Supplement of

Short-term cooling, drying and deceleration of an ice-rich rock glacier

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1 Supplementary Tables

Table S1: Overview of locations, variables, abbreviations, units, sensors/models, and computed descriptive statistics for weather stations and ground surface temperature measurements (GST) during the observation period from January 2020 to June 2023.

Station name (abbreviation)	Coordinates (x | y), elevation [1]	Used variables, abbreviation [unit]	Sensor / model	Descriptive figures [8]
Puoz Bass [2] (BER3)	2'790'343 | 1'146'291, 2'625 m asl	air temperature, TA [°C]	Rotronic MP102H/HC2 [3]	mean ± sd; median ± mad; min; max; frost days; icing days; degree days
		rainfall, RA [mm]	Campbell Scientific ARG100 [4]	sum; max; rain days
Valetta [2] (BER2)	2'783'955 | 1'157'064, 2'512 m asl	height of snowpack, HS [cm]	Campbell SnowVUE10 [4]	mean ± sd; median ± mad; max;
		snow water equivalent, SWE [mm]	SNOWPACK [5]	mean ± sd; median ± mad; max;
Schafberg (WS)	2'790'949 | 1'152'587, 2'756 m asl	air temperature, AT [°C] rainfall, RA [mm]	METER Group ATMOS41 [6]	*see TA and RA for IMIS stations*
GST01	2790833 | 1152763, 2'723 m asl	ground surface temperature	SLF BLE [7]	zero curtain period; zero curtain days; min; max;
GST02	2790860 | 1152746, 2'732 m asl	ground surface temperature	SLF BLE [7]	
GST03	2790893 | 1152773, 2'738 m asl	ground surface temperature	SLF BLE [7]	

[1] swiss grid (CH1903+, LV95; EPSG: 2056); [2] IMIS snow station (IMIS, 2023); [3] Rotronic AG, Bassersdorf, CH (www.rotronic.com); [4] Campbell Scientific, Inc., Logan, UT, USA (www.campbellsci.com); [5] Bartelt and Lehning, 2002; Lehning *et al.*, 2002a; Lehning *et al.*, 2002b; [6] METER Group, Inc., Pullman, WA, USA (www.metergroup.com); [7] *Bluetooth Low Energy* (BLE), developed at SLF (www.slf.ch); [8] mean: arithmetic average; mad: median absolute deviation; others: see definitions in text.

Table S2: Statistical key figures for the meteorological variables air temperature (TA), rainfall (RA), height of snow (HS), and snow water equivalent (SWE) of the two IMIS stations Motta Bianca (BER2), Puoz Bass (BER3) and the Schafberg weather station (WS). Key figures were calculated for each quarter of each year with available data. Not assigned values (*NA*s) mainly are due to malfunctioning sensors.

BER2 - Motta Bianca

	key figure	2020					2021					2022					2023	
		Q1	Q2	Q3	Q4	Y	Q1	Q2	Q3	Q4	Y	Q1	Q2	Q3	Q4	Y	Q1	Q2
TA	mean	-4.0	3.2	8.5	-1.9	1.4	-6.2	1.2	7.7	-1.5	0.3	-4.5	4.2	8.6	-0.4	2.0	-4.5	2.6
	sd	4.5	3.9	4.2	4.8	6.5	4.9	6.4	3.0	4.9	7.1	4.6	6.1	4.6	5.6	7.2	4.7	5.6
	median	-4.1	2.9	8.9	-1.7	1.5	-6.3	0.4	7.6	-0.5	0.4	-4.5	4.9	9.0	-0.5	1.8	-4.2	3.1
	mad	4.8	3.5	3.8	4.9	6.9	5.3	6.4	3.0	4.6	8.0	4.9	7.1	3.9	6.3	8.6	4.9	6.0
	max	10.4	15.9	18.4	12.0	18.4	12.3	16.2	17.5	9.4	17.5	8.7	16.6	18.8	12.4	18.8	9.0	18.1
	min	-16.0	-14.8	-6.2	-14.2	-16.0	-19.2	-16.2	-0.9	-15.4	-19.2	-14.9	-13.5	-3.8	-15.6	-15.6	-16.6	-11.4
	frost days	85	42	6	77	210	88	59	3	75	225	87	36	14	58	195	88	43
	icing days	50	4	3	36	93	67	19	0	33	119	56	9	0	39	95	58	20
	5°C-days	9	61	85	21	176	8	41	89	22	160	8	57	80	29	174	7	53
	10°C-days	1	15	61	1	78	2	27	48	0	75	0	39	63	10	112	0	21
	15°C-days	0	2	14	0	16	0	2	8	0	10	0	6	22	0	28	0	4
RA	sum	0	42	274	34	350	0	37	316	45	398	0	*NA*	*NA*	90	*NA*	2	56
	daily max	0	10	86	27	86	0	7	43	28	43	0	*NA*	*NA*	50	*NA*	2	15
	days	0	21	45	4	70	1	14	41	6	62	0	*NA*	*NA*	12	*NA*	1	23
HS	mean	166	85	7	57	79	192	188	7	32	104	94	64	6	29	48	72	78
	sd	23	67	4	52	72	32	71	1	20	95	36	55	1	24	48	15	51
	median	154	100	7	30	34	199	220	7	39	53	115	68	6	23	25	65	101
	mad	10	107	1	28	43	27	27	1	19	71	24	90	1	25	29	6	46
	max	219	194	180	166	219	253	262	10	85	262	144	141	11	80	144	116	160
SWE	mean	607	454	12	165	309	654	843	0	82	329	285	246	0	70	149	205	294
	sd	66	209	31	143	269	128	299	0	63	397	114	226	1	52	175	45	198
	median	572	502	0	101	232	734	975	0	122	139	323	331	0	53	56	183	342
	mad	31	334	0	90	344	87	134	0	43	206	112	292	0	37	83	11	204
	max	730	735	140	432	735	831	1097	0	182	1097	403	534	15	176	534	326	543

