Supplementary Figures

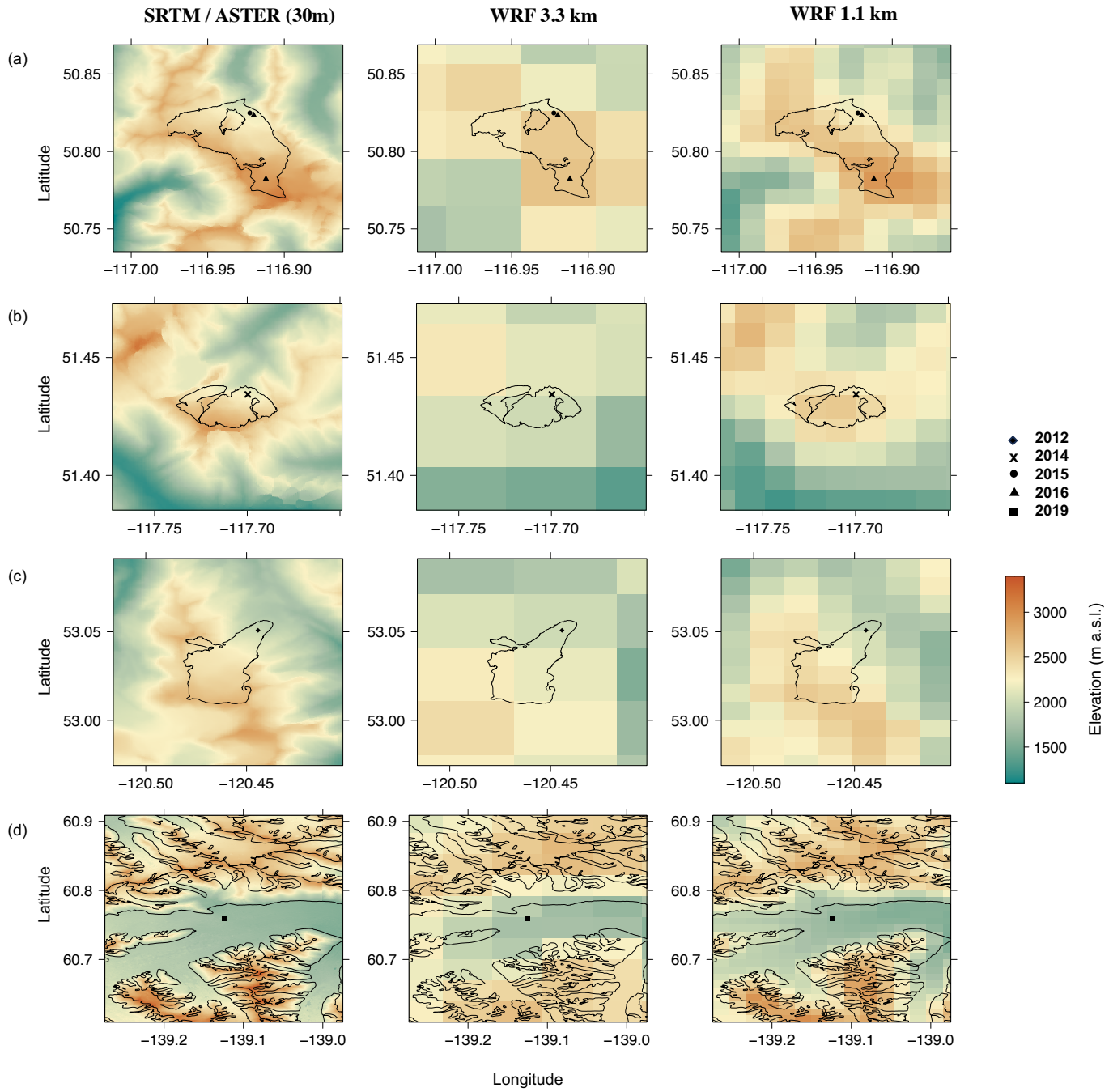

Figure S1: Topography for the domain covering (a) Conrad, (b) Nordic and (c) Castle Creek and (d) Kaskawulsh glaciers from a high-resolution DEM at 30 m grid spacing in comparison to the topography from WRF at 3.3 km and 1.1 km grid spacing. DEM data from SRTM (NASA JPL, 2013; Farr et al., 2007) were used for Castle Creek, Nordic and Conrad glaciers, and ASTER (ASTER, 2019; Abrams et al., 2020) for Kaskawulsh glacier. Markers indicate the AWS sites in different years. The outlines of the glaciers (black lines) are taken from the Randolph Glacier Inventory (RGI V6; RGI Consortium, 2017). Only on the map with Kaskawulsh glacier the neighboring glaciers are also shown.

