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Supplement of

Spatio-temporal reconstruction of winter glacier mass balance in the Alps, Scandinavia, Central Asia and western Canada (1981–2019) using climate reanalyses and machine learning

Matteo Guidicelli et al.

Correspondence to: Matteo Guidicelli (matteo.guidicelli@unifr.ch)

1 Supplemental Figures

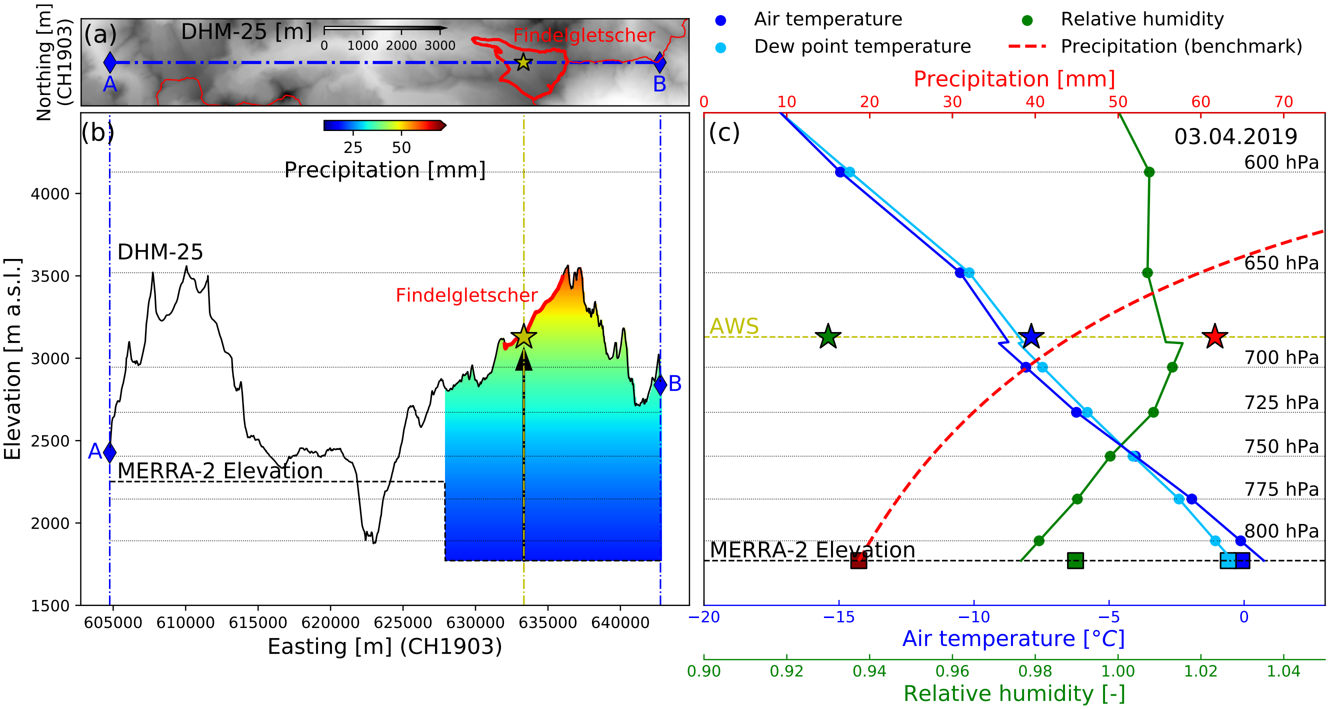

Figure S1. The downscaling methods for daily precipitation using the benchmark method (cf. Sec. 3.2.1 of the manuscript), air temperature and relative humidity at the example of Findelgletscher, Southern Switzerland. (a) High-resolution topography in the region of Findelgletscher. (b) The elevation of the MERRA-2 grid is compared with the elevation of a detailed terrain model, showing a longitudinal cross-section of the glacier (bold red line) and the surrounding regions. (c) Resulting downscaled daily variables on 3 April, 2019. The stars indicate the observations by an automatic weather station (AWS) located on the glacier. The measured precipitation refers to the daily difference of SWE measured by a cosmic ray sensor (see Gugerli et al., 2019).