BER3 - Puoz Bass

	key figure	2020					2021					2022					2023	
		Q1	Q2	Q3	Q4	Y	Q1	Q2	Q3	Q4	Y	Q1	Q2	Q3	Q4	Y	Q1	Q2
TA	mean	-4.6	2.4	7.6	-2.4	0.8	-6.8	0.4	6.9	-2.3	-0.4	-5.2	3.5	7.7	-1.0	1.3	-5.4	1.8
	sd	4.7	3.8	4.5	5.0	6.5	5.1	6.6	3.3	5.0	7.1	4.7	6.2	4.7	5.8	7.2	4.9	5.7
	median	-4.5	2.1	8.0	-1.9	0.9	-7.3	-0.3	6.7	-1.4	-0.2	-5.2	4.1	8.1	-1.1	1.2	-5.1	2.2
	mad	5.3	3.3	4.2	5.3	6.7	5.7	6.5	3.4	4.5	7.6	4.8	7.0	4.0	6.7	8.5	5.1	6.1
	max	6.1	14.3	17.4	9.7	17.4	9.5	16.4	16.5	7.6	16.5	7.0	17.0	18.0	12.0	18.0	8.4	16.9
	min	-16.9	-11.7	-7.2	-15.5	-16.9	-18.2	-17.9	-1.4	-16.3	-18.2	-15.3	-15.6	-5.1	-17.0	-17.0	-17.8	-14.1
	frost days	87	55	10	78	230	87	59	5	80	231	88	44	13	60	205	88	46
	icing days	50	2	3	39	94	66	24	0	35	125	59	9	1	41	110	57	21
	5°C-days	4	50	83	18	155	6	38	87	12	143	6	57	80	30	173	7	49
	10°C-days	0	12	57	0	69	0	17	43	0	60	0	33	61	4	98	0	17
	15°C-days	0	0	13	0	13	0	3	4	0	7	0	5	16	0	21	0	2
RA	sum	2	49	293	19	362	0	4	111	12	126	0	123	180	19	322	0	96

	daily max	2	13	54	11	54	0	1	23	5	23	0	18	21	7	21	0	22
	days	1	15	40	6	62	0	5	31	6	42	1	26	32	9	68	0	22
HS	mean	91	32	6	33	40	109	70	6	30	53	49	23	6	16	23	44	41
	sd	15	34	1	29	39	17	37	1	19	45	4	21	3	11	20	9	30
	median	86	16	6	18	18	113	88	6	36	45	49	6	6	14	13	42	52
	mad	15	17	0	18	19	10	16	0	18	58	4	2	0	13	11	3	41
	max	131	106	16	104	131	154	125	9	67	154	60	85	178	37	178	78	101
SWE	mean	*NA*	*NA*	2	92	*NA*	328	301	0	68	173	134	69	0	35	59	98	132
	sd	*NA*	*NA*	4	75	*NA*	59	164	0	48	169	8	77	1	20	64	25	103
	median	*NA*	*NA*	0	57	*NA*	369	395	0	90	114	132	0	0	29	28	90	149
	mad	*NA*	*NA*	0	48	*NA*	15	33	0	40	169	11	0	0	16	41	10	128
	max	*NA*	*NA*	14	220	*NA*	382	436	0	132	436	146	182	13	71	182	150	299