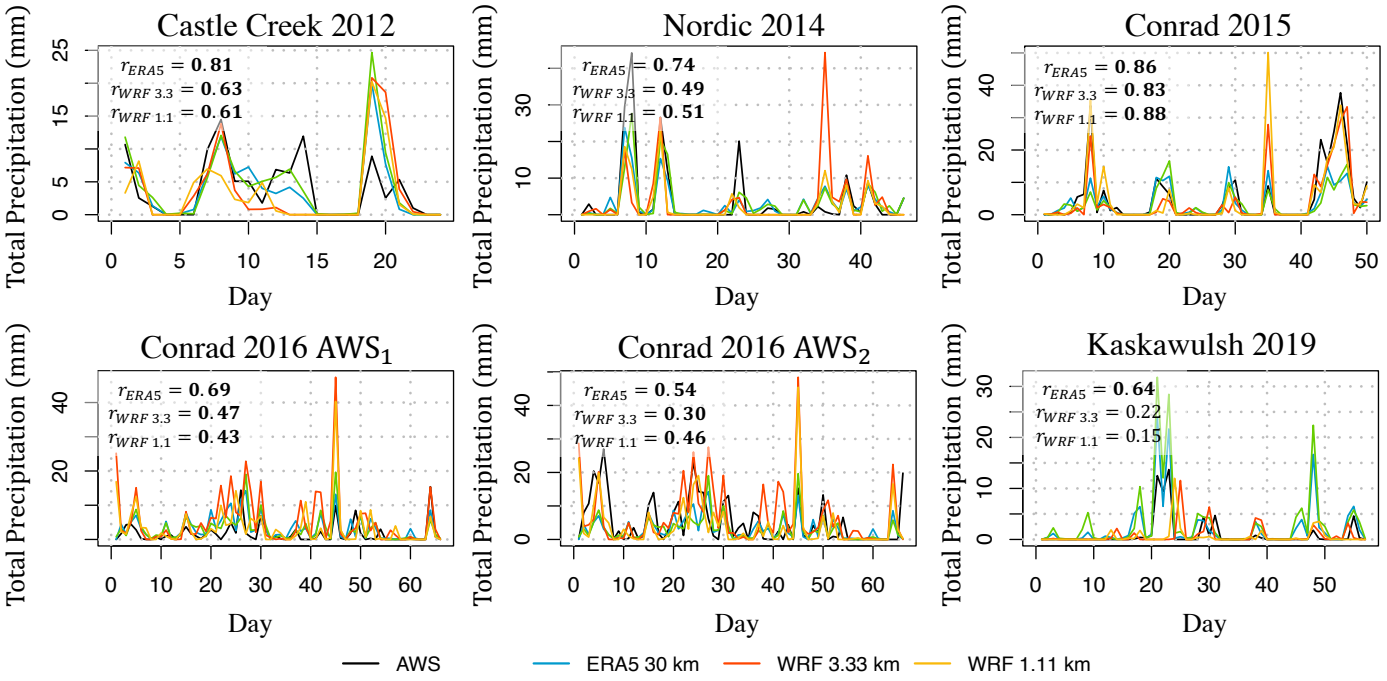

Figure S2: Modeled (ERA5, WRF at 3.3 km and WRF at 1.1 km) and observed (AWS data) timeseries of daily total precipitation over the observational period at each site. Bold values of correlation coefficient, r_{sp}, indicate a statistically significant correlation at the 5 % confidence level. WRF is run with the REF configuration.