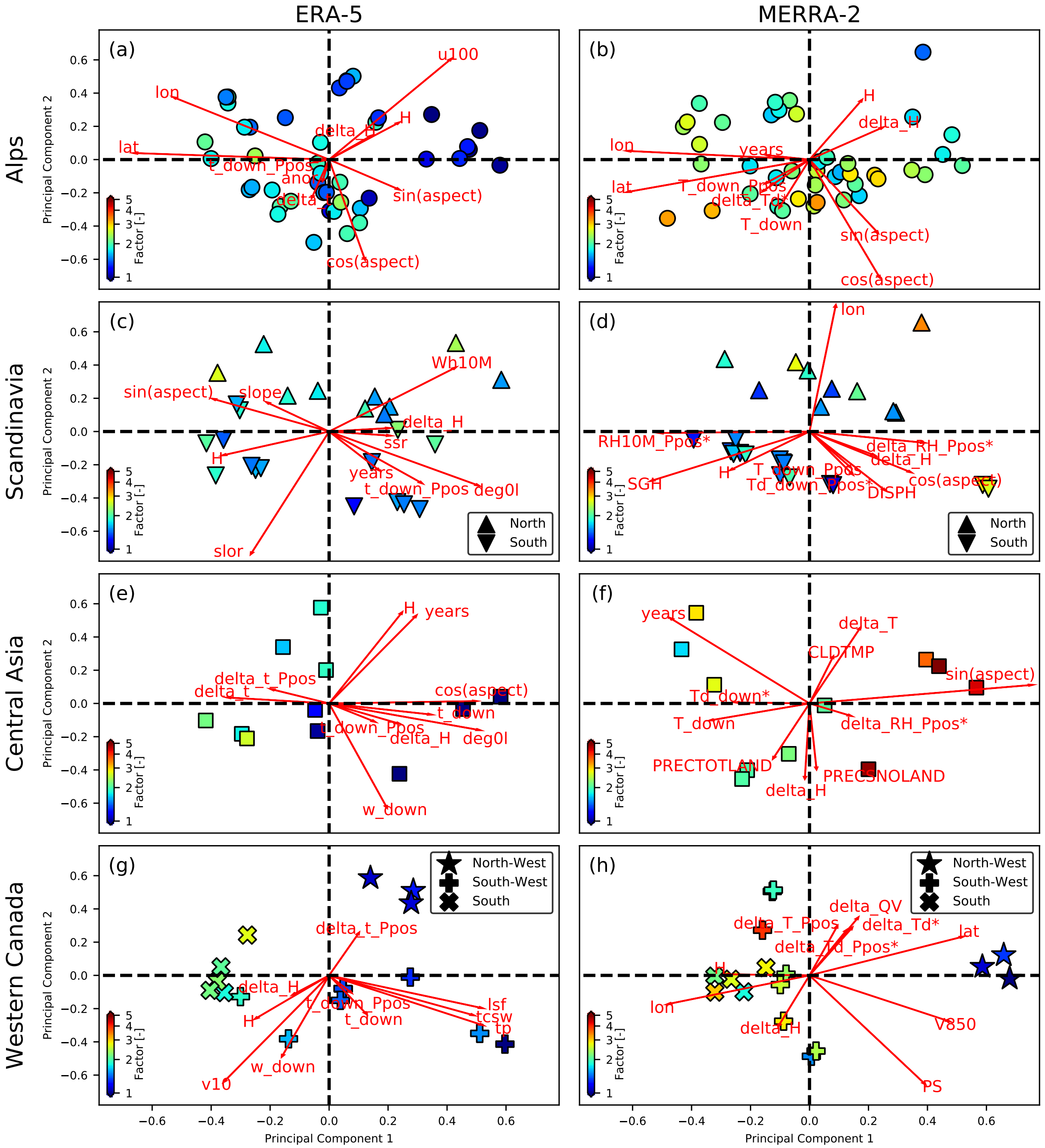

Figure S2. Principal component analysis (PCA) biplots for the regional site-independent GBR models, considering the ten most used predictors of (a, c, e, g) ERA-5 and (b. d. f. h) MERRA-2. The PCA projects the set of ten predictors into a new space characterized by the principal components, which are uncorrelated and orthogonal. Each principal component is the result of a linear combinations between the predictors and the first component explains the largest part of the predictors' variance. The colors represent the factors between B_w and the total precipitation of ERA-5 and MERRA-2, respectively. The meaning of the predictors' names is described in the Appendix of the manuscript in Tables B1 (original ERA-5 variables), B2 (original MERRA-2 variables) and B3 (downscaled ERA-5 and MERRA-2 variables).

