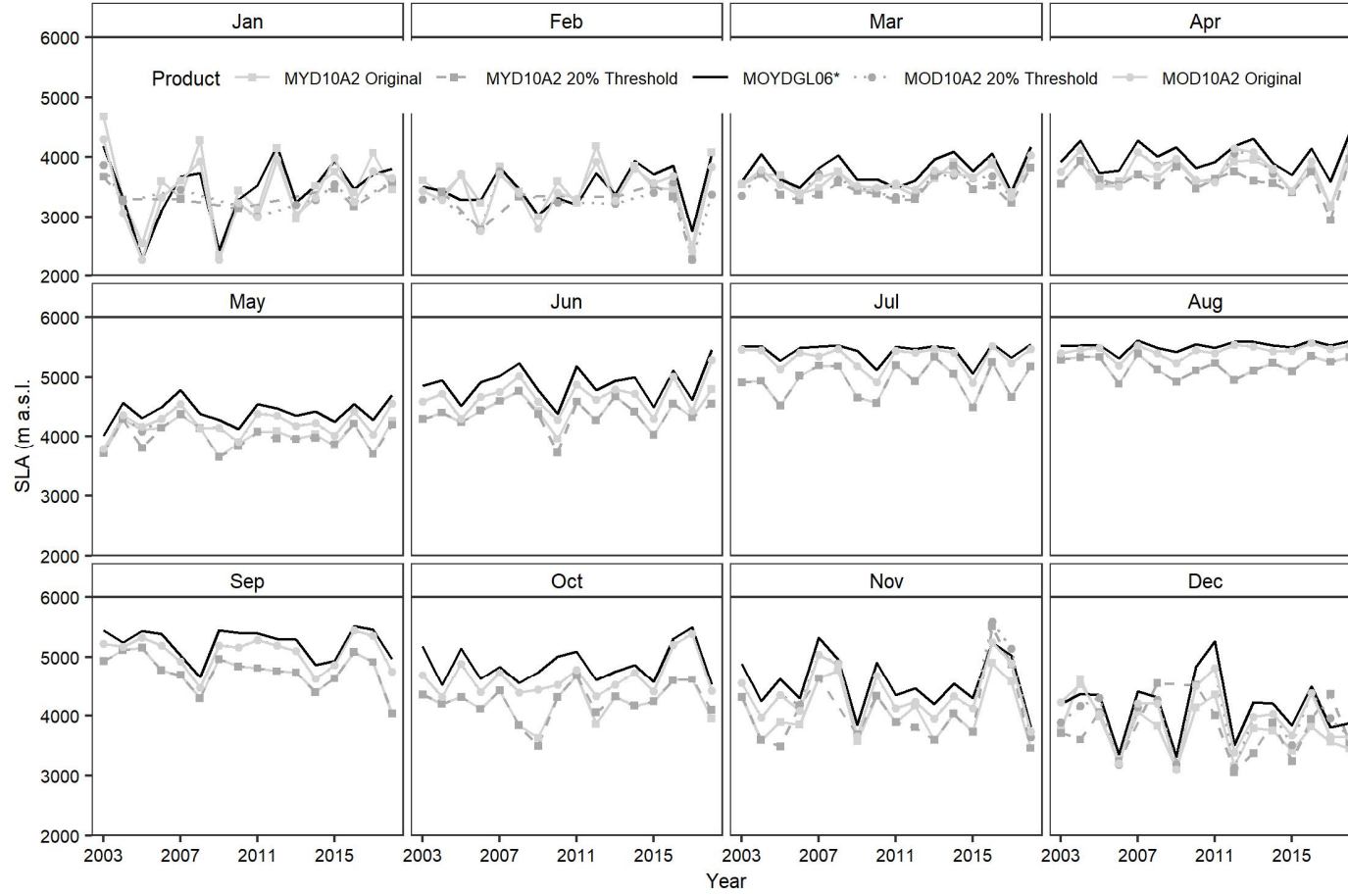


Figure S11. Time series of monthly average SLA for Shyok subbasin from 2003 to 2019.

Table S1. Cloud cover in the original M*D10A2 products. Number in the table represents the images. A total of 735 images are analyzed.

Product	MOD10A2						MYD10A2					
	>50	>40	>30	>20	>10	>5	>50	>40	>30	>20	>10	>5
Karakoram	25	37	67	122	215	295	41	78	123	189	313	417
Hunza	43	62	94	140	234	328	75	111	152	221	336	442
Shigar	75	93	138	182	275	354	125	175	211	292	390	463
Shyok	39	65	97	139	228	296	39	65	97	139	228	296

Table S2. Mean and standard deviation of annual minimum and maximum SCA (%) of the Karakoram region and subbasins using all the snow products.