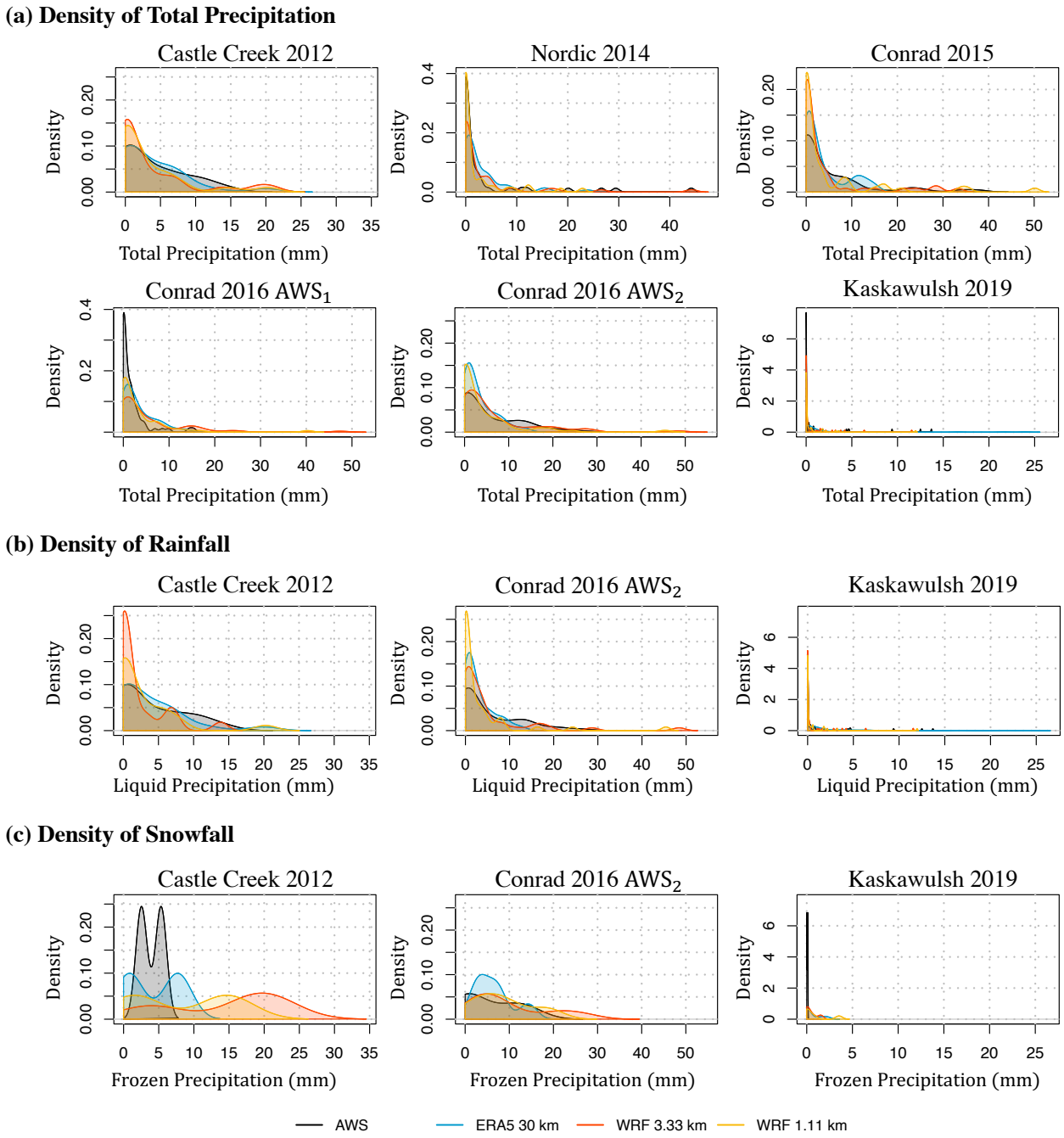

Figure S3: Modeled (ERA5, ERA5-Land, WRF at 3.3 km and WRF at 1.1 km) and observed (AWS data) densities of (a) total, (b) liquid and (c) frozen daily precipitation over the observational period. We differentiate between liquid and frozen precipitation using a temperature threshold of 0 °C. The densities of liquid and frozen precipitation are displayed only if there were days with snowfall during the observational period. WRF is run with REF configuration.