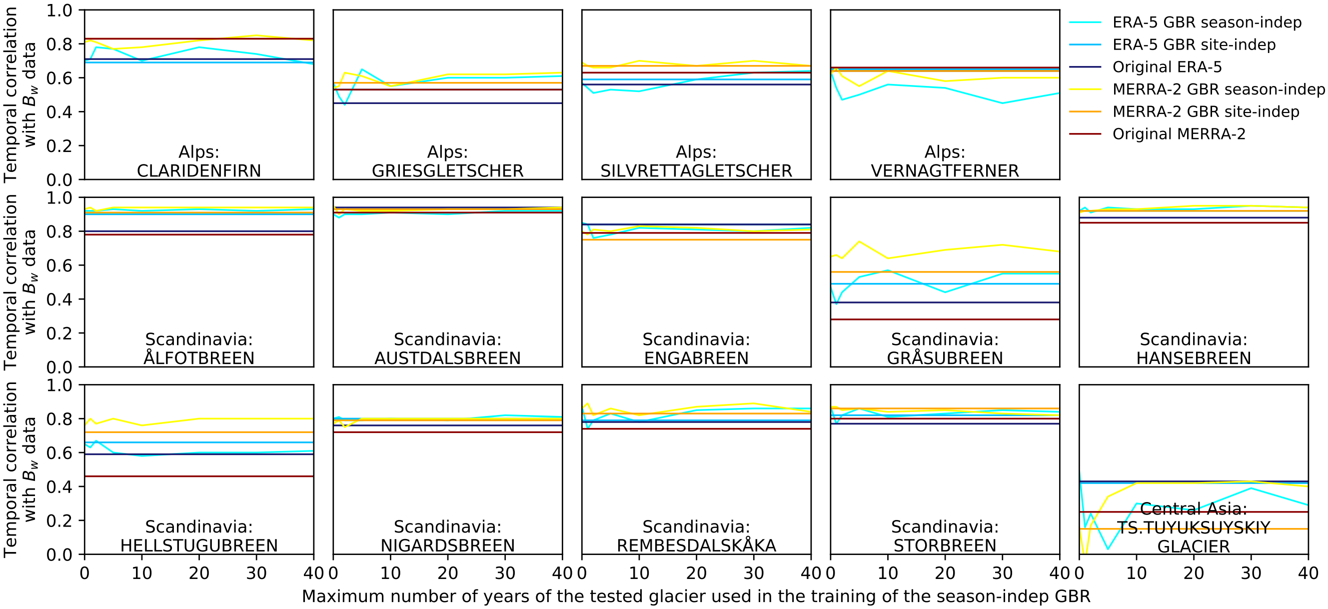

Figure S3. Sensitivity test of the temporal correlation between B_w and GBR models for the glaciers with more than 30 years of B_w data available. The season-independent GBRs are trained with different number of years of the tested glacier (from no data of the tested glacier to a maximum of 40 years of data of the tested glacier are used in the training, similarly to Fig. 7a, c, e and g). The Pearson correlation between GBR models and glacier-wide B_w over the accumulation seasons (temporal correlation) are reported accordingly.

2 Supplemental Tables

Table S1. Scores of the reanalysis-based models against the B_w along the vertical profiles. Here, we report the mean score of all the accumulation seasons. Only glaciers with a minimum of five seasons and a minimum of ten elevation intervals of B_w data per season are reported. The Pearson correlation (r [-]) and the coefficient of variation (CV [%], corresponding to the percentage ratio of the standard deviation to the mean) are reported.