Product	MYD10A2 Original		MYD10A2 20% Threshold		MOYDGL06*		MOD10A2 20% Threshold		MOD10A2 Original	
	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.
Karakoram	19±12	85±3	48±5	85±3	36±3	87±3	40±3	86±4	28±11	86±4
Hunza	14±11	93±2	58±5	93±2	51±3	93±2	52±6	93±2	22±15	93±2
Shigar	5±4	91±1	56±7	91±1	50±4	96±2	50±6	92±2	10±8	92±2
Shyok	13±10	87±3	44±5	87±3	34±3	89±4	36±4	89±4	18±11	89±4

Table S3. Annual minimum and maximum snow cover trends (% per year) in the Karakoram region and subbasins. Italic bold numbers are statistically significant at the 90% confidence level.

Product	MYD10A2 Original		MYD10A2 20% Threshold		MOYDGL06*		MOD10A2 20% Threshold		MOD10A2 Original	
	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.
Karakoram	<i>0.85</i>	-0.13	-0.37	-0.13	-0.22	-0.18	-0.28	-0.42	0.89	-0.42
Hunza	0.66	-0.03	-0.21	-0.03	-0.16	-0.03	0.1	-0.03	0.99	-0.03
Shigar	0.17	-0.02	0.07	-0.02	-0.05	0.22	-0.28	<i>-0.28</i>	0.6	<i>-0.28</i>
Shyok	0.29	-0.16	<i>-0.59</i>	-0.16	<i>-0.26</i>	-0.23	<i>-0.44</i>	<i>-0.41</i>	1.05	<i>-0.41</i>

Table S4. Trend analysis of monthly mean SCA (% per year) from 2003 to 2018. Numbers in italicized bold are statistically significant at 90% confidence level.

Area	Karakoram					Hunza					Shigar					Shyok				
	a	b	c	d	e	a	b	c	d	e	a	b	c	d	e	a	b	c	d	e
Jan	0.9	0.3	-0.1	0.1	0.7	1.5	0.4	0.0	0.1	1.4	1.3	0.5	-0.1	0.5	1.5	1.1	-0.6	-0.2	0.0	0.5
Feb	0.3	-0.8	-0.5	-0.7	0.2	0.3	-0.4	-0.2	-0.5	0.5	0.1	1.6	-0.2	-0.3	0.3	0.2	0.6	-0.3	-0.4	-0.1
Mar	-0.2	-0.7	-0.2	-0.4	-0.1	0.4	0.1	0.1	-0.3	0.4	0.1	-0.2	-0.1	-0.4	0.1	-0.4	-0.2	-0.2	-0.1	-0.3
Apr	-0.3	-0.1	-0.1	-0.1	-0.1	-0.4	0.1	0.0	-0.1	0.1	-0.7	-0.1	-0.1	-0.1	-0.1	-0.4	-0.2	-0.1	0.0	-0.1
May	-0.3	-0.4	-0.3	-0.3	0.0	-0.1	0.0	-0.1	-0.1	0.2	-0.4	-0.3	-0.2	-0.3	-0.2	-0.2	-0.1	-0.5	-0.3	-0.2
Jun	-0.1	-0.3	-0.4	-0.2	-0.2	-0.2	-0.4	-0.3	-0.2	0.0	-0.5	-0.6	-0.2	-0.2	0.1	-0.2	-0.2	-0.4	-0.2	-0.2
Jul	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1
Aug	-0.1	-0.1	-0.3	-0.4	-0.4	0.0	-0.1	-0.1	-0.3	-0.3	0.1	-0.1	-0.2	0.0	-0.3	-0.2	-0.2	-0.2	-0.3	-0.3
Sep	0.1	0.1	0.1	-0.1	-0.1	-0.2	-0.3	-0.2	-0.3	-0.3	0.1	0.1	-0.1	-0.1	-0.1	0.3	0.3	0.3	0.3	0.3
Oct	-0.4	-0.1	-0.4	-0.4	-0.5	-0.6	0.2	0.0	0.0	-0.4	-0.8	-0.2	-0.3	-0.2	-1.0	-0.3	-0.2	-0.3	-0.5	-0.5
Nov	0.0	-0.1	0.2	0.1	0.1	0.0	0.2	-0.1	-0.5	0.1	-0.1	0.4	0.3	0.1	-0.1	0.0	0.2	0.5	0.3	0.1
Dec	0.8	-0.1	0.1	0.0	1.0	0.9	-0.1	0.0	-0.2	1.1	0.9	0.3	0.0	-0.2	1.2	1.1	0.1	0.5	0.0	1.4

where a, b, c, d, and e represents MYD10A2 Original, MYD10A2 20% Threshold, MOYD10A2*, MOD10A2 Original and MOD10A2 20% Threshold products respectively.

Table S5. Mean and standard deviation of annual minimum and maximum SLA (m a.s.l.) for the Karakoram region.