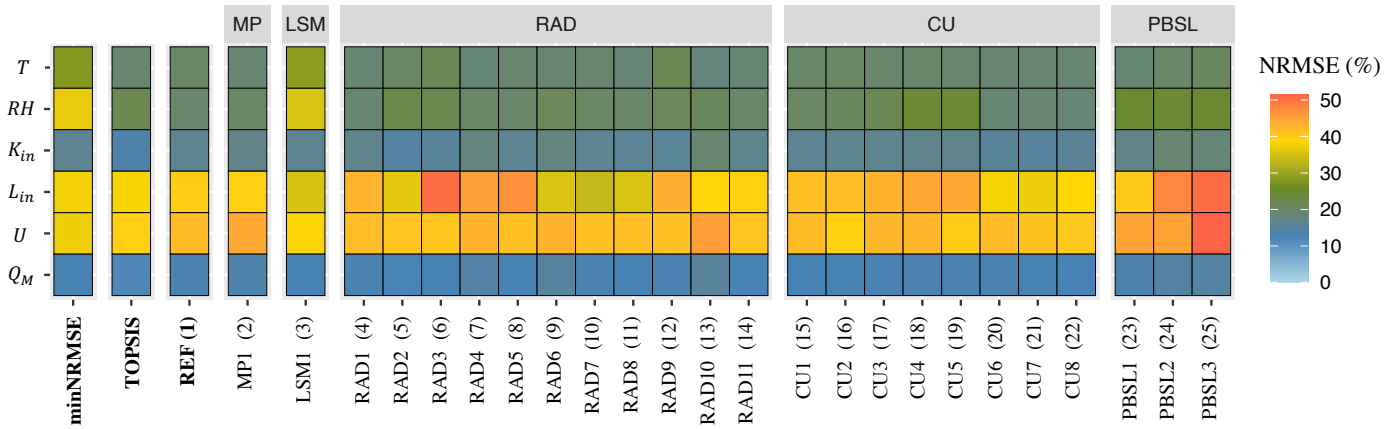

Figure S4: Visual representation of NRMSE calculated from the multiple 6-day WRF runs with three different configurations (minNRMSE, TOPSIS, REF) and the configurations used in the sensitivity runs (enumerated in brackets) with labels corresponding to their parameterization category with scheme that differs from REF. For full names of parameterization categories see Table S2. The NRMSE is calculated for each of the following variables: air temperature (T), relative humidity (RH), incoming shortwave (K_{in}) and longwave (L_{in}) radiation, wind speed (U) and total melt energy (Q_M).