WS - Schafberg

	key figure	2022			2023	
		Q3	Q4	Y	Q1	Q2
TA	mean	NA	-1.7	NA	-6.5	0.6
	sd	*NA*	5.7	*NA*	5.0	5.9
	median	*NA*	-1.2	*NA*	-6.0	1.2
	mad	*NA*	6.5	*NA*	5.3	6.2
	max	*NA*	12.0	*NA*	6.3	17.2
	min	*NA*	-19.3	*NA*	-19.4	-15.6
	frost days	*NA*	64.0	*NA*	90.0	52.0
	icing days	*NA*	42.0	*NA*	69.0	28.0
	5°C-days	*NA*	25.0	*NA*	1.0	43.0
	10°C-days	*NA*	4.0	*NA*	0.0	14.0
	15°C-days	*NA*	0.0	*NA*	0.0	4.0
RA	sum	*NA*	4	*NA*	0	42
	daily max	*NA*	1	*NA*	0	2
	days	*NA*	8	*NA*	15	26

Mean: arithmetic average; sd: standard deviation; mad: median absolute deviation; frost days (TAmin < 0 °C); icing days (TAmax < 0 °C); 5 °C-days, 10 °C-days, and 15 °C days (TAmax > 5°C, TAmax > 10 °C, and TAmax > 15 °C, respectively); rain days (RA > 0 mm); daily max: RA of the day with the RA maximum of the corresponding quarter;

Table S3: Spring zero curtain (ZC) periods, number of days with ZC and maximum and minimum ground surface temperature (GST) values for the three GST sensors GST01, GST02 and GST03.

			GST01	GST02	GST03
spring zero curtain (ZC)	winter 2019/20	ZC period	15 Apr - 14 May 2020	10 Apr - 07 May 2020	26 Apr - 21 May 2020
		ZC days	29	27	25
	winter 2020/21	ZC period	11 May - 19 Jun 2021	09 May - 14 June 2021	15 May - 19 Jun 2021
		ZC days	39	36	35
	winter 2021/22	ZC period	07 May - 12 May 2022	02 May - 11 May 2022	21 Apr - 14 May 2022
		ZC days	5	9	23
	winter 2022/23	ZC period	20 May - 10 Jun 2023	30 Apr - 06 June 2023	29 Apr - 01 Jun 2023
		ZC days	21	37	33
GST_{max}	summer 2020	date	09 Aug 2020	09 Aug 2020	30 Jul 2020
		temperature [°C]	15.1	15.4	13.1
	summer 2021	date	15 Aug 2021	14 Aug 2021	15 Aug 2021
		temperature [°C]	15.7	16.2	14.3
	summer 2022	date	22 Jul 2022	21 Jul 2022	22 Jul 2022
		temperature [°C]	16.5	16.1	15.6
GST_{min}	winter 2020/21	date	12 Mar 2021	14 Oct 2020	11 Jan 2021
		temperature [°C]	-10.9	-3.7	-11.7
	winter 2021/22	date	29 Nov 2021	07 Mar 2022	29 Nov 2021
		temperature [°C]	-3.6	-7.6	-13.9
	winter 2022/23	date	19 Nov 2022	12 Feb 2023	22 Jan 2023
		temperature [°C]	-9.5	-3.8	-14.2

Table S4: Results of the robust non-parametric Kruskal-Wallis *H*-test statistic and eta-squared measure to assess significance and strength of the relation for ground temperature, piezometric pressure, resistivity, and horizontal displacement velocity data.

		Kruskal-Wallis H-test statistic			eta-squared measure η_H^2	
variable	n	statistic	df	p-value	effect size	magnitude
ground temperature	7170	4639	29	0	0.646	large
piezometric pressure	5742	673	29	3.64E-123	0.113	moderate
resistivity	36156	2379	22	0	0.0652	moderate
velocity	1330	696	4	2.90E-149	0.522	large

n: tested sample size; df: degrees of freedom;

Table S5: Results of the Dunn's test (pairwise comparisons) for ground temperature, piezometric pressure, resistivity, and horizontal displacement velocity data. The differences between the years were tested for each month. Significant adjusted p-values are in bold and italic. Note: Horizontal velocities are measured only once a year (in July).