Product	MYD10A2 Original		MYD10A2 20% Threshold		MOYDGL06*		MOD10A2 20% Threshold		MOD10A2 Original	
	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.
Karakoram	2289±309	4655±92	2510±237	4655±92	2666±424	5259±196	2286±297	5118±212	2157±339	5145±221
Hunza	2133±249	4110±130	2306±251	4110±130	2531±197	4636±82	2230±287	4511±91	2093±284	4511±91
Shigar	2241±119	4674±753	2382±270	4426±96	2297±199	4637±76	2282±160	4534±104	2217±118	4544±103
Shyok	2766±421	5473±78	2988±408	5459±73	2964±467	5603±42	3012±400	5556±50	2664±393	5563±59

Table S6. Annual average SLA trend analysis (m a.s.l. per year) using all the products. Italic bold numbers are statistically significant at the 90% confidence level.

Product	MYD10A2 Original		MYD10A2 20% Threshold		MOYDGL06*		MOD10A2 20% Threshold		MOD10A2 Original	
	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.	Annual Min.	Annual Max.
Karakoram	-3.93	<i>7.85</i>	-9.55	<i>7.85</i>	14.33	<i>12.77</i>	-6.12	16.93	7.85	11.25
Hunza	4.17	-0.5	-5.83	-0.5	0.5	6.33	0	<i>9.62</i>	-0.5	<i>9.62</i>
Shigar	<i>0</i>	-0.5	-12.61	2.58	<i>0</i>	2.61	<i>-4.72</i>	4.08	-0.5	5
Shyok	-10.71	4.77	-11.56	3.88	0	3	-6	5.58	4.77	5.58

Table S7. Trend analysis of annual average SLA (m a.s.l. per year) for the different temporal windows.

Statistics Area/Period	Trend annual average SLA		
	2003-2010	2011-2018	2003-2018
Karakoram	4.17	9.25	<i>8.03</i>
Hunza	14.64	-0.58	3.91
Shigar	-5.02	-1.52	2.15
Shyok	-34.06	-7.91	4.29

Table S8. Trend analysis of monthly mean SLA (m a.s.l. per year) from 2003 to 2018. Numbers in italicized bold are statistically significant at 90% confidence level.

Area Month/Product	Karakoram					Hunza					Shigar					Shyok				
	a	b	c	d	e	a	b	c	d	e	a	b	c	d	e	a	b	c	d	e
Jan	44.5	-47.9	35.7	21.9	34.3	0.3	-35.3	17.6	0.8	16.2	2.1	-86.7	1.1	-8.3	0.6	12.5	-15.0	34.4	10.0	23.4
Feb	10.6	17.5	30.0	35.0	22.4	23.4	28.8	24.1	<i>46.3</i>	<i>24.4</i>	-13.0	-24.0	16.5	2.7	8.5	3.4	-16.0	25.2	7.4	12.1
Mar	12.9	<i>26.3</i>	13.1	<i>21.4</i>	12.9	1.7	1.8	-1.5	4.7	-1.4	9.7	2.7	6.4	19.3	4.3	11.4	7.7	14.4	5.8	15.2
Apr	7.9	2.3	1.0	0.4	-0.7	-0.7	-3.5	-1.1	3.2	2.5	6.3	3.3	4.3	3.7	5.9	7.5	-7.5	1.4	-3.3	-1.1
May	2.2	2.2	7.0	11.0	8.0	3.4	5.4	2.4	11.8	7.5	3.5	10.8	4.3	11.8	8.7	-8.7	-1.3	5.5	11.8	8.4
Jun	9.0	8.6	9.2	11.1	11.1	15.7	<i>16.1</i>	11.0	12.5	12.4	<i>15.8</i>	<i>19.8</i>	7.8	6.3	5.5	11.3	5.7	11.7	15.0	15.0
Jul	7.7	7.7	11.0	9.1	9.1	0.4	0.2	7.1	7.2	7.2	0.9	-1.6	4.3	5.4	5.4	10.4	10.4	0.3	0.5	0.5
Aug	1.1	1.1	15.5	12.5	12.5	-1.4	0.5	4.7	2.7	2.7	1.0	-1.0	3.8	5.3	5.5	1.4	1.4	5.5	7.8	7.8
Sep	-1.3	-1.3	0.0	2.5	2.5	-9.2	-7.9	6.4	7.7	7.7	-5.0	-6.5	1.7	-1.4	2.5	<i>-33.8</i>	<i>-33.8</i>	-8.0	-7.9	-7.9
Oct	10.0	9.7	9.5	<i>10.5</i>	<i>10.7</i>	-2.7	-4.2	0.1	0.8	2.0	3.8	5.9	6.5	7.2	9.9	6.2	6.7	3.5	11.5	11.5
Nov	-2.5	-5.6	4.0	1.6	1.6	-14.2	-6.3	1.6	-2.8	3.4	-17.0	-13.6	-12.8	-11.0	-7.4	-2.3	6.7	-9.2	-2.5	-1.1
Dec	-1.7	-3.3	22.0	4.2	1.2	5.7	-2.9	1.2	0.4	15.2	-6.2	-24.6	9.3	-6.7	21.5	-36.7	-12.2	-15.5	-10.0	-25.1