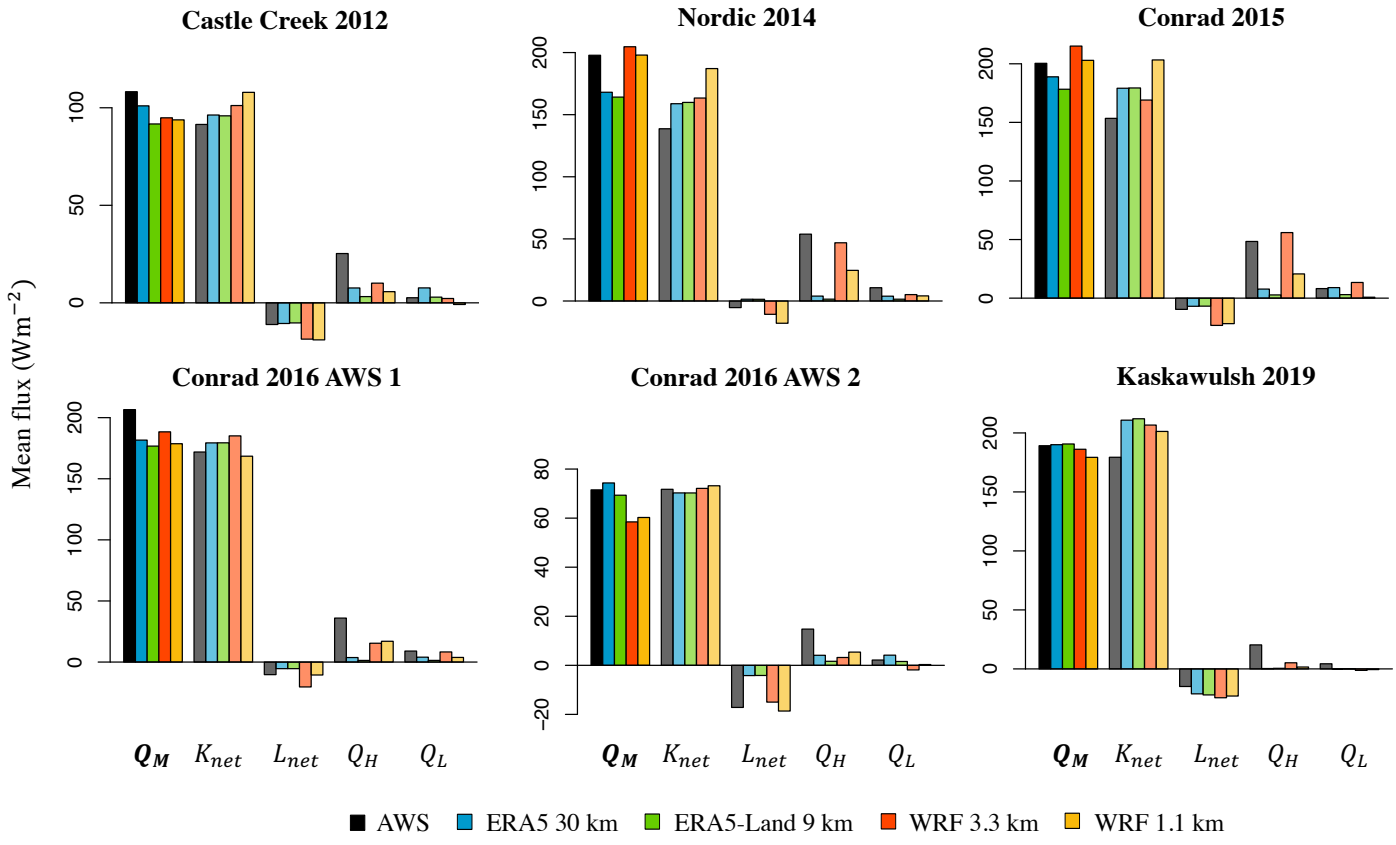

Figure S5: Mean daily total of melt energy (Q_M), as averaged over the observational period at each site, and the mean daily SEB components, including net shortwave (K_{net}) and longwave (L_{net}) radiation, sensible (Q_H) and latent (Q_L) heat fluxes, per glacier site using data from observations (AWS), ERA5 at 30 km grid spacing, ERA5-Land at 9 km, WRF at 3.3 km and WRF at 1.1 km. The REF configuration is used in the WRF runs. For this figure, only hourly values with $Q_M > 0$ are used in the calculation of mean daily fluxes.

Supplementary Tables

Table S1: Elevation for each study site (in meter above sea level) derived from AWS (on-site GPS), ERA5 at 30 km grid spacing, ERA5-Land at 9 km, WRF at 3.3 km and 1.1 km, and a high-resolution DEM at 30 m grid spacing: SRTM (NASA JPL, 2013; Farr et al., 2007) for Castle Creek, Nordic and Conrad glaciers, and ASTER (ASTER, 2019; Abrams et al., 2020) for Kaskawulsh glacier). Numbers in brackets show the respective difference to the AWS elevation.

Glacier site	**AWS**	**ERA5**	**ERA5-Land**	**WRF 3.3 km**	**WRF 1.1 km**	**SRTM / ASTER**
Castle Creek 2012	**1967**	1762 (-205)	1987 (+20)	2157 (+190)	1915 (-52)	1977 (+10)
Nordic 2014	**2208**	1785 (-423)	1866 (-342)	2124 (-84)	2298 (+90)	2203 (-5)
Conrad 2015	**2138**	1901 (-237)	2145 (+7)	2412 (+274)	2184 (+46)	2163 (+25)
Conrad 2016 AWS_1	**2164**	1901 (-263)	2145 (-19)	2567 (+403)	2217 (+53)	2182 (+18)
Conrad 2016 AWS_2	**2909**	1901 (-1008)	2145 (-764)	2618 (-291)	2944 (+35)	2910 (+1)
Kaskawulsh 2019	**1666**	2122 (+456)	2159 (+493)	1709 (+43)	1659 (-7)	1709 (+43)