variable	group 1	group 2	p - value	adjusted p-value
ground temperature	Jan 2021	Jan 2022	0.04242	1
	Jan 2021	Jan 2023	0.00183	0.79437
	Jan 2022	Jan 2023	0.27670	1
	Feb 2021	*Feb 2022*	*3.92E-24*	*1.70E-21*
	Feb 2021	*Feb 2023*	*6.64E-30*	*2.89E-27*
	Feb 2022	Feb 2023	0.22016	1
	Mar 2021	*Mar 2022*	*1.71E-17*	*7.42E-15*
	Mar 2021	*Mar 2023*	*6.59E-17*	*2.87E-14*
	Mar 2022	Mar 2023	0.86969	1
	Apr 2021	*Apr 2022*	*3.00E-09*	*1.31E-06*
	Apr 2021	*Apr 2023*	*1.31E-07*	*5.69E-05*
	Apr 2022	Apr 2023	0.51337	1
	May 2021	May 2022	0.31214	1
	May 2021	May 2023	0.02706	1
	May 2022	May 2023	0.23019	1
	Jun 2021	Jun 2022	0.58446	1
	Jun 2021	Jun 2023	0.47477	1
	Jun 2022	Jun 2023	0.21444	1
	Jul 2021	Jul 2022	0.03464	1
	Aug 2021	Aug 2022	0.07277	1
	Sep 2021	Sep 2022	0.11389	1
	Oct 2021	Oct 2022	0.20412	1
	Nov 2021	Nov 2022	0.43566	1
	Dec 2021	Dec 2022	0.32556	1
Piezometric pressure	*Jan 2021*	*Jan 2022*	*1.7867E-10*	*7.77213E-08*
	Jan 2021	*Jan 2023*	*1.60472E-21*	*6.98052E-19*
	Jan 2022	Jan 2023	0.00164	0.71198
	Feb 2021	*Feb 2022*	*1.64323E-09*	*7.14806E-07*
	Feb 2021	*Feb 2023*	*7.47292E-22*	*3.25072E-19*
	Feb 2022	Feb 2023	0.00035	0.15101
	Mar 2021	*Mar 2022*	*1.14087E-11*	*4.9628E-09*
	Mar 2021	*Mar 2023*	*8.62367E-28*	*3.75129E-25*
	Mar 2022	*Mar 2023*	*2.06753E-05*	*0.00899*
	Apr 2021	*Apr 2022*	*3.60128E-08*	*1.56656E-05*
	Apr 2021	*Apr 2023*	*1.2534E-24*	*5.45229E-22*
	Apr 2022	*Apr 2023*	*2.19E-06*	*0.00095*

	May 2021	*May 2022*	*3.93481E-06*	*0.00171*
	May 2021	*May 2023*	*9.03398E-18*	*3.92978E-15*
	May 2022	*May 2023*	*7.16215E-05*	*0.03116*
	Jun 2021	*Jun 2022*	*4.81904E-06*	*0.00210*
	Jun 2021	*Jun 2023*	*2.11723E-19*	*9.20994E-17*
	Jun 2022	*Jun 2023*	*9.22823E-06*	*0.00401*
	Jul 2021	Jul 2022	0.00014	0.06134
	Aug 2021	Aug 2022	0.00017	0.07235
	Sep 2021	Sep 2022	0.00030	0.12942
	Oct 2021	Oct 2022	0.00055	0.23790
	Nov 2021	Nov 2022	0.00030	0.13192
	Dec 2021	Dec 2022	0.00059	0.25688
resistivity	Jan 2022	Jan 2023	0.05772	1
	Feb 2022	Feb 2023	0.06445	1
	Mar 2022	Mar 2023	0.00266	0.67252
	Apr 2022	*Apr 2023*	*1.58E-08*	*3.99E-06*
	May 2022	*May 2023*	*1.10E-22*	*2.80E-20*
	Jun 2022	Jun 2023	0.05503	1
	Aug 2021	Aug 2022	0.04858	1
	Sept 2021	Sept 2022	0.86761	1
	Oct 2021	Oct 2022	0.77475	1
	Nov 2021	Nov 2022	0.50108	1
	Dec 2021	Dec 2022	0.49742	1
velocities	*Jul 2019*	*Jul 2020*	*3.71807E-20*	*3.71807E-19*
	Jul 2020	*Jul 2021*	*7.08764E-55*	*7.08764E-54*
	Jul 2021	*Jul 2022*	*6.78298E-38*	*6.78298E-37*
	Jul 2022	*Jul 2023*	*5.16177E-12*	*5.16177E-11*

group1: year 1 in comparison; group2: year 2 in comparison; adjusted p-value based on the Bonferroni correction.