			r (CV)				CV	n seasons	avg n obs
	Benchmark		GB site-indep		GB season-indep		B_w		
Glacier	ERA-5	MERRA-2	ERA-5	MERRA-2	ERA-5	MERRA-2			
Adlergletscher	-0.56 (28)	-0.60 (37)	0.71 (13)	0.67 (12)	0.70 (22)	0.68 (19)	26	10	12
Allalingletscher	-0.40 (43)	-0.46 (51)	0.66 (18)	0.61 (19)	0.86 (19)	0.88 (21)	19	16	19
Findelgletscher	0.46 (30)	0.40 (38)	0.78 (15)	0.56 (11)	0.91 (26)	0.88 (20)	33	11	14
Hohlaubgletscher	-0.74 (30)	-0.77 (35)	0.73 (8)	0.78 (11)	0.91 (12)	0.84 (13)	23	8	13
Rhonegletscher	0.81 (27)	0.79 (30)	0.9 (26)	0.92 (14)	0.95 (32)	0.90 (26)	37	8	14
Vedretta de La Mare	0.76 (19)	0.76 (19)	0.70 (12)	0.80 (14)	0.79 (18)	0.81 (16)	25	14	18
Vedretta Lunga	-0.24 (13)	-0.25 (15)	-0.13 (15)	-0.15 (13)	-0.04 (9)	-0.06 (12)	14	13	14
Vedretta Malavalle	0.73 (17)	0.73 (18)	0.58 (3)	0.88 (12)	0.89 (19)	0.86 (20)	27	14	17
Goldbergkees	-0.39 (15)	-0.39 (15)	-0.3 (11)	-0.33 (16)	-0.21 (6)	-0.20 (10)	14	15	15
Hallstaetter Gletscher	0.95 (15)	0.95 (15)	0.82 (4)	0.89 (6)	0.96 (12)	0.88 (12)	32	6	14
Hinterisferner	0.31 (25)	0.29 (28)	0.76 (19)	0.75 (11)	0.84 (21)	0.77 (16)	26	7	25
Venedigerkees	0.90 (20)	0.89 (21)	0.78 (9)	0.82 (11)	0.85 (19)	0.79 (15)	32	6	20
Vernagtferner	0.52 (18)	0.52 (19)	0.53 (4)	0.69 (5)	0.55 (6)	0.62 (6)	15	31	17
Wurtenkees	-0.16 (13)	-0.16 (13)	-0.1 (3)	-0.12 (8)	0.26 (3)	0.20 (5)	18	26	13
Zettalunitz/Mullwitzkees	-0.02 (16)	-0.03 (17)	0.44 (1)	0.47 (6)	0.80 (6)	0.65 (7)	27	6	16
Blomstoelskardsbreen	0.96 (11)	0.96 (11)	0.97 (18)	0.98 (16)	0.97 (18)	0.97 (17)	23	10	12
Graafjellsbreen	0.97 (11)	0.97 (11)	0.95 (33)	0.96 (21)	0.96 (27)	0.96 (21)	25	10	12
Harbardsbreen	-0.09 (13)	-0.09 (13)	-0.01 (20)	0.05 (19)	0.09 (15)	0.08 (18)	10	5	14
Hellstugubreen	0.88 (13)	0.88 (14)	0.77 (16)	0.73 (8)	0.92 (27)	0.88 (19)	34	37	14
Nigardsbreen	0.96 (26)	0.96 (27)	0.96 (54)	0.96 (55)	0.97 (53)	0.97 (53)	51	38	14
Rembesdalskåka	0.93 (13)	0.93 (13)	0.92 (27)	0.92 (32)	0.95 (40)	0.94 (39)	42	38	14
Rundvassbreen	0.98 (12)	0.98 (13)	0.94 (32)	0.97 (31)	0.94 (40)	0.96 (40)	49	8	13
Storbreen	0.94 (12)	0.94 (12)	0.85 (16)	0.88 (19)	0.92 (21)	0.91 (21)	27	30	13
Svartisheibreen	0.60 (12)	0.60 (13)	0.81 (30)	0.75 (31)	0.85 (19)	0.78 (24)	19	7	13
Svelgjabreen	0.97 (15)	0.97 (15)	0.97 (36)	0.97 (36)	0.98 (35)	0.98 (33)	31	10	16
Rabots Glaciaer	0.95 (14)	0.95 (14)	0.96 (31)	0.97 (28)	0.97 (38)	0.97 (32)	37	6	30
Storglaciären	0.88 (10)	0.88 (11)	0.80 (20)	0.80 (18)	0.89 (31)	0.84 (25)	44	5	28
Abramov glacier	0.13 (28)	0.10 (31)	0.82 (5)	0.86 (17)	0.97 (39)	0.97 (37)	40	14	13
Golubin glacier	0.35 (22)	0.34 (23)	0.70 (10)	0.76 (15)	0.86 (45)	0.85 (32)	56	8	22
Shumskiy glacier	-0.48 (25)	-0.49 (28)	-0.26 (31)	0.12 (19)	0.53 (14)	0.57 (17)	24	7	39
Ts. Tuyuksuyskiy glacier	-0.49 (15)	-0.50 (16)	0.04 (2)	0.4 (9)	0.80 (14)	0.80 (14)	19	31	12
Leviy Aktru glacier	0.29 (28)	0.28 (28)	0.79 (19)	0.70 (15)	0.80 (22)	0.72 (23)	26	7	13
Maliy Aktru glacier	0.80 (29)	0.79 (29)	0.78 (31)	0.82 (25)	0.85 (41)	0.82 (37)	48	7	15
Bench glacier	0.76 (28)	0.76 (28)	0.86 (19)	0.89 (14)	0.93 (29)	0.91 (29)	36	5	14
Bridge glacier	0.92 (30)	0.92 (29)	0.98 (38)	0.96 (36)	0.98 (42)	0.98 (44)	44	5	16
Sykora glacier	0.92 (26)	0.92 (26)	0.95 (34)	0.95 (36)	0.95 (37)	0.95 (36)	37	5	14
Tiedemann glacier	0.68 (60)	0.70 (57)	0.93 (31)	0.87 (48)	0.97 (38)	0.93 (45)	36	5	26

The original ERA-5 and MERRA-2 are not reported since they do not vary along the vertical profile of the glacier (a unique grid cell is assigned to the glacier).

References

Gugerli, R., Salzmann, N., Huss, M., and Desilets, D.: Continuous and autonomous snow water equivalent measurements by a cosmic ray sensor on an alpine glacier, The Cryosphere, 13, 3413–3434, https://doi.org/10.5194/tc-13-3413-2019, 2019.