Table S2: Summary of WRF configurations with physics parameterization schemes used in the 25 sensitivity runs. Radiation schemes (RAD) are split into longwave (LW) and shortwave (SW) schemes. The choice of planetary boundary (PBL) and surface layer (SL) schemes is interdependent, and therefore aggregated into one PBSL category. In the parameterization for the cumulus process (CU), the on/off label in brackets refers to the parameterization being switched 'on' or 'off' in each of the WRF domains d_1 (30 km) – d_2 (10 km) – d_3 (3.3 km) – d_4 (1.1 km). For each of the sensitivity runs, only one physics parameterization scheme is changed at a time, and all other specifications are the same as for the reference (REF) configuration (Table 3).

Microphysics (MP)	
MP1	Morrison 2-Moment[a]
Land Surface Model (LSM)	
LSM1	Unified Noah[b]
Radiation (RAD)	
RAD1	LW/SW: CAM[c]
RAD2	LW: RRTM[d], SW: Dudhia[e]
RAD3	LW: CAM, SW: Dudhia
RAD4	LW: CAM, SW: Goddard[f]
RAD5	LW: CAM, SW: RRTMG[g]
RAD6	LW: RRTM, SW: Goddard
RAD7	LW: RRTM, SW: CAM
RAD8	LW: RRTM, SW: RRTMG
RAD9	LW: RRTMG. SW: Dudhia
RAD10	LW: RRTMG. SW: Goddard
RAD11	LW: RRTMG, SW: CAM

Cumulus (CU)	
CU1	Grell 3D Ensemble[h] (on – on – on – off)
CU2	Grell 3D Ensemble (on – on – on – on)
CU3	Kain–Fritsch[i] (on – on – off – off)
CU4	Kain–Fritsch (on – on – on – off)
CU5	Kain–Fritsch (on – on – on – on)
CU6	Betts–Miller–Janjic[j] (on – on – off – off)
CU7	Betts–Miller–Janjic (on – on – on – off)
CU8	Betts–Miller–Janjic (on – on – on – on)
Planetary Bound./Surface Layer (PBSL)	
PBSL1	PBL: MYNN[k] Level 2.5 SL: MYNN
PBSL2	PBL: Yonsei University[l] SL: Revised MM5[m]
PBSL3	PBL: Mellor–Yamada–Janjic (MYJ)[n] SL: Eta Similarity[o]

[a] Morrison et al. (2009)
[b] Tewari et al. (2004)
[c] Collins et al. (2004)
[d] Mlawer et al. (1997)
[e] Dudhia (1989)
[f] Max and Suarez (1994); Matsui et al. (2018)
[g] Iacono et al. (2008)
[h] Grell (1993); Grell and Dévényi (2002)
[i] Kain (2004); The Kain-Fritsch trigger option was set to default.
[j] Janjić (1994)
[k] Nakanishi and Niino (2006, 2009); Olson et al. (2019)
[l] Hong et al. (2006)
[m] Jiménez et al. (2012)
[n] Janjić (1994); Mesinger (1993)
[o] Monin and Obukhov (1954); Janjić (1994, 1996, 2002)

Table S3: EC-derived roughness lengths [m] for momentum (z_{0v}), temperature (z_{0T}) and humidity (z_{0q}) used in the calculations of sensible and latent heat fluxes at each study site.

Site	z_{0v}	z_{0t}	z_{0q}
Castle Creek 2012	$10^{-2.5}$	$10^{-4.5}$	$10^{-4.0}$
Nordic 2014	$10^{-2.5}$	$10^{-5.0}$	$10^{-6.0}$
Conrad 2015	$10^{-2.5}$	$10^{-4.0}$	$10^{-3.5}$
Conrad 2016 AWS_1	$10^{-3.0}$	$10^{-4.5}$	$10^{-4.5}$
Conrad 2016 AWS_2	$10^{-2.5}$	$10^{-5.0}$	$10^{-5.0}$
Kaskawulsh 2019	$10^{-3.1}$	$10^{-5.9}$	$10^{-5.9}$

Table S4: Model performance, evaluated by r_{sp} and NNSE, over the whole observational period in simulating daily air temperature (T), relative humidity (RH), total precipitation (P), wind speed (U), incoming shortwave (K_{in}) and longwave (L_{in}) radiation, sensible (Q_H) and latent (Q_L) heat fluxes and total melt energy (Q_M). The melt energy is estimated according to the SEB model (Eq. 1). The WRF runs are based on three configurations of physics parameterizations: REF, minNRMSE and TOPSIS. The model performance is shown as the mean (± one standard deviation) across the six study sites, with equal weighing of each site. Values in bold highlight the best performing model for the given variable. Values in purple highlight a statistically significant correlation at the 5 % confidence level for at least four of the six glacier sites.

Variable	ERA5 30 km	ERA5-Land 9 km	WRF 3.3 km REF	WRF 3.3 km minNRMSE	WRF 3.3 km TOPSIS	WRF 1.1 km REF	WRF 1.1 km TOPSIS	WRF 1.1 km minNRMSE
				r_{sp}				
T	0.86 ± 0.19	0.89 ± 0.14	0.89 ± 0.05	0.86 ± 0.04	0.88 ± 0.03	**0.91** ± 0.03	0.88 ± 0.03	0.90 ± 0.01
RH	0.74 ± 0.20	**0.75** ± 0.15	0.70 ± 0.21	0.55 ± 0.19	0.72 ± 0.19	0.71 ± 0.20	0.53 ± 0.25	0.71 ± 0.17
P	**0.71** ± 0.11	**0.71** ± 0.11	0.49 ± 0.22	0.44 ± 0.28	0.55 ± 0.21	0.51 ± 0.24	0.53 ± 0.24	0.49 ± 0.26
U	0.19 ± 0.36	0.13 ± 0.32	0.15 ± 0.15	0.10 ± 0.16	0.16 ± 0.20	**0.23** ± 0.20	0.20 ± 0.20	0.19 ± 0.24
K_{in}	**0.80** ± 0.09	**0.80** ± 0.09	0.60 ± 0.10	0.58 ± 0.19	0.56 ± 0.11	0.52 ± 0.16	0.55 ± 0.18	0.47 ± 0.14
L_{in}	**0.79** ± 0.11	0.78 ± 0.12	0.62 ± 0.07	0.56 ± 0.11	0.41 ± 0.12	0.54 ± 0.07	0.54 ± 0.14	0.35 ± 0.17
Q_H	0.29 ± 0.36	0.23 ± 0.38	0.54 ± 0.23	0.47 ± 0.23	**0.50** ± 0.24	0.47 ± 0.25	0.49 ± 0.33	0.40 ± 0.30
Q_L	0.20 ± 0.18	0.15 ± 0.22	0.55 ± 0.14	0.48 ± 0.19	0.55 ± 0.17	0.59 ± 0.12	0.53 ± 0.14	**0.61** ± 0.10
Q_M	**0.86** ± 0.03	**0.86** ± 0.03	0.71 ± 0.08	0.73 ± 0.07	0.69 ± 0.12	0.76 ± 0.05	0.75 ± 0.07	0.74 ± 0.07
				NNSE (%)				
T	58 ± 25	54 ± 24	56 ± 18	46 ± 11	55 ± 18	**62** ± 29	51 ± 11	**62** ± 29
RH	22 ± 10	24 ± 11	47 ± 24	30 ± 23	48 ± 23	**48** ± 24	38 ± 16	44 ± 23
P	**57** ± 11	52 ± 19	41 ± 20	36 ± 18	43 ± 18	45 ± 16	41 ± 15	46 ± 20
U	17 ± 9	14 ± 6	27 ± 7	23 ± 9	**28** ± 9	24 ± 7	23 ± 10	23 ± 7
K_{in}	**69** ± 9	68 ± 10	49 ± 6	44 ± 20	49 ± 13	43 ± 4	45 ± 18	47 ± 10
L_{in}	**65** ± 13	**65** ± 14	41 ± 10	44 ± 10	39 ± 10	39 ± 10	45 ± 10	41 ± 11
Q_H	30 ± 12	27 ± 9	39 ± 10	33 ± 9	**41** ± 10	38 ± 11	33 ± 10	37 ± 10
Q_L	42 ± 8	45 ± 10	44 ± 7	47 ± 8	41 ± 4	**50** ± 7	**50** ± 7	47 ± 5
Q_M	**74** ± 10	71 ± 9	62 ± 6	53 ± 10	56 ± 5	67 ± 5	54± 11	59 ± 6

Table S5: Model performance, evaluated by MAPE and NMBE, over the whole observational period in simulating daily air temperature (T), relative humidity (RH), total precipitation (P), wind speed (U), incoming shortwave (K_{in}) and longwave (L_{in}) radiation, sensible (Q_H) and latent (Q_L) heat fluxes and total melt energy (Q_M). The melt energy is estimated according to the SEB model (Eq. 1). For evaluating P, only days with positive observed P have been taken into account. The WRF runs are based on three configurations of physics parameterizations: REF, minNRMSE and TOPSIS. The model performance is shown as the mean (± one standard deviation) across the six study sites, with equal weighing of each site. Values in bold highlight the best performing model for the given variable.

Variable	ERA5 30 km	ERA5-Land 9 km	WRF 3.3 km REF	WRF 3.3 km minNRMSE	WRF 3.3 km TOPSIS	WRF 1.1 km REF	WRF 1.1 km minNRMSE	WRF 1.1 km TOPSIS
MAPE (%)								
T	67 ± 60	71 ± 52	57 ± 43	67 ± 47	**54** ± 36	63 ± 53	71 ± 53	53 ± 34
RH	33 ± 14	31 ± 13	16 ± 5	27 ± 12	16 ± 7	**15** ± 5	20 ± 8	17 ± 6
P	287 ± 303	**278** ± 299	438 ± 349	547 ± 465	471 ± 382	279 ± 215	325 ± 263	437 ± 335
U	61 ± 10	71 ± 7	43 ± 7	48± 9	**41** ± 7	46 ± 13	49 ± 14	46 ± 11
K_{in}	**23** ± 7	**23** ± 7	37 ± 7	32 ± 7	29 ± 4	41 ± 17	31 ± 4	32 ± 7
L_{in}	**4** ± 2	**4** ± 3	7 ± 1	6 ± 2	7 ± 1	7 ± 2	6 ± 1	7 ± 1
Q_H	94 ± 22	98 ± 18	89 ± 28	99 ± 31	87 ± 29	81 ± 23	101 ± 30	**78** ± 25
Q_L	279 ± 227	**150** ± 76	268 ± 150	284 ± 185	255 ± 115	234 ± 191	263 ± 157	215 ± 155
Q_M	35 ± 20	**34** ± 20	48 ± 25	50 ± 26	50 ± 23	37 ± 16	51 ± 26	47 ± 27
NMBE (%)								
T	-9 ± 73	2 ± 69	-13 ± 42	-33 ± 50	**0** ± 46	-17 ± 48	-43 ± 43	-2 ± 37
RH	33 ± 14	31 ± 13	**-3** ± 14	19 ± 23	-6 ± 13	-9± 11	11± 17	-12 ± 9
P	235 ± 318	227 ± 317	352 ± 353	463 ± 473	368 ± 373	**117** ± 206	231 ± 263	320 ± 335
U	-61 ± 10	-71 ± 7	-20 ± 18	-36 ± 14	**-16** ± 20	-40 ± 16	-42 ± 13	-38 ± 15
K_{in}	18 ± 10	18 ± 10	20 ± 10	-14 ± 19	**0** ± 11	31 ± 24	-7 ± 21	9 ± 14
L_{in}	**0** ± 4	**0** ± 4	-5 ± 3	**0** ± 4	-2 ± 3	-5 ± 3	-1 ± 3	-2 ± 2
Q_H	-86 ± 32	-96 ± 19	-36 ± 28	-68 ± 13	**-17** ± 28	-59 ± 27	-77 ± 14	-44 ± 23
Q_L	-194 ± 237	-126 ± 78	41 ± 150	-70 ± 83	**2** ± 140	5 ± 195	-5 ± 137	-24 ± 151
Q_M	-6 ± 9	-13 ± 9	**-4** ± 26	-32 ± 29	-6 ± 25	-9 ± 19	-28 ± 28	-14 ± 